THE CONCEPT OF A NEW WETTZELL LASER RANGING SYSTEM WITH DUAL-PURPOSE CAPABILITY

W. Schlüter, G. Soltau
Institut Für Angewandte Geodäsie (Abt, II DGFI),
Richard Strauss Allee 11
D 6000 Frankfurt 70

Telephone 069 6333 1
Telex 413592

R. Dassing, R. Höpfl
Institut Für Astronomische und Physikalische Geodäsie
Der tu München
Arcisstrasse 21
D 8000 München 2

Telephone 089 2105 2409
Telex 5213550

ABSTRACT

A new Laser Ranging System with a dual purpose capability : lunar and satellites, is being discussed to substitute the present Nd/YAG System at Wettzell. The description of the conceptual design of this system is given in the following.

THE CONCEPT OF A NEW WETTZELL LASER RANGING SYSTEM WITH DUAL-PURPOSE CAPABILITY

Introduction

Some efforts have been made in the past towards Lunar Laser Ranging [1] by the group** acting within the Sonderforschungsbereich 78 - Satellitengeodäsie.

---

* MEMBER of the Sonderforschungsbereich 78 (SFB 78) Satellitengeodäsie of the Technische Universität München

** a) Institut für Astronomische und Physikalische Geodäsie der Technischen Universität München

b) Institut für Angewandte Geodäsie in Frankfurt am Main

c) Deutsches Geodätisches Forschungsinstitut (Abt. I) in München

d) Bayerische Kommission für die Internationale Erdmessung der Bayerischen Akademie der Wissenschaften in München.

e) Geodätisches Institut der Universität Bonn

A recent hardware analysis showed clearly that the Satellite Laser Ranging System designed in 1974 and operated since 1977 at Wettzell will no longer be suitable for performing operational ranging to the moon, in the manner necessary to meet the requirements of the programme for Establishment and Maintenance of a Conventional Terrestrial Reference System (Cotes) defined jointly by the IAG and IAU [2].

The new concept mainly worked out by the authors together with Dr. Greene (NATMAP) and Dr. Wilson (IfAG) foresees that the new Wettzell Laser Ranging System (WLRS) would have the capability of tracking different reflectors on the moon as well as geodynamic satellites such as LAGEOS and STARLETTE.

The design for the WLRS requires the following features:

a) ranging to lunar retroreflectors with a 20 minute normal point precision of 5 cm.

b) ranging to LAGEOS with an RMS error of less then 3 cm over 1 minute, day or night.

c) a capability of measuring to terrestrial targets.

d) sub-system modularity to allow upwards compatibility with new technology.

e) totally identical systems for ranging to lunar or satellites targets.

f) minimisation of the level of technology required to diagnose and repair faults.

g) real-time calibration of the ranging system.

h) rapid (less than 10 minutes) changeover from lunar to satellite laser ranging.

i) maximum degree of automation in operating calibrating, testing, and maintaining the system.

The WLRS-concept

The design concept for the WLRS is shown in Figure 1. It is similar to the NATMAP Lunar Laser Ranging System (NLRS) design [3].

The system will have a day/night satellite capability with the required precision, and shall be able to convert rapidly to LLR.

The measurement procedure should be identical for SLR and LLR, allowing comparisons of the data and results without a concern for systematic errors between measurement systems.

Telescope

The telescope system would have the following characteristics:

a) minimum aperture of 75 cm - clear

b) common full-aperture for transmit and receive optics

c) identical optics for transmit and receiver and guiding

d) a mechanical mount pointing error of less than 2 arc seconds referred to the transmitting aperture

e) adequate tracking and acceleration speeds for low satellites

f) high optical quality Coudé path

g) high precision servo control system to allow pointing errors (servo only) of < 0.5 arc second and track rate errors of < 0.25 arc sec/sec

h) mount configuration: ALT/AZ

i) mount position readout precision of better than 1.0 arc second RMS on both axes

j) a field of view, unvignetted, at the Coudé room entry port, of 3 to 5 arc minutes

k) total hemispheric sky coverage

l) minicomputer control of servo system

m) transmission efficiency of 10% from Coudé room entry port (similarly for receiving)

n) simple adjustment facilities

o) prevention of condensation on the optical parts

p) elevation range -5^{o} to 185^{o}

q) operating conditions in temperature of -20^{o} to 40^{o} C and up to 95% humidity.

Telescope and mount should be computer controlled, and they should be connected via a Coudé path to the guiding station, T/R-system, laser, and receiver placed in a controlled environment.

Guiding System

The prime data acquisition mode is planned to be final the absolute guiding mode. However, other guiding systems are necessary for development of the absolute guiding capability as well as for backup, system diagnostics, and real-time checking of the system's optical parameters.

The WLRS proposed guiding systems consist of

a) a wide-field finder TV mounted on a small (10 cm) auxiliary telescope. This system can also be mounted at the Cassegrain position, with a smaller field of view.

b) an eyepiece placed at a guiding station in the Coudé room (field of view 5 arc min).

c) a TV imaging system placed in the guiding station to allow electronic image enhancement for manual guiding.

d) a star tracking system (eg. quadrant detector) placed at the guiding station also.

The guiding station concept is shown in figure 2. The eyepiece is always available for use. The beamsplitter is used to optically switch between star tracking system and TV (lunar tracking).

The WLRS would initially become operational with manual guiding for LLR from the guide station. Absolute guiding should be possible as soon as the mount model is improved to give an RMS error overall of less than 4 arc seconds.

T/R-Switching System and Receiver System

The requirement for a transmit/receive switching system (T/R) arises because common optics would be used for transmitting and receiving. The requirements for the transmit/receive switching system (T/R) are:

a) to connect the Coudé path to the laser during time of fire.

b) to connect the Coudé path to the receiver at the time of expected returns.

c) high efficiency in the transmitting and receiving mode.

d) to operate at high laser pulse rate of max. 10 Hz.

Filters for the receiver will be employed between the T/R and the receiver

e) suitable spacial filters.

f) suitable spectral filters.

The receiver system should consist of

a) a suitable photomultiplier (RCA 8850 or MCP/Micro Channel Plate) and

b) a matched preamplifier and discriminator.

Laser

A Quantel Nd:YAG Laser, Model YG 402 DP, would be chosen. This Laser can work in the following 4 modes:

	Mode 1	Mode 2	Mode 3	Mode 4
No. of pulses/shot	1	4	8	1
Pulse width	100 ps	50-250 ps	50-250 ps	3 ns
Pulse spacing	-	8 ns	8 ns	-

	Mode 1	Mode 2	Mode 3	Mode 4
Pulse energy	100 mJ	250 mJ	350 mJ	350 mJ
Mean Power	1 W	2,5 W	3,5 W	3,5 W

Further parameters:

Pulse repetition rate	0.3 - 10 Hz
Wave length	532 nm
Beam diameter	9,5 mm
Beam divergence	< 0.7 mrad

The single pulse (mode 1) would be used for SLR. The other 3 modes are for LLR. It is expected that mode 3 would be the most frequently used when the WLRS is in its final configuration.

Timing System

Reference to UTC within 0.1 µs (1 pps) and a stable 5 MHz-reference-frequency (H-Maser) is available from the existing timing system of the station. The internal timing system of the Laser should be driven and synchronized by the time system of the station. The epoch of Laser ranging events is determined by combining a real time determination of UTC (accurate to 0.1 µs) with a relative determination using time interval techniques (± 100 ps).

The system would have the following components:

a) time interval counters for multiple-event-counting (± 125 ps; Le Croy time interval unit) or the new high resolution (± 20 ps) Le Croy TDC if available.

b) time interval counter (HP 5370B) for calibration.

Software

The following software components are foreseen:

a) SLR prediction software, for the generation of telescope point angles and range predictions for satellite ranging, based on daily IRV inputs.

b) LLR prediction software, for the generation of telescope point angles and range predictions for lunar ranging, based on a lunar ephemeris.

c) A real-time laser ranging programme for the acquisition of lunar and satellite range data.

d) Pre-processing software to produce quick-look data files to GSFC specification, and full rate data magnetic tape for analysis and archiving.

e) Software drivers for all devices to be interfaced to the main computer (CAMAC-CRATE, Telescope- and Dome Control System, T/R and Receiver, Timing Range Gate and Range Window electronics).

f) Stand-alone diagnostic programs for each interfaced device, to allow testing of individual devices, interfaces, and drivers.

g) Mount modelling software (option).

h) Calibration software for off-line calibration.

i) Calibration software for simulated ranging, terrestrial target calibration, differential path calibration, and real-time calibration whilst ranging (incorporated into c)).

j) Software aids for system alignment, laser monitoring and testing, weather monitoring.

The software would be installed on a HP-A900 computer system in order to be compatible with the NATMAP software development.

Electronics

The WLRS control electronics visualised consist of the following (cf. fig. 1):

a) Laser Ranging Controller (LRC).

b) CAMAC Controller and electronic interface to HP-A900 computer.

c) Guiding system electronic interface to HP-A900 computer.

d) Telescope system electronic interface to HP-A900 computer.

e) T/R control system and electronic interface to HP-A900 computer.

f) Dome control system and electronic interface to HP-A900 computer.

g) Timing system for laser ranging, including electronic interface to HP-A900 computer.

h) Wideband signal processing electronics.

The electronics for the WLRS should be designed and constructed to operate in cohesive and integrated fashion so as to allow software control and monitoring of the entire laser ranging process.

The major electronics sub-systems are shown in figure 1, WLRS OVERVIEW. In this figure, the receiver system incorporates the active spectral filter control, the telescope system includes the dome control and interface, the signal processing electronics are distributed between the CAMAC system and the LRC, and the ranging timing system between the LRC and the CAMAG system.

References

[1] Peter Wilson: Zur Erweiterung des Nd:YAG Laserentfernungsmeßsystems der Station Wettzell für Entfernungsmessungen zum Mond. - Veröff. d. Bayer. Kommiss. f. d. Internationale Erdmessung, Heft 38, München 1978.

[2] MERIT/COTES Joint Working Groups: MERIT Campaign, Connection of Reference Frames. - BIH, Paris, 1983.

[3] John Mck. Luck: NATMAP Laser Ranging System. - CSTG Bulletin No. 5 (1983).

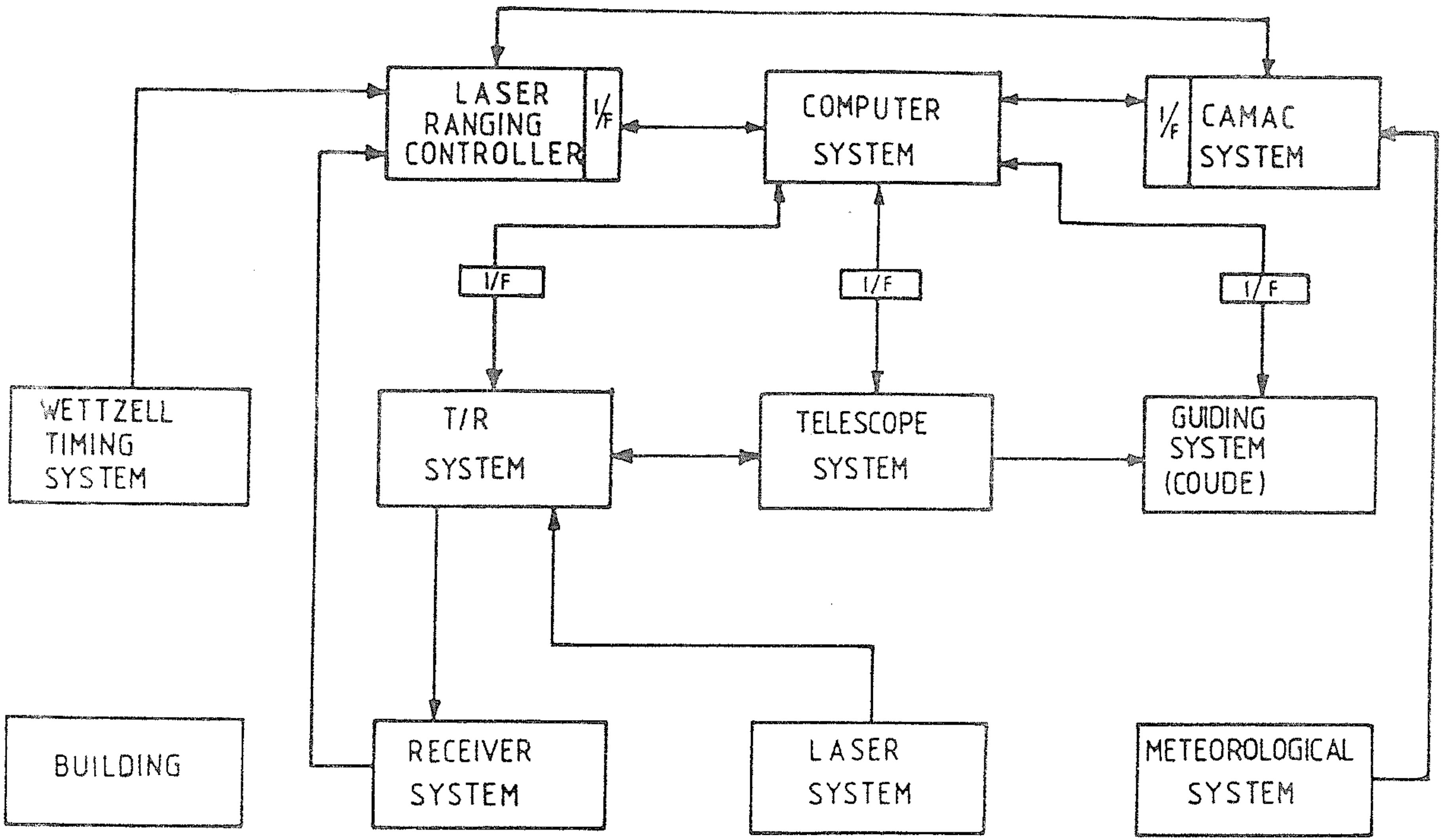
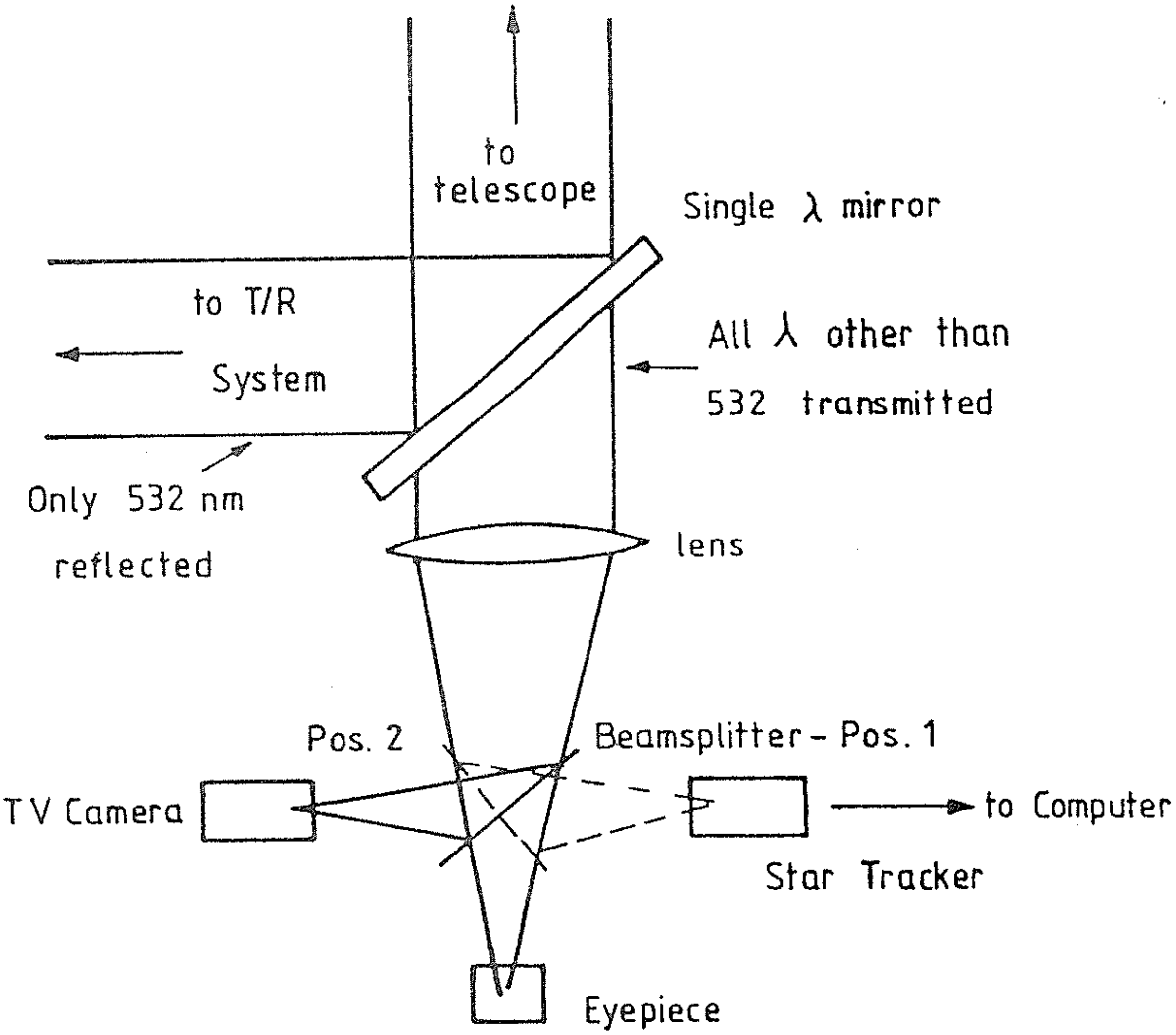


Figure 1 WLRS OVERVIEW

Figure 2

GUIDING STATION CONCEPT



THE TRANSPORTABLE LASER RANGING SYSTEM MARK III

T.S. Johnson
Instrument Electro Optics Branch
NASA Goddard Space Flight Center
Greenbelt, Maryland 20771

Telephone (301) 344 7000
TWX 710 828 9716

W.L. Bane, C.C. Johnson, A.W. Mansfield, P.J. Dunn
EG & G WASC,
6801 Kenilworth Avenue, Riverdale, Maryland 20737

Telephone (301) 779 2800
Telex 590613

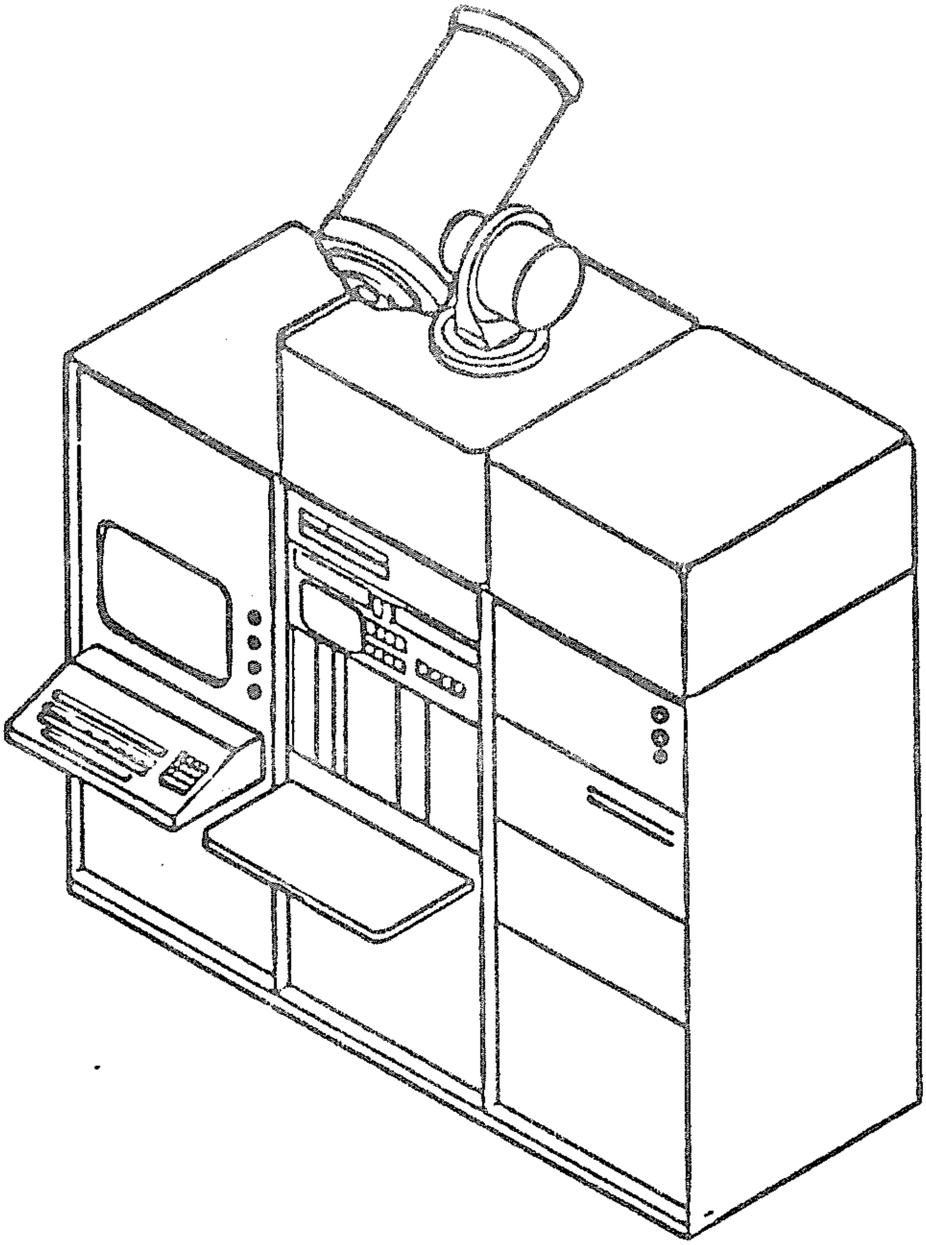
ABSTRACT

The transportable laser ranging system (TLRS-3) has been designed to take advantage of the latest developments in satellite ranging instrumentation and techniques. Satellite returns at the single photo-electron level are detected from low power laser light transmitted trough a compactly designed mount. Modular construction efficiently integrates the computer system, with terminal entry, disc sotrage and graphic display and a time transfer system driving a precise frequency standard. Station, star and satellite acquisition data are read from floppy discs, which can also be used as the final medium for shipping the ranging data. An azimuth/elevation tracking mount can be calibrated from visual observations of automatically selected stars. A single shot rms noise level of a few centimeters is observed on satellite at a return data interval around one second. The light-weight system consumes little power and requires no more than two operators for a normal satellite tracking shift.

THE TRANSPORTABLE LASER RANGING SYSTEM MARK III

The transportable laser ranging system (TLRS-3) has been designed to take advantage of the latest developments in satellite ranging instrumentation and techniques. Its architecture is based on that of TLRS-2, which has successfully completed campaigns in Greenbelt in 1982 and on Easter Island and Otay Mountain in 1983, and is now making measurements at other normally inaccessible and undeveloped sites. Collocation tests have demonstrated agreement between the ranging observations taken by the transportable machines and high power laser systems at the centimeter level. A single shot r.m.s. noise level of a few centimeters is observed on satellite ranges at a return data interval around one second. Mount pointing repeatability of a few seconds of arc can be maintained during an occupation period of several weeks.

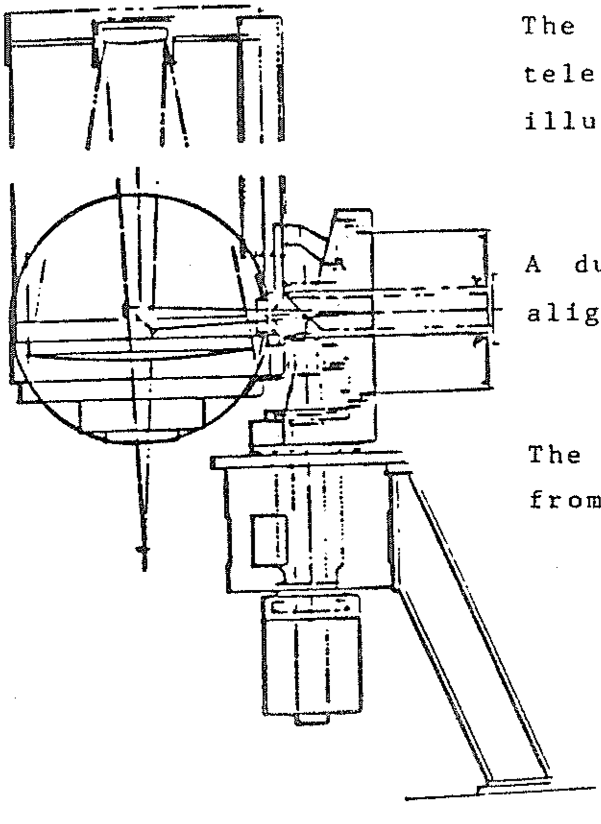
Satellite returns at the single photo-electron level are detected from low power laser light transmitted through a compactly designed mount. The modular construction efficiently integrates the computer system, with terminal entry, disc storage and graphic display and a time transfer system driving a precise frequency standard. Station, star and satellite acquisition data are read from floppy discs, which can also be used as the final medium for shipping the ranging data. An azimuth/elevation tracking mount can be calibrated from visual observations of automatically selected stars. During the satellite pass, a three-level interrupt sequence coordinates the computer's system control, prediction and data recording functions. The light-weight system consumes little power and requires no more than two operators for a normal satellite tracking shift.



In the configuration shown, the laser is mounted in its shipping container above the rack to the right, which contains the chiller and power supply, with the optical path folded within the central case which also covers the pedestal. Below the mount in the central rack, the microprocessor with disc storage units and the ranging and mount control electronics are housed. The console panel includes a small graphics display screen, digital readout devices and control switches. A timing system is mounted in the third unit.

TRACKING MOUNT

A 280 mm. aperture optical telescope with near diffraction limited optics and f/10 focal ratio is mounted off the axis of an azimuth elevation mount to give a common transmit/receive path for the light signal. A mirror within the telescope deflects the light path along the elevation axis and into the mount support where a second mirror turns the path down the azimuth axis. The mount is positioned with motor/tachometer/inductosyn encoder assemblies for azimuth and elevation control. A mirror inside the pedestal, rotated by a motor synchronized with the laser firing sequence, deflects the transmitted signal up the azimuth axis, after it has been sampled with a pellicle mounted in the horizontal path of the laser output.



The modified Schmidt-Cassegrain telescope is sectioned in this illutration.

A dual-bearing mount allows easy alignment of the optical system.

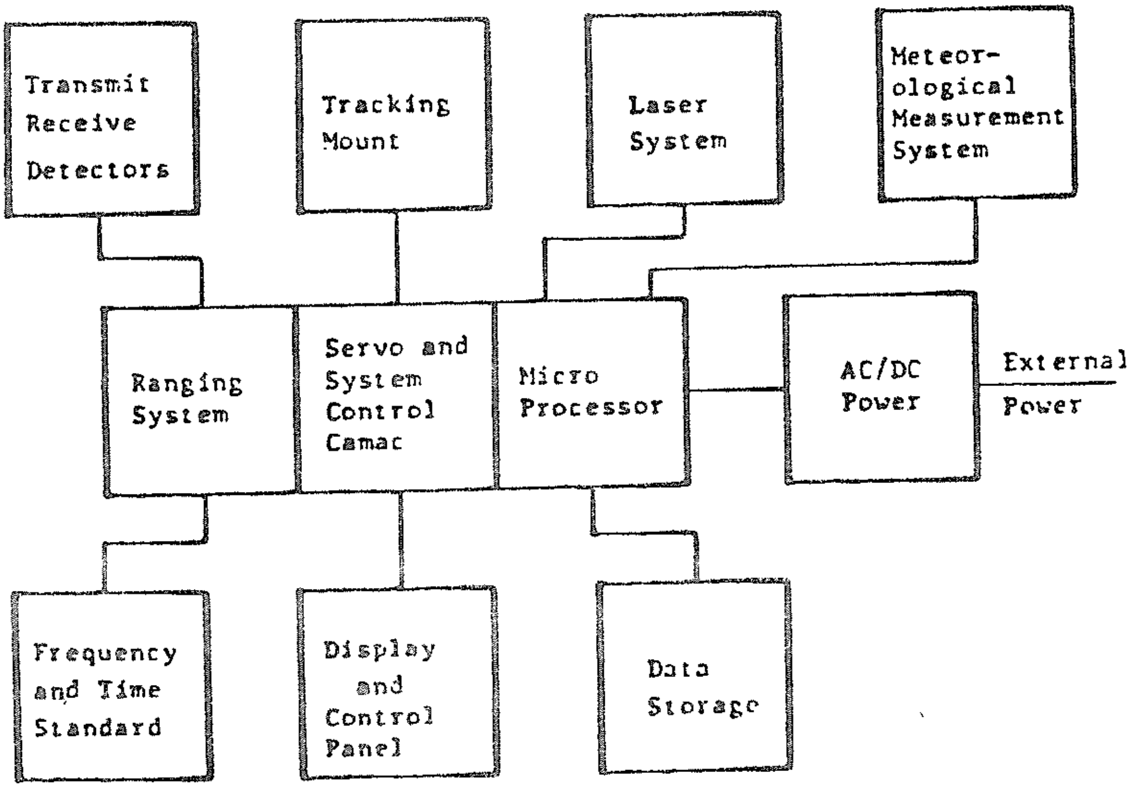
The pedestal tripod is constructed from aluminum weldments.

TIMING SYSTEM

A master oscillator provides primary timing signals at 20 MHz, 1 MHz and 1 pps to a module which distributes frequency and pulse information throughout the system. The difference between the system 1 pps clock and a GPS receiver is used to establish epoch time to within one microsecond of a master clock.

LASER SYSTEM

The transmitter consists of a passively mode-locked Neodynium-YAG laser with a pulse slicer and double-pass amplifier. The fundamental frequency of 1062 nm. is doubled to produce green light at 10 pulses per second. The transmitter is supported by capacitor banks, a control unit, power supply and a cooler carrying deionized water to dissipate heat generated by the flash lamps and laser rods.



SERVO AND SYSTEM CONTROL

The central control sytem uses a 20 pps interrupt timing signal from the frequency and pulse distribution module to position the optical axis of the tracking mount. Angle error commands are received from the computer through a digital-to-analog converter and compared with shaft encoder position signals. The correct speed and direction of travel for the azimuth and elevation motors can then be specified to the servo amplifiers.

TRANSMIT/RECEIVE DETECTORS

A laser monitor diode triggers a start pulse when it detects the light transmitted through a dichroic mirror placed in the optical path of the laser transmitter. The green light reflected by the dichroic mirror passes through a negative laser coupling lens before the rotating mirror reflects it into the tracking optics. The received laser pulse is detected by a photomultiplier and arrives at the PMT distribution unit after the start pulse. Constant fraction discriminators separately shape the start and stop pulses which are transmitted to the ranging system.

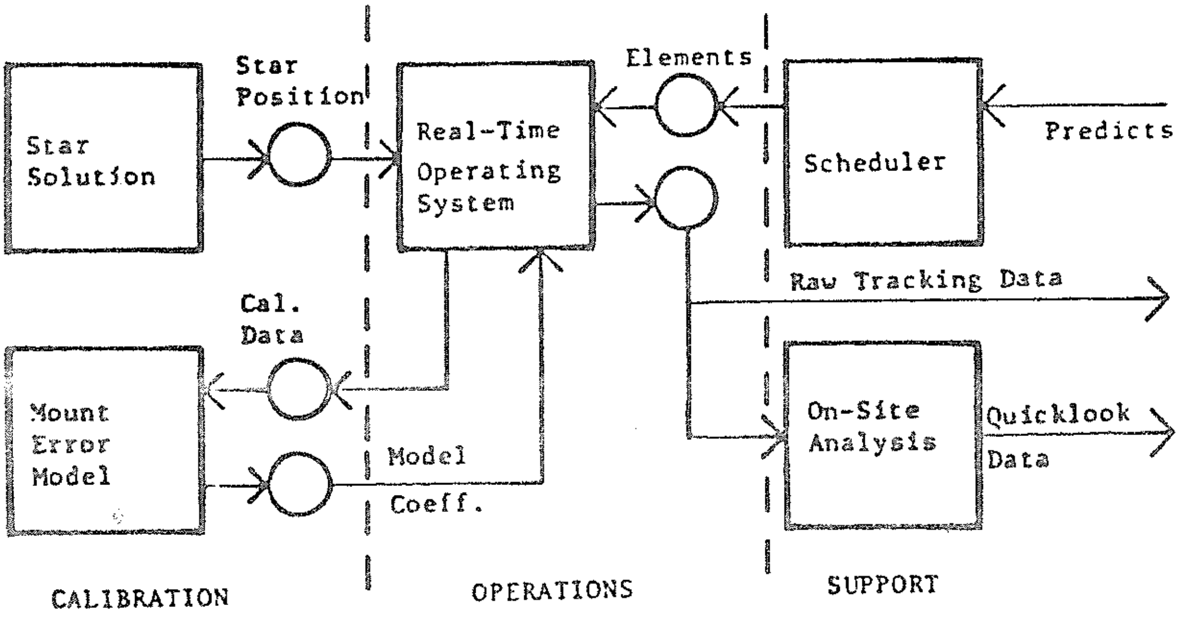
RANGING SYSTEM

The range measurement system is driven by the system 10 pps interrupt signal and consists of a multichannel 50 picosecond resolution time interval counter. A common start signal is received from the transmit discriminator and up to seven separate signals may be accepted from the receiver discriminator in any measurement cycle. In addition, the ranging system measures the amplitude of each individual start or stop signal as well as the epoch time of the start signal and the mean background rate (the number of noise photo electrons/sec).

COMPUTER SUBSYSTEM

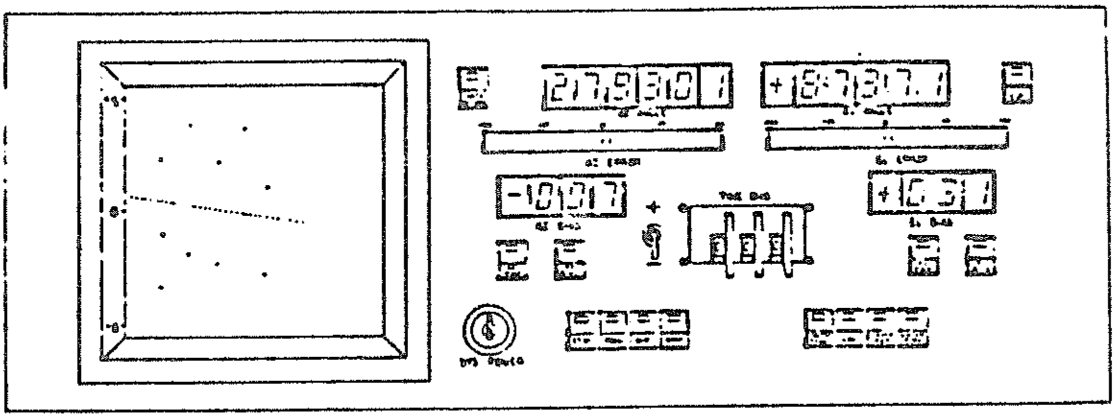
The computer communicates with the other subsystems through a CAMAC dataway. Control and service routines are driven by hardware-generated interrupts in foreground. Trajectory computation is performed as a background task, with display and data recording scheduled for execution by foreground routines. Computer peripheral input/output operations are controlled asynchronously.

A numerical integration scheme is used to compute the orbit for a satellite pass based on a power series representation. The travel time for a particular laser pulse and the range gate window needed to accurately measure the return time is predicted, as well as the pointing angle required to place the target within the laser beam. The computer system also operates in a star tracking mode for mount error calibration and computes cable delay corrections from both internal and external targets. A ranging analysis software package allows on-site analysis of data for quality control and a comprehensive set of diagnostic routines support the field operation.



TRACKING OPERATION

Passive star calibration and active ground and satellite ranging are conducted under computer control. A console panel allows operator tuning of each mode of operation based on information displayed on the screen, and contains switches to initiate the required mode. Angle biases can be applied to star observations to derive a mount error model, and to compensate for any target position errors during tracking. The dominant satellite positioning error is along the orbit track and is compensated by applying a bias to the epoch of the laser pulse's predicted travel time. In the illustration, range residuals to a satellite with a small along-track orbit prediction error are shown on the screen.



The details of each transmitted pulse are recorded together with enough data on the returns to properly monitor system performance. Automatically recorded measurements of the pressure, temperature, and relative humidity at the site accompany the tracking data to allow the measurements to yield their intrinsic accuracy at the centimeter level.

THE SOFTWARE SYSTEM FOR TLRS II

P.J. Dunn, C.C. Johnson, A.W. Mansfield
EG & G WASC,
6801 Kenilworth Avenue, Riverdale, Maryland 20737

Telephone (301) 779 2800
Telex 590613

T.S. Johnson
Instrument Electro-Optics Branch
NASA Goddard Space Flight Center
Greenbelt, Maryland 20771

Telephone (301) 344 7000
TWX 710 828 9716

ABSTRACT

The Transportable Laser Ranging System Mark II has been designed for accurate satellite tracking operations with low power consumption. The performance of the system can be regularly monitored with software which also provides on site capability to assess data quality and to confirm that the system is working at the single photoelectron return level. This short report briefly describes the software suite and illustrates the date quality assessment procedure for satellite and ground target observations.

THE SOFTWARE SYSTEM FOR TLRS II

The Transportable Laser Ranging System Mark II is a new type of highly mobile laser satellite tracking system. It is designed for rapid deployment to normally inaccessible and undeveloped sites within the laser network operated as part of the Goddard Space Flight Center Crustal Dynamics Project. The system is packaged in shipping containers which will fit in the cargo holds of normal passenger jet airlines, and emphasises modular construction and low power requirements. A single photoelectron system receives returns on seven channels through a 25 cm. aperture refractive optical system from a passively modelocked, frequency doubled Nd:Yag laser transmitter.

System control, pointing, data recording and post-flight data analysis is accomplished with a CAMAC packaged microprocessor. The principal interfaces for the software suite are shown in Figure 1, and the three functions of calibration, operation and support are categorized. An overview of the Real-Time operating system is presented in Figure 2, which also provides details of the hardware configuration. A flow chart of the main control routine for real-time operation is given in Figure 3 and indicates the procedure by which the system is prepared for satellite acquisition or star tracking for mount calibration.

The instrument has completed successful campaigns at Greenbelt, Maryland, Easter Island, Otay Mountain and Cabo San Lucas, Mexico. The capabilities of the on-site data analysis software have helped to control data quality and to indicate occasional system malfunctions. The performance of the post-flight analysis software is the focus of this report and is illustrated in Figures 4, 5 and 6.

The post-flight recontruction of the real-time screen display for a pass of LAGEOS taken at Cabo San Lucas in March 1983 is shown in Figure 4. The vertical scale has been set to 50 nanoseconds in round-trip flight time to show the noise level of the returns, although the range gate actually used for acquisition was one microsecond. The horizontal scale is in seconds from the predicted point of closest approach and the pattern of returns is caused by orbit prediction error which in this case amounts to a few meters. The increased background noise visible as the pass progresses is caused by the occurrence of sunrise. The histogram of returns shown to the right of the screen display is redundandant in this reconstruction and the statistics listed below the histogram apply to all of the information on the screen. Options to display quicklook data, to fit low order polynomials to selected points, change plot scales and redefine plotting variables are available to the operator as part of the quality control procedure.

In Figure 5, three consecutive screen displays are shown to illustrate the sequence used by the operator to assess the data quality. A low order polynomial is fitted to the screen pattern to produce a symmetrical histogram of returns. Although manual editing capability is available, in this example, automatic editing based on the observed noise level of the data was applied to produce the final display of acceptable returns. The noise level of 487 measurements taken from all channels of the receiver system amounted to 10.4 centimeters. This is higher than expected and is partly due to the application of nominal interpolator scale factors to each of the channels.

The screen display of Figure 6 shows returns detected in a single channel from three separate horizontal targets. The noise level is 5.7 cm for 588 observations, which is close to nominal for the system, but will include some survey error for the targets at the centimeter level. The horizontal target calibration establishes the system delay at 4.93 m. and this value was maintained consistently throughout the occupation. Figure 6 also shows a plot of range against return power amplitude to establish that the system is operating at the single photon level for which it was designed, and which corresponds to about 60 units on the horizontal scale. A histogram of returns as a function of return power is also shown and exhibits a Poisson distribution with peaks at the multiple photoelectron levels.

The TLRS-2 quality control software has been found to efficiently indicate any aberrations in the system which might lead to adjustments to improve the performance of the laser, the discriminators or the operating power level. It has efficiently assisted the operators in their efforts to maintain the accuracy of this new transportable instrument.

FIGURE 1. TLRS—II SOFTWARE ORGANIZATION

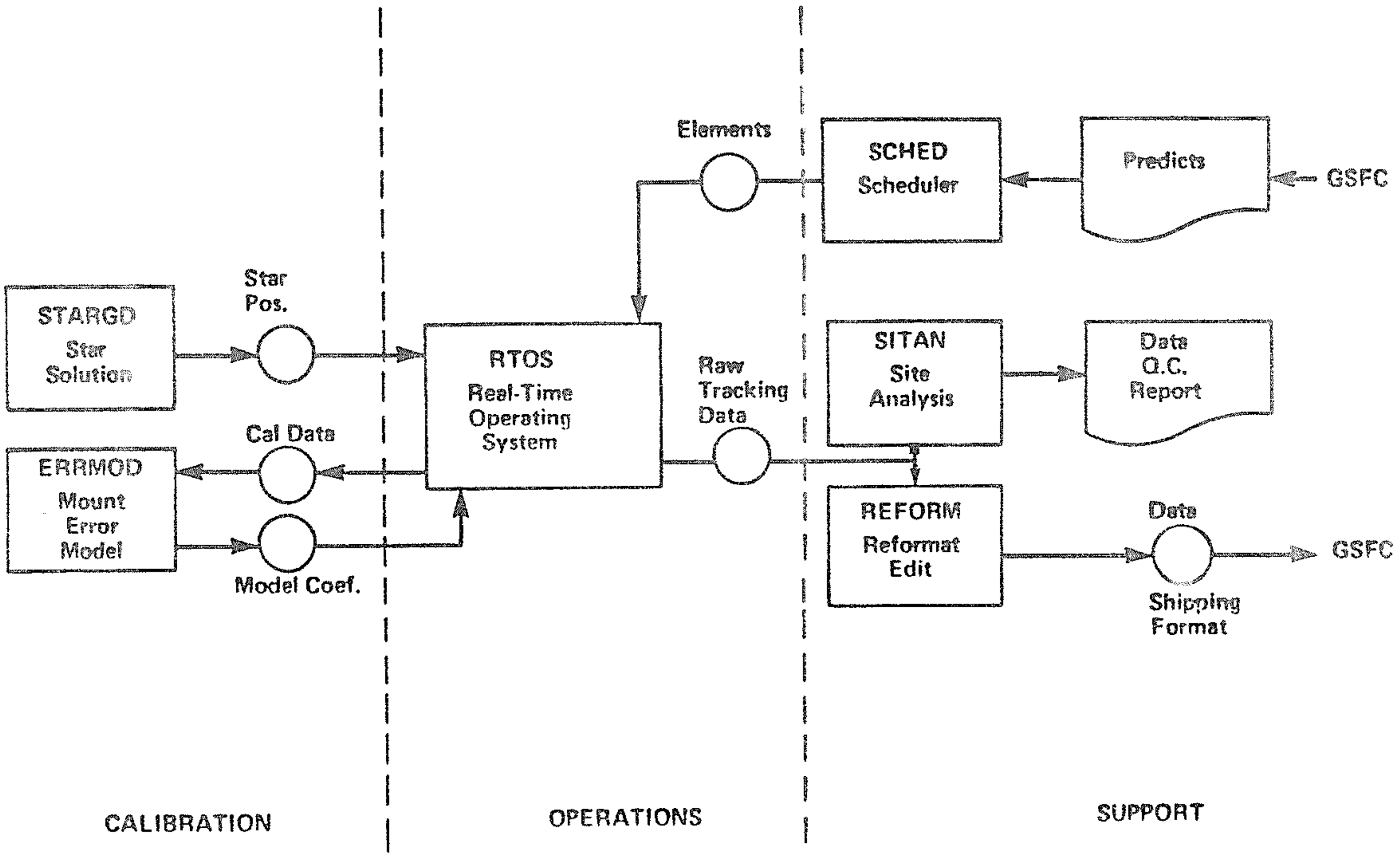


FIGURE 2. TLRS–II REAL–TIME OPERATING SYSTEM

Language:	FORTRAN ≈1600 Lines Executable Code ASSEMBLY ≈1100 Lines Executable Code + Resident System Routines	
Machine Environment:	CAMAC – Packaged Standard Engineering Corp. MIK 11/23 Microprocessor–based functional equivalent to PDP–11 32K storage (16-bit words) (volatile) KEF–11 Floating Point Option RT–11 SJ Operating System	
Trajectory Computation Strategy:	Numerical integration of power series orbit representation J2, J3, J4 Real-time steps of 1 sec Interpolated to 20 pps for servo bandwidth constraints	
Core Utilization:	Essentially 100%, but without overlays	
Real-Time Mechanization:	Foreground:	Control and service routines driven by 1, 10 and 20 pps hardware-generated interrupts.
	Background:	Trajectory computation, display and data recording scheduled for execution by foreground routines.
	Asynchronous:	All computer peripheral I/O: display terminal and disk.
Additional Modes:	Star tracking for mount calibration. Fixed-target mode for target-board ranging electronics calibration.	
Graphic Ranging Display:	Timing bias, AZ–EL position and range residuals.	

FIGURE 3. CONTROL ROUTINE FOR REAL-TIME OPERATIONS

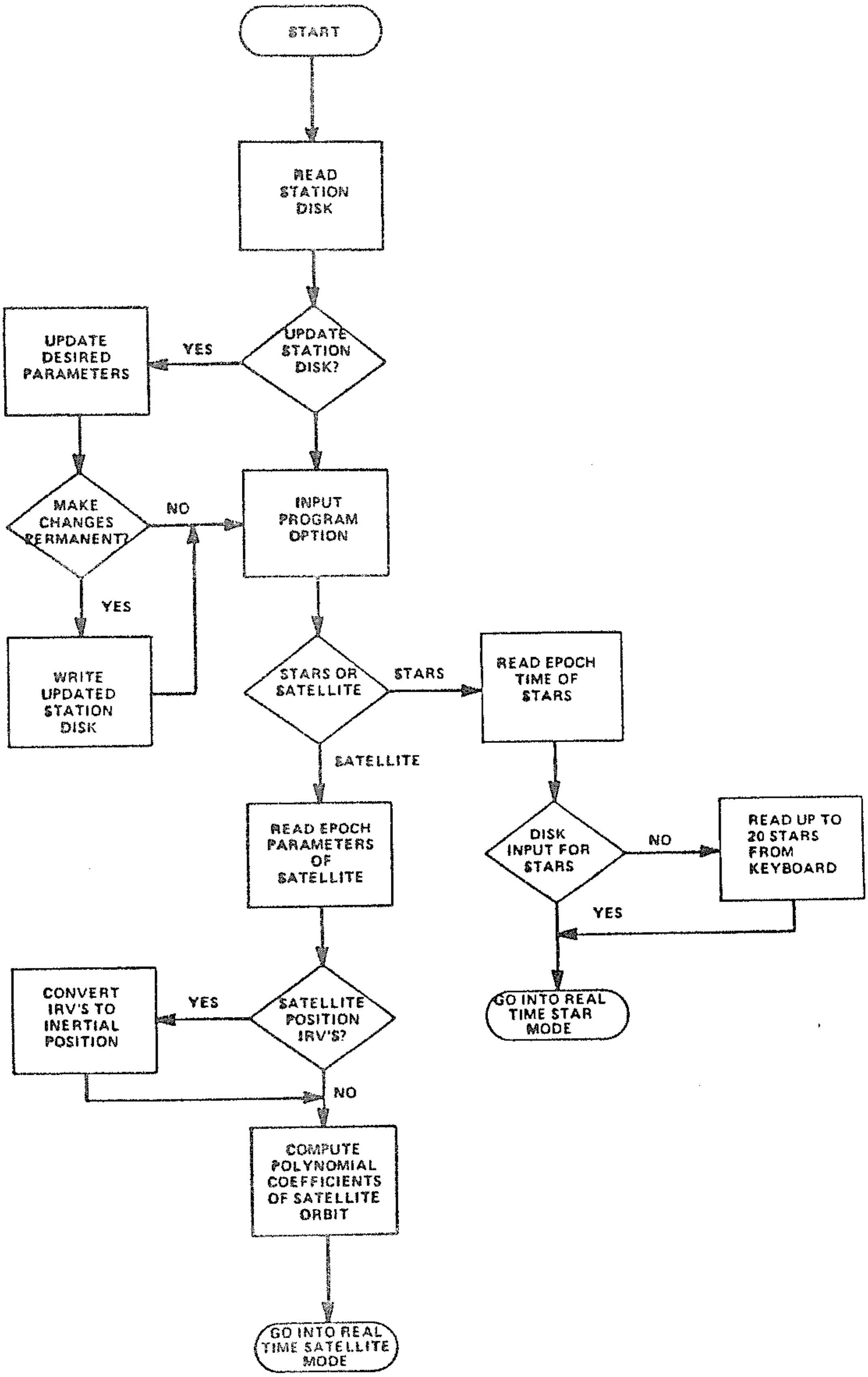
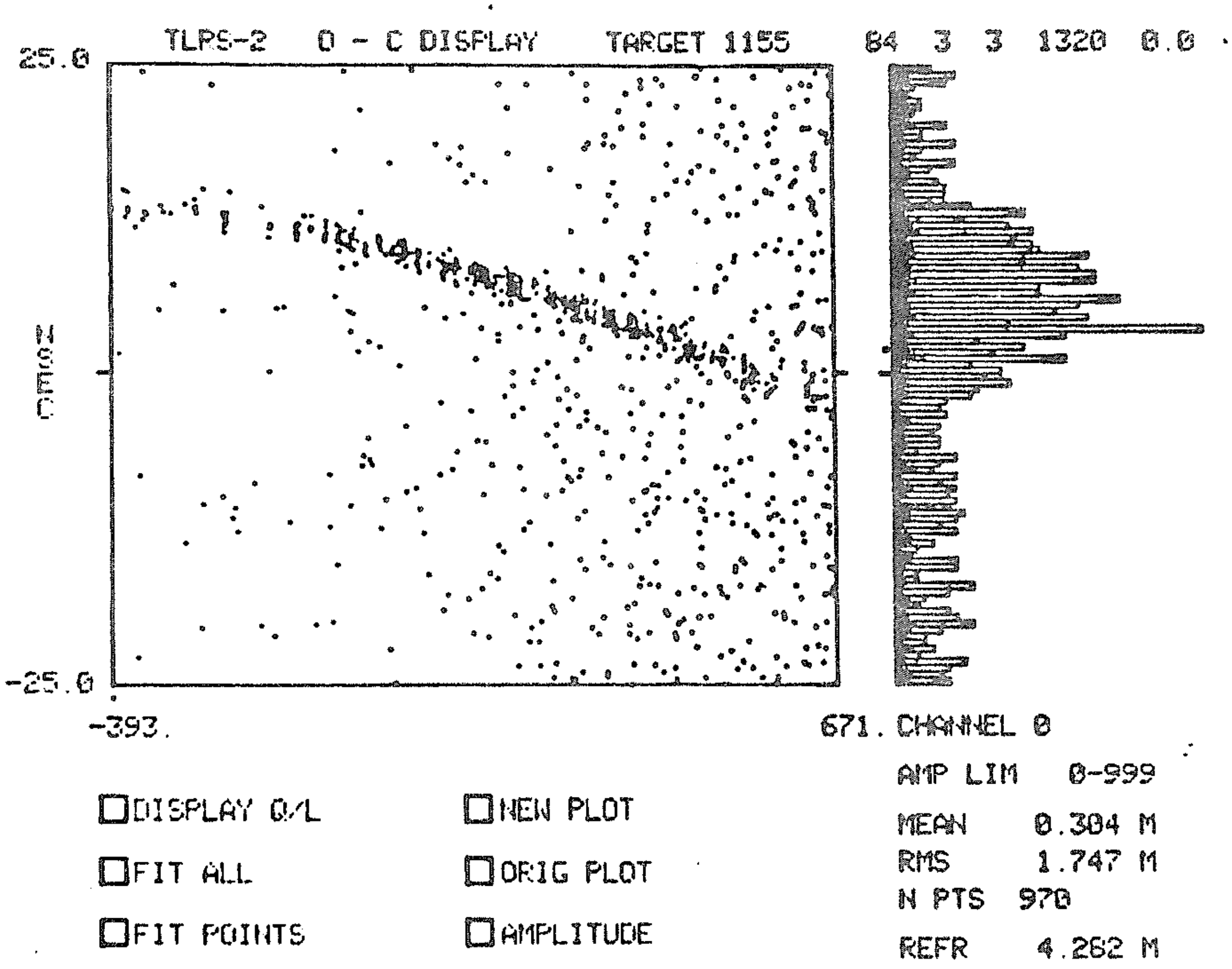


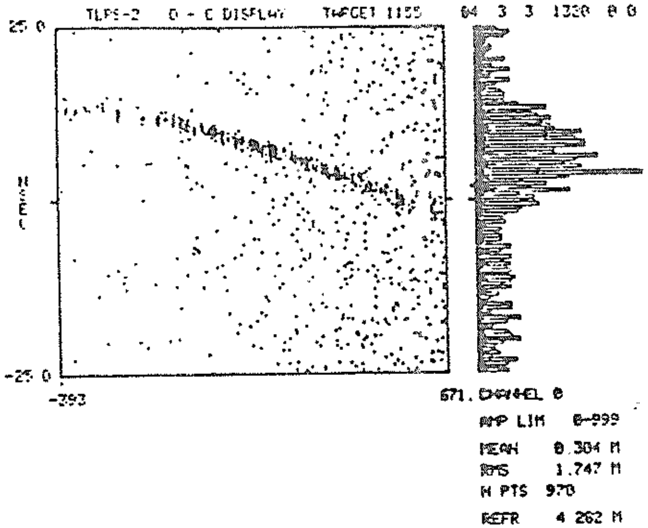
FIGURE 4. RECONSTRUCTION OF A LAGEOS PASS

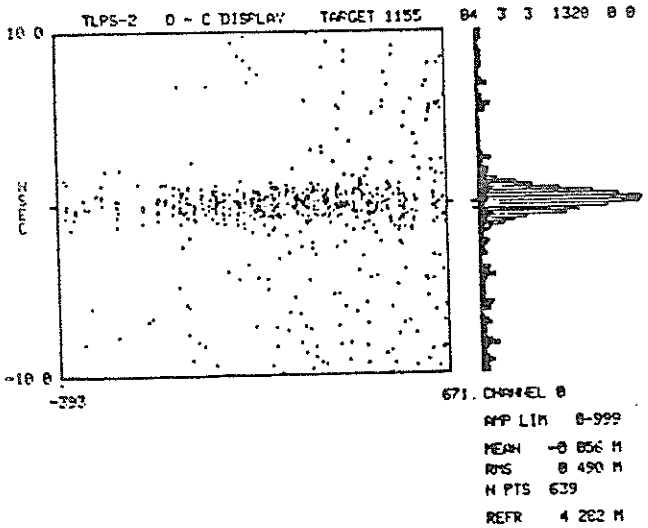


TLPS-2 O - C DISPLAY TARGET 1155 84 3 3 1320 0.0

AMP LIM 0-999
MEAN 0.304 M
RMS 1.747 M
N PTS 970
REFR 4.282 M

FIGURE 5. DATA QUALITY
ASSESSMENT FOR
A SATELLITE PASS





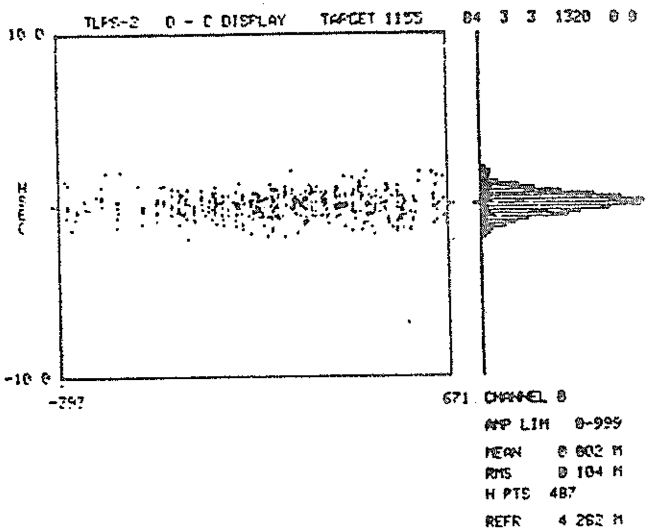
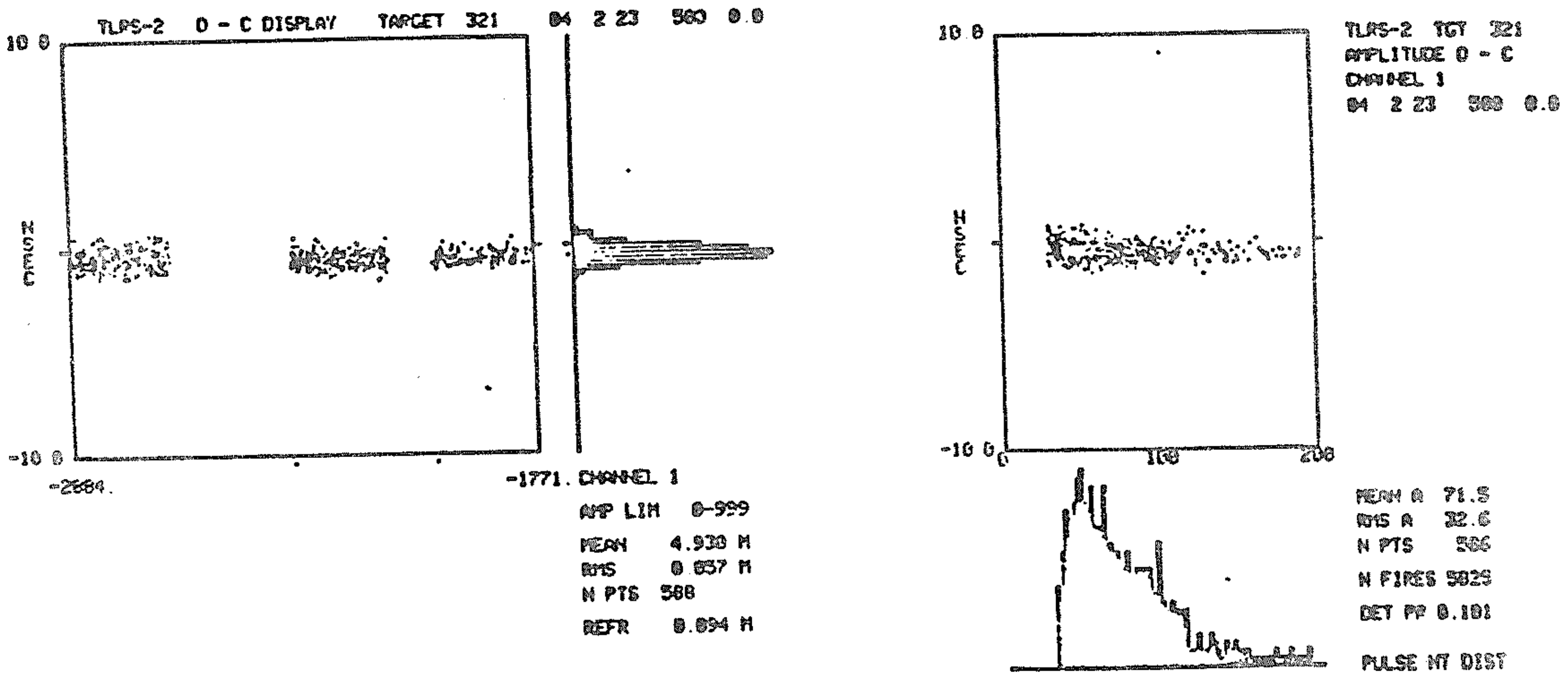


FIGURE 6. DATA QUALITY ASSESSMENT FOR A HORIZONTAL TARGET CALIBRATION



MTLRS SOFTWARE AND FIRMWARE

E. Vermaat, K.H. Otten
Department of Geodesy
Delft University of technology
Thijsseweg 11
2629 JA Delft, The Netherlands

Telephone 057 69 341
Telex 36442

M. Conrad
Institute for Applied Geodesy
Richard Strauss Allee 11
6000 Frankfurt / M, F.R.G.

Telephone 069 63 331
Telex 413592

ABSTRACT

This paper reviews the software and firmware which has been developed to date for the Modular Transportable Laser Ranging System (MTLRS). Four major tasks are identified some of which involve real time communication with the system hardware. One of the main characteristics of the overall system design is the separation of the computer hardware into three independent but mutually cooperating microprocessors. Consequently the software and firmware package of MTLRS has a modular design.

1. Introduction

The computer configuration of the Modular Transportable Laser Ranging System (MTLRS) is primarily characterized by the deployment of three microprocessors: an HP 1000 L main processor and two Motorola M6809 slave processors. The main processor together with its peripherals can be used stand-alone for any computing task, whereas the real time utilization of the total ranging system also involves the two slave processors, each addressing an independent task.

Therefore the software designed for MTLRS always involves the main processor and only in some cases requires the use of the two slave processors.

Due to the limited memory capacity of the main processor and of the external storage devices, the total amount of software developed for the system is separated into four major tasks, each requiring an individual bootstrap loading of the operating system.

2. The hardware configuration

The computer configuration (figure 1) comprises one HP 1000 L model 5 16-bit microsystem and two Motorola 8-bit microcomputer systems.

The HP 1000 computer or main processor has 128 Kbytes of RAM at its disposal for the operating system and the real time programs. The data communication with the two diskette units and the two Motorola microsystems is established through two IEEE-488 interfaces. An HP 2623 graphics terminal with an internal hardcopy unit functions as system console. Support for data communication over public telephone lines is feasible by a Silent 700 terminal with 20 Kbytes of bubble memory and acoustic coupler. All programs are executing under control of the disc based RTE-XL operating system.

The two Motorola microcomputer systems, i.e. the predictor processor and the formatter processor, are slaved to the main processor. Each of the processors comprises one 5 MHz microcomputer board based on an M6809 MPU, one IEEE-488 listener/talker i/o board with two additional 8-bit PIA's (parallel interface adapter) providing for interprocessor and MTLRS electronics data i/o. A memory board with 16 Kbytes of RAM installed, is available to each of the slaves and is used for real time program data storage. An APU (arithmetic processing unit) board based on an AMD 9511 is attached to the predictor processor and an additional IEEE-488 listener/talker board is modified to provide for the controller function of the data communication link between the formatter processor and the two HP 5370 range counters.

The real time programs of the slave processors are supported by a selfmade operating system. The operating system as well as the real time programs are installed in EPROM.

3. The real time software system

The MTLRS is controlled by three cooperating microprocessor based computer systems. Each processor hosts a task, executing a well defined function to achieve a minimum of interaction between the processors. These three functions can be described as:

- final prediction and correction of the direction and the speed of movement of the optical axis of the telescope,
- collection and formatting of the observational data into a compact data format,
- data acquisition during and control of the observational activities.

The first two functions are performed by the predictor and the formatter processor respectively while the last one is carried out by the main processor because of its complexity and variety concerning data handling. The predictor as well as the formatter task are programmed in assembler to meet the requirements of time dependency during real time operation whereas the task of the main processor has been established in Fortran IV. For overall synchronization of the different processors, the start-up procedure and the observational activities have been broken down into several levels, each of them representing a certain state of operation. A change of state is mainly caused by a binary command string from the main processor's monitor program to the predictor and formatter processors, but also by the detection of a certain condition by either processor. At all times both slave processors notify the monitor program about a change of state, while during the real time operation also the predictor and formatter processors interchange state information. In this section the major states of operation of both the predictor (figure 2) and formatter processor (figure 3) will be discussed in some detail.

Start-up The predictor and formatter processor system command handlers are entered after power-up, ready to receive a command from the main processor's monitor program for system function initiation like memory dump, program loading and (real time) program execution. At this level diagnostics may be loaded and executed.

On behalf of the observational activities the real time predictor and formatter programs residing in EPROM are started by the monitor program. Both programs examine all the communication links they are going to use, reset the encoders of both the telescope's axes as well as the range counters after which they automatically proceed to the next state.

Session idle The session idle state is defined as a resting-point for both the predictor and formatter real time programs to allow off-line operation of the main processor.

At this level there is no interaction with the MTLRS guiding and detection system and between both slave processors. For future use, functions like telescope encoder readings and time synchronization of the main processor may be added to the predictor and formatter programs, callable by monitor user commands.

To leave the session idle state, the monitor program may issue a user command to return to the processor system command handler or to proceed to the session initiate state for the execution of a series of observational activities.

Session initiate All data transfers between the main processor and the slave processors will be performed under interrupt control from this state onwards to guarantee that the 10 Hz operation rate of the predictor and the formatter programs will not be disturbed.

After receipt of the initiation command by both slaves, the predictor program receives a set of equally spaced topocentric predictions from the monitor program. The predictions are to be used for target tracking (satellite path) or fixed target pointing (ground targets), the latter one mostly being time independent. In the case of time independent pointing the movement from one target to another is performed under monitor command. Optionally the directional mode of observation may be chosen instead of the ranging mode.

To maintain azimuth angle accuracy of tracking predictions at higher elevation, the predictor program defines separate coordinate systems for adjacent groups of four satellite points utilized during real time 3rd degree interpolation.

Concurrently the formatter program optionally initializes the two range counters and prepares observational data formatting. Before entering the session active state the predictor and formatter program synchronize for the first 0.1 second observation cycle, as will be described in the next section.

Session active Three major tasks have to be performed during a 0.1 second observation cycle, i.e.

- calculation and correction of a prediction,

- synchronization of the predictor processor and the formatter processor,
- formatting of the observational data records.

The prediction calculation and correction task is carried out by the predictor program. The predictor program subsequently passes through three substates during the session active state. The first one is the prediction ready state while it waits for the first prediction epoch. It remains in the prediction valid state until the last prediction epoch is encountered, whereafter the prediction exhausted state is entered. In the prediction ready state the telescope's direction is moved to the first predicted point, being a satellite position or a ground target. The prediction valid state comprehends either the selection of a pointing prediction or the interpolation of a tracking prediction and the correction of that prediction, to be used for the next observation cycle. While in the prediction exhausted state, telescope pointing in the direction of the last calculated position is maintained.

The predictor and the formatter programs synchronize every 0.1 second observation cycle, by using the well defined epoch whereupon the mount positioner accepts a prediction message from the prediction program. The predictor program then transmits a synchronization message, including the current prediction to the formatter program and in turn receives a message from the formatter program containing the corrections to be applied to the next prediction.

The formatting of the observational data records is performed by the formatter program. The observational data is received from the multiplexor and one of the two range counters which are alternatingly used every 0.1 observation cycle. Three different types of 8 byte records may repeatedly appear in an observation message, i.e. the time record, the direction record and the observation record.

The time record contains the absolute epoch and appears every 25.6 seconds in the stream of observation messages. Every 1.6 seconds the current elevation and azimuth of the telescope are formatted into a direction record. If a successful observation is detected, an observation record is formatted, including time fractions of the laser firing epoch, the simultaneous calibration and the range count. Because the MTLRS can be utilized for direction observations, the observation record may contain azimuth and elevation angles instead of ranging data. Both the direction and the observation record contain unambiguous time offsets of their epoch. Every 1.6 seconds, the currently formatted observation message, together with an optional multiple-stop timer message are submitted to the interrupt system for transmission to the main processor.

Calibration mode of ranging may be selected during the whole session active state with either the telescope being directed to a predefined point or with the telescope continuing to point or track. The session active state may be terminated at all times by user command to the predictor program whereafter both the predictor and formatter programs return to their respective wait state.

4. Task 1: Site Installation

Mobile laser ranging involves frequent moves of a laser ranging system between site locations. Before the actual ranging can start upon arrival at a new site, a variety of activities has to be performed, such as orientation, a lignments, system checks, etc. Some of these activities allow automation especially if they involve data taking utilising the system, data reduction or data storage. A software system has been designed combining the computer aided installation activities in one task (figure 4). This task is made up of four subtasks:

a. the astronomical orientation of the telescope mount axes together with the determination of astronomical latitude and longitude,
b. the positioning of the mount relative to local markers,
c. the initialization of terrestrial range targets and finally
d. the recording of data and results obtained from these subtasks on selected external storage devices.

Geodetic astronomy A high accuracy orientation is required for tracking a predicted satellite orbit with a laserbeam of 10 arcsec. minimum divergence. Therefore this subtask first determines the orientation of both the azimuth and elevation encoder system in an astronomical reference frame. Since, the reach of hand paddle corrections in elevation and azimuth in tracking mode is limited to ±0.127 degrees, the orientation is obtained in two steps.
An initial azimuth orientation is determined from star observations in static pointing mode, manually operating the mount positioner. Subsequently accurate azimuth and elevation orientations are obtained observing optimally selected meridian stars in tracking mode, making full use of the computer controlled systems for mount positioning and data recording. The data reduction results are tested statistically and if these results are not accepted, the observational procedure is re-scheduled immediately.

If the orientation is satisfactory the subtask secondly determines astronomical latitude and longitude simultaneously, by observing zenith distances of optimally

selected ex-meridian stars in tracking mode.
Latitude and longitude are required to obtain baseline corrections in a global reference frame from locally obtained eccentric positions of the system, as well as for proper transformation of predicted satellite positions to topocentric coordinates.

Survey local markers This second subtask determines the position of the telescope mount relative to a number of survey markers available on the site pad. A positioning device is utilised to obtain azimuth and elevation readings to these markers, employing the computer controlled mount-positioning system and data recording system. If four or five optimally arranged markers are observed (Vermaat and Van Gelder, 1983) the positioning of the ranging system can be obtained with sub-millimeter precision from a specially designed data reduction method (Vermaat, 1984).

Initialize range targets If terrestrial range targets are going to be observed in a lateration mode, these targets will be identified in the third subtask. This very simple process involves manual pointing at a target utilising the mount-positioning system and the subsequent reading and recording of the telescope position under computer control. This initial identification facilitates the ranging to any of these targets employing the ranging task and the real time software system.

Finish the installation task OK-bits identifying each of the previously described subtasks will be set as soon as the particular subtask has been completed satisfactorily. If all OK-bits are set, i.e. if the complete installation task has produced acceptable results, the present termination subtask will perform a specific process of data storage. First, all observations obtained during any of the previous subtasks will be stored in a uniquely identified site log file on a specific data diskette. This enables the reconstruction of the complete installation task at any time, using the original observations. Subsequently, site identification parameters such as site number and occupation number together with the results from the installation process, e.g. astronomical latitude and longitude, the baseline correction vector, etc., will be stored on the system diskettes of all subsequent tasks. This procedure safeguards these subsequent tasks against the use of wrong site dependent data and requires each of these subsequent tasks to start with a check on the identity of the current site.

5. Task 2: Satellite prediction

Satellite ephemerides must be available in the form of inertial state vectors (comprising position and velocity components) at an epoch close to the rise time of the satellite for a particular site. Thus each satellite pass for a site requires one state vector. These state vectors can be obtained from any established method of orbital prediction, performed by the authority responsible for the deployment of the system. To facilitate the use of any available data communication method, the state vectors are required in an ASCII-character format.

The task performing the satellite prediction comprises two subtasks: the re-formatting of newly received ephemerides and the actual prediction of individual satellite passes (figure 5).

Processing of new ephemerides This subtask checks the ASCII-character input data for transmission errors and subsequently re-formats the data into a compact binary internal format. This binary format allows efficient use of storage space on diskette as well as efficient access to the data by the prediction software.

Pass prediction This subtask performs a numerical integration of the satellite pass from the input state vector over the time-span of visibility at the site. Due to the limited time-span a very simplified force model can be employed for the equations of motion. The parameters for the integration have been tuned to minimise computing time on the HP-1000 L processor and to maintain the excellent prediction capability of the laser geodynamics satellite LAGEOS, utilising input state vectors derived from ephemerides provided by the Center for Space Research of the University of Texas (Schutz, et al., 1981). The software produces topocentric satellite positions at a satellite dependent constant time spacing. This time spacing has been tuned to the real time 3rd degree interpolator in the prediction processor. The predictions are stored in a binary format in data files on a prediction diskette, and are thus readily available for the ranging task.
At the hardcopy unit of the HP 2623 A graphics terminal an alert list is produced, summarizing the rise- and set times of the satellite in the predicted period.

6. Task 3: Ranging

The ranging task (figure 6) employs several programs, some of them may be called optionally, e.g. to update ranging parameters, others are necessary during ranging and are designed to reduce delay times of data transmission. The real time ranging activities are executed by three programs, i.e. the range program, the alarm program and the disk program. The overall control of the ranging activities is performed by the range program, which schedules the alarm and disk programs to become memory resident before real time operation. The alarm program is scheduled on a time interval basis. It repeatedly polls the predictor and formatter processors for pending data messages, which it routes to the range program. The disk program is reactivated by the range program every time the observation buffer is filled with observational data to be recorded on diskette.

The range program initiates the observation activities selecting a set of predictions from diskette, prepared in the previous task. The predictions are sent to the predictor processor and are also recorded on the observation diskette for use in the data evaluation task. The calibration mode of ranging is selected when the predictor and formatter program indicate their readiness for pre-calibration. Because calibrations are taken using a prism mounted to the front end of the telescope, the direction of the telescope is moved to a predefined point to eliminate effects caused by the possibly inhomogeneous wave front of the laser beam. When sufficient calibration observations have been collected, satellite ranging mode is turned on and tracking is automatically started on the first satellite prediction epoch. During satellite ranging, the multiple-stop timer counts, four of every 0.1 second observation cycle are displayed on the system console to aid in optimizing the prediction corrections. Six different corrections are possible during tracking, i.e. time-, cross track-, azimuth-, elevation-, range gate delay- and window correction. A histogram of the simultaneous calibration provides a permanent indication of the stability of the system. After pass termination and post-calibration all observational data is available on the observation diskette for data evaluation.

7. Task 4: Data evaluation

Processing of observed data Reliable deployment of mobile satellite laser ranging equipment calls for the availability of a method of data evaluation on-site. This method must basically aim at:

a. the determination of the noise level of satellite data and the search for outliers,

b. the validation of system performance,
c. the updating of orbital parameters.

The software designed to meet these requirements for MTLRS (figure 7) initially produces range residuals, i.e. the differences between observed and predicted ranges. These residuals are displayed on the HP 2623 A graphics terminal, facilitating the visual recognition of the satellite ranges among noise data. Optionally a range window can be defined about the predicted ranges by selecting a time- and range bias and a window size. All residuals outside this window will be flagged for rejection. This simple technique of editing enables the elimination of a large portion of the noise data facilitating the subsequent analysis, especially at a high level of noise data. The accepted range residuals are then subjected to a curve fitting utilizing orthogonal polynomials followed by a procedure of iterative statistical testing (Aardoom, et al. 1982). The resulting residuals are displayed on the graphics terminal and the range data is flagged according to the result of the tests. This powerful method of datafiltering automatically discriminates satellite returns from noise data. Pre- and post calibration data obtained from the optional retro-reflective calibration mirror at the telescope as well as simultaneously obtained calibration data from the Le Croy counter can be analysed utilising the same filtering technique. All data editing only effects 2-bit flags available in each range record in the data file, thus no data will be lost or altered and the data-evaluation of each pass of data can be replayed any number of times.

Accepted residuals define an RMS value which is a measure for the precision of the obtained ranges. The accepted satellite ranges are also used to evaluate a time- and a range bias for the particular pass. These biases allow the updating of satellite predictions for future passes and thus enhance the data acquisition capability of the system, especially in the case of low satellites.

List data summary This task consists of a procedure for listing a summary of all data obtained at the current site, enabling the crew to appreciate the progress made to date.

Select quick-look data A third subtask selects quick-look data from previously evaluated passes. A selection is made out of all accepted satellite ranges. This data is corrected for system delay estimated from the processed pre- and post calibration data.

8. Concluding remarks

The aim to build a highly mobile and field operational satellite laser ranging system has been realized in the hardware and software of the MTLRS. The MTLRS has demonstrated its reliability and quality during the collocation experiment at the satellite observatory in Kootwijk in spring 1984. About 3000 single photo-electron observations taken with a single shot precision better than 6 cm RMS represent the normal results of a Lageos pass during clear sky conditions.

The choice to subdivide the observation task into three subtasks, each of them executed almost independently by a separate microcomputer has an important positive impact on the reliability of the MTLRS.
The two relatively small 8-bit Motorola M6809 microcomputers, hosting the EPROM resident real time prediction and formatting tasks, provide complete and efficient control of all time-critical observational activities.
Consequently the third microcomputer, i.e. an HP 1000 L 16-bit microsystem with the RTE-XL operating system, is relieved from the time critical aspects, being left with routinely data acquisition during and overall control of the observational activities. This multi processor set-up and consequent modular task design will facilitate easy future software upgrading.

A software system designed to determine the astronomical orientation of the telescope mount axes together with the astronomical latitude and longitude has been used successfully. The scrupulous approach to positioning the mount relative to local markers has proven its value. The technique deployed to merge site dependent parameters automatically with all data files produced, enhances the reliability of the data output of the MTLRS.

State vectors derived from the ephemerides for Lageos, provided by the Center for Space Research of the University of Texas and utilized in the advanced integration program of the MTLRS, enable field missions of several months without receiving prediction updates from the outside world. Time biases to be applied to the epoch of the state vectors and information to monitor system performance during a mission are derived from the data evaluation program.

References

Aardoom, L., B.H.W. van Gelder and E. Vermaat, 1982. "Aspects of the analysis and utilization of Satellite Laser Ranging Data at the Kootwijk Observatory". In: Forty years of thought... Anniversary volume in honour of Prof. Baarda's 65th birthday, Delft 1982, pp. 275-317.

Vermaat, E. and B.H.W. van Gelder, 1983. "On the eccentricity of MTRLS". Delft University of Technology. Reports of the Department of Geodesy, Mathematical and Physical Geodesy, No. 83.4.

Vermaat, E. 1984. "Establishing ground ties with MTLRS; performance and results". Preprint. Delft University of Technology. Reports of the Department of Geodesy, Mathematical and Physical Geodesy, No. 84.3.

Otten, K.H., 1984. Microprocessor controlled real time operation of the MTLRS". Delft University of Technology. Reports of the Department of Geodesy, Mathematical and Physical Geodesy, No. 84.5.

Schutz, B.E., B.D. Tapley, R.J. Eanes, B. Cuthbertson, 1982. Lageos ephemeris predictions. Proceedings of the IV International Workshop on Laser Ranging Instrumentation, 12-16 October 1981, University of Texas, Austin, Texas, USA. University of Bonn, 1982, pp. 145-171.

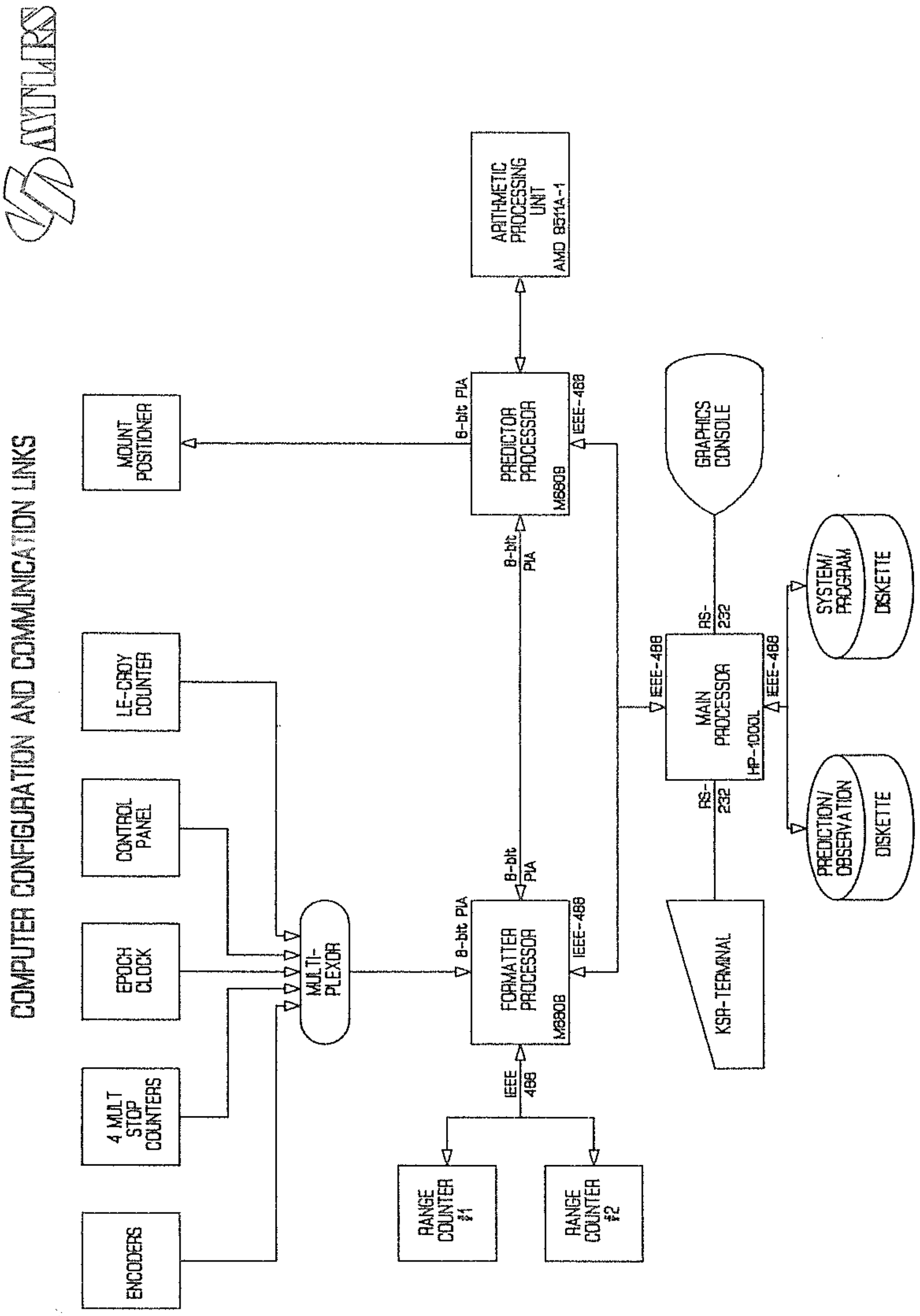


figure 1 Configuration diagram of the three MTLRS microprocessors including the communication links to the peripherals and the MTLRS hardware.

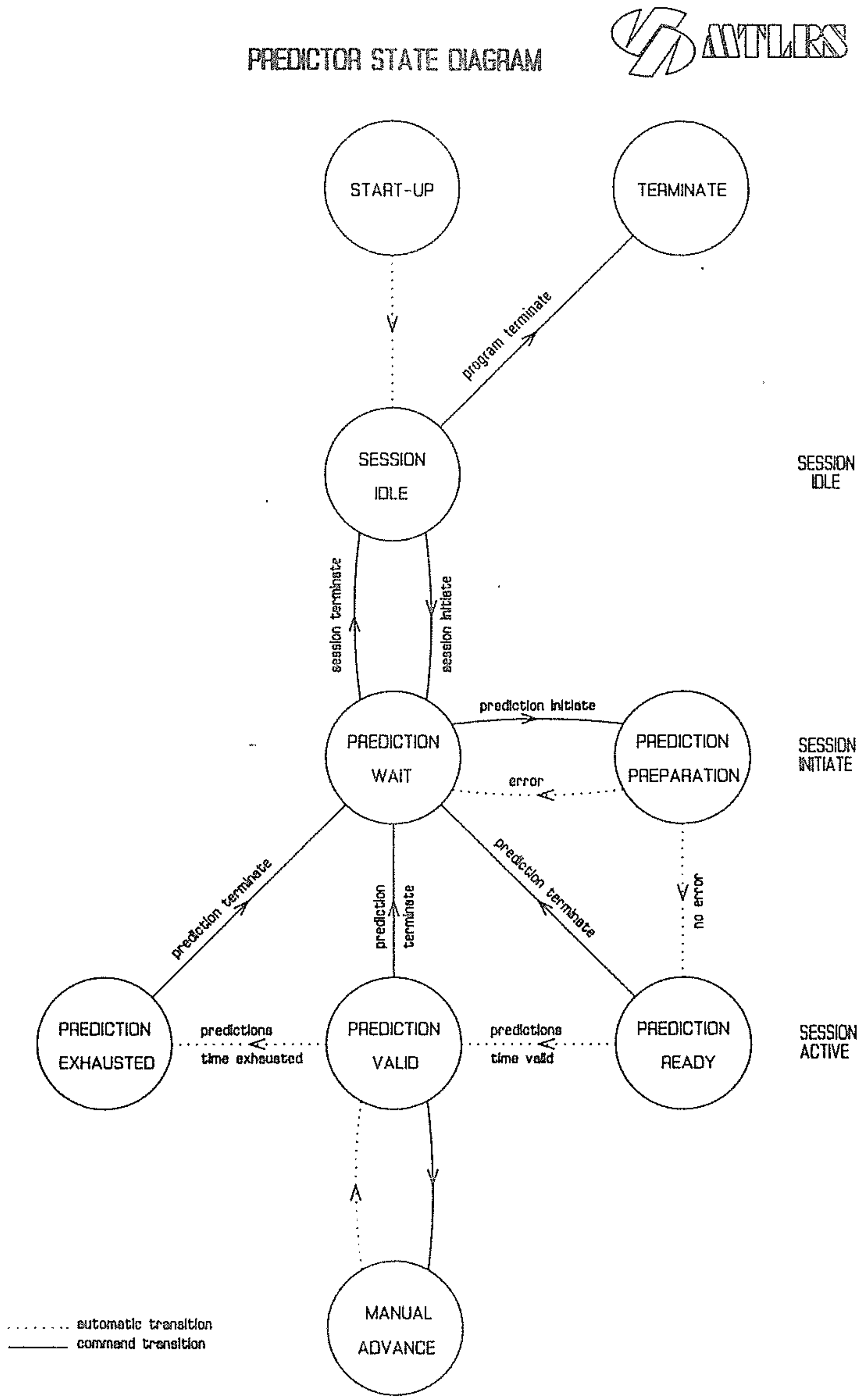


figure 2 State diagram of the real time predictor program including the commands and conditions causing the state transitions.

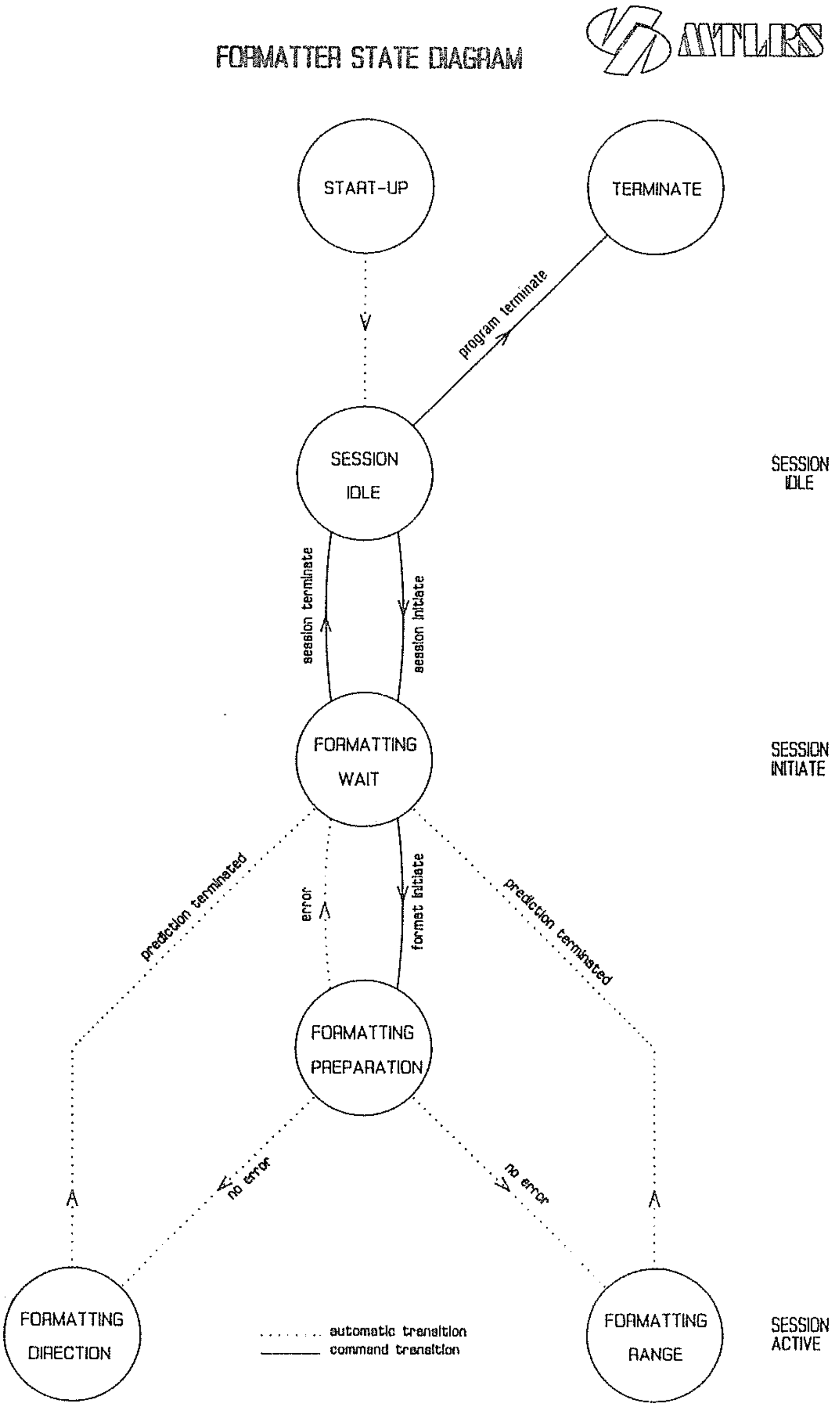


figure 3 State diagram of the real time formatter program including the commands and conditions causing the state transitions.

TASK # 1: **SITE INSTALLATION**

Subtasks:

1. GEODETIC ASTRONOMY
2. SURVEY LOCAL MARKERS
3. INITIALIZE RANGE TARGETS
8. FINISH TASK # 1 (all OK-bits set)

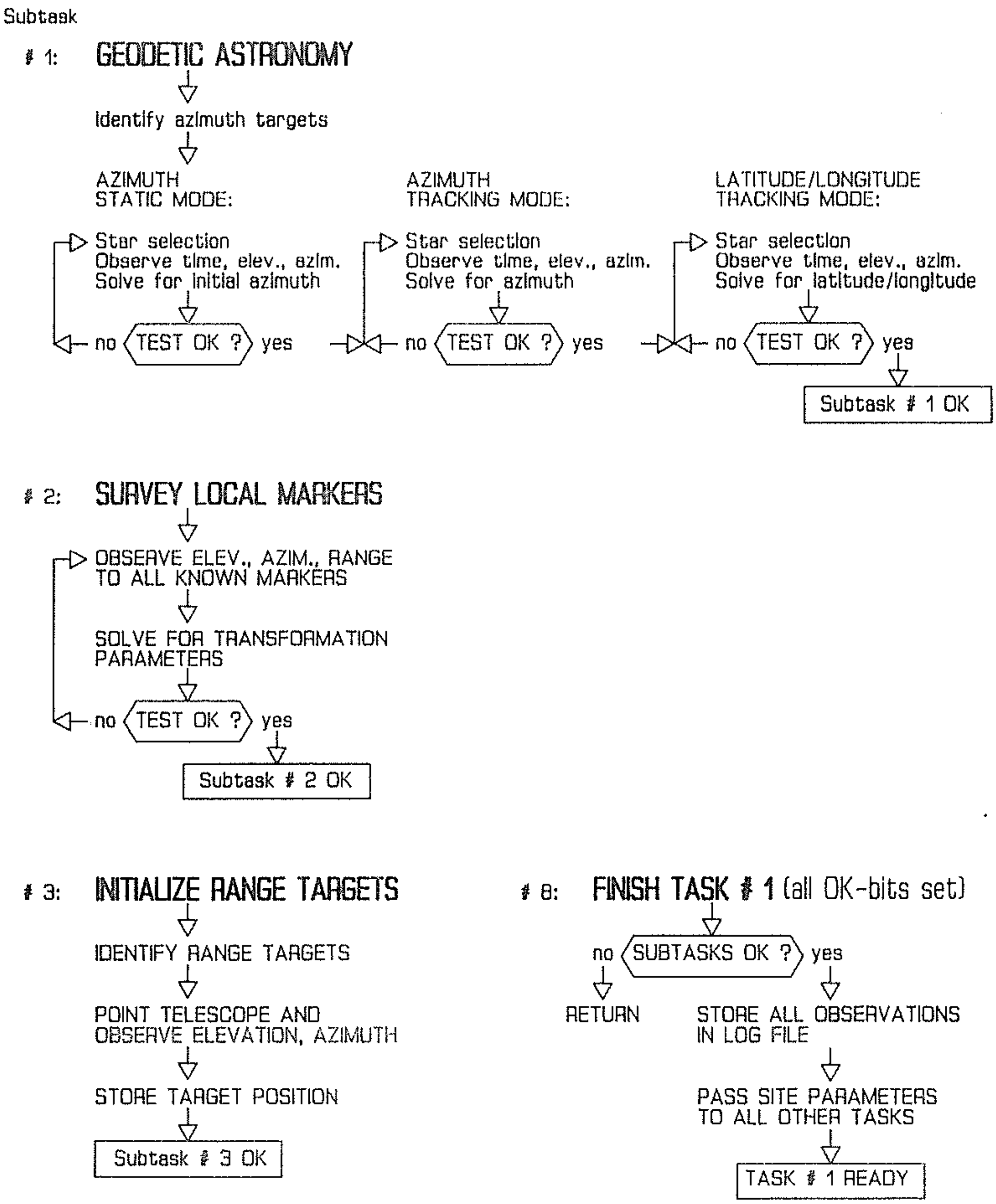


figure 4 Task-1: Diagram of the site installation activities and the procedure followed to determine the site parameters by using the MTLRS direction mode of observation.

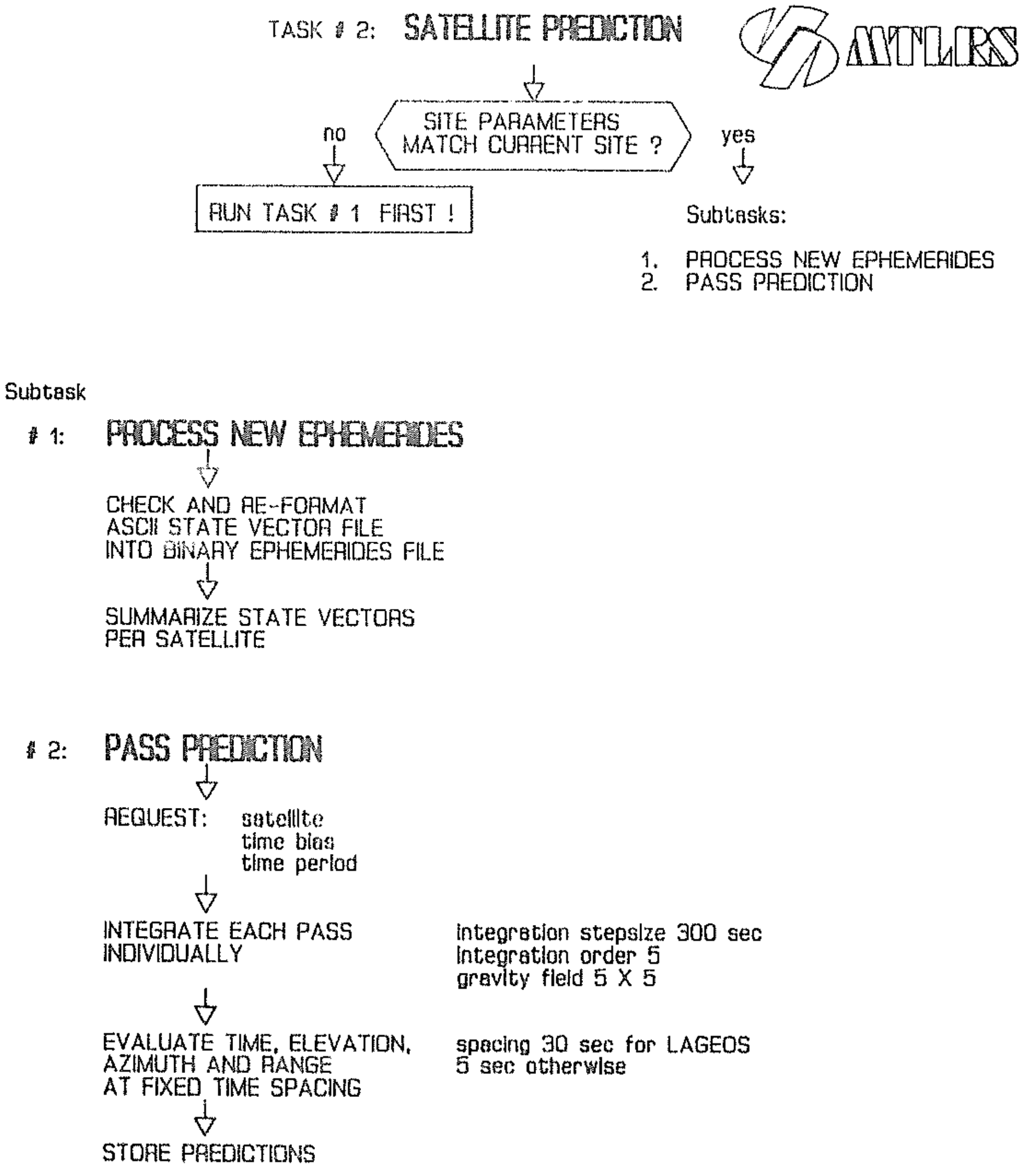


figure 5 Task-2 Diagram of the satellite-pass prediction calculation using specific state vectors supplied for every single pass.

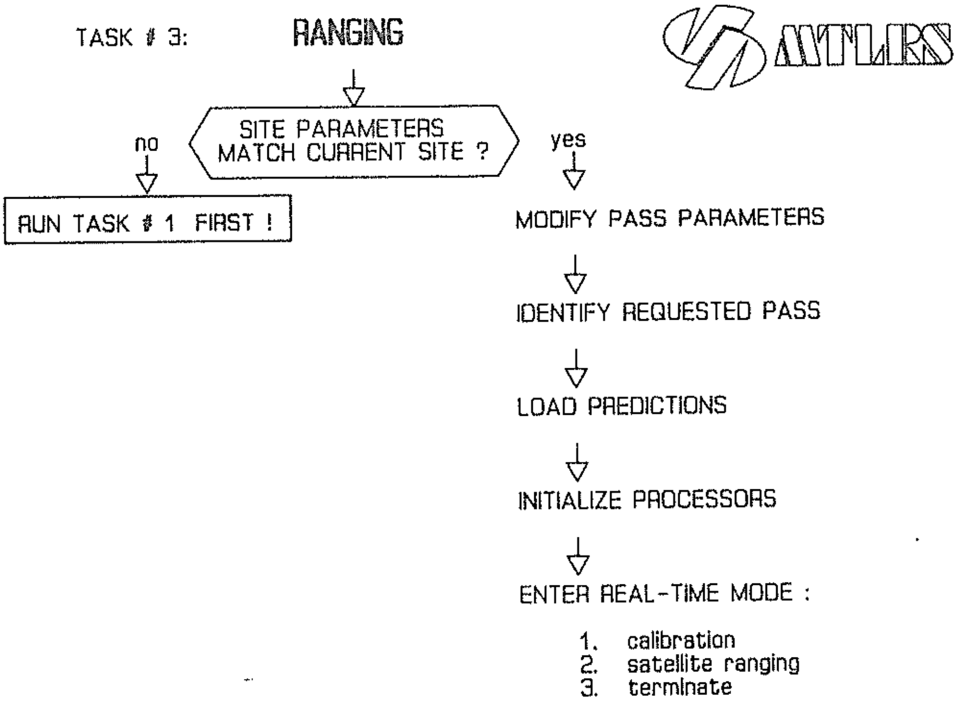


figure 6 Task-3: Diagram of the satellite ranging activities.

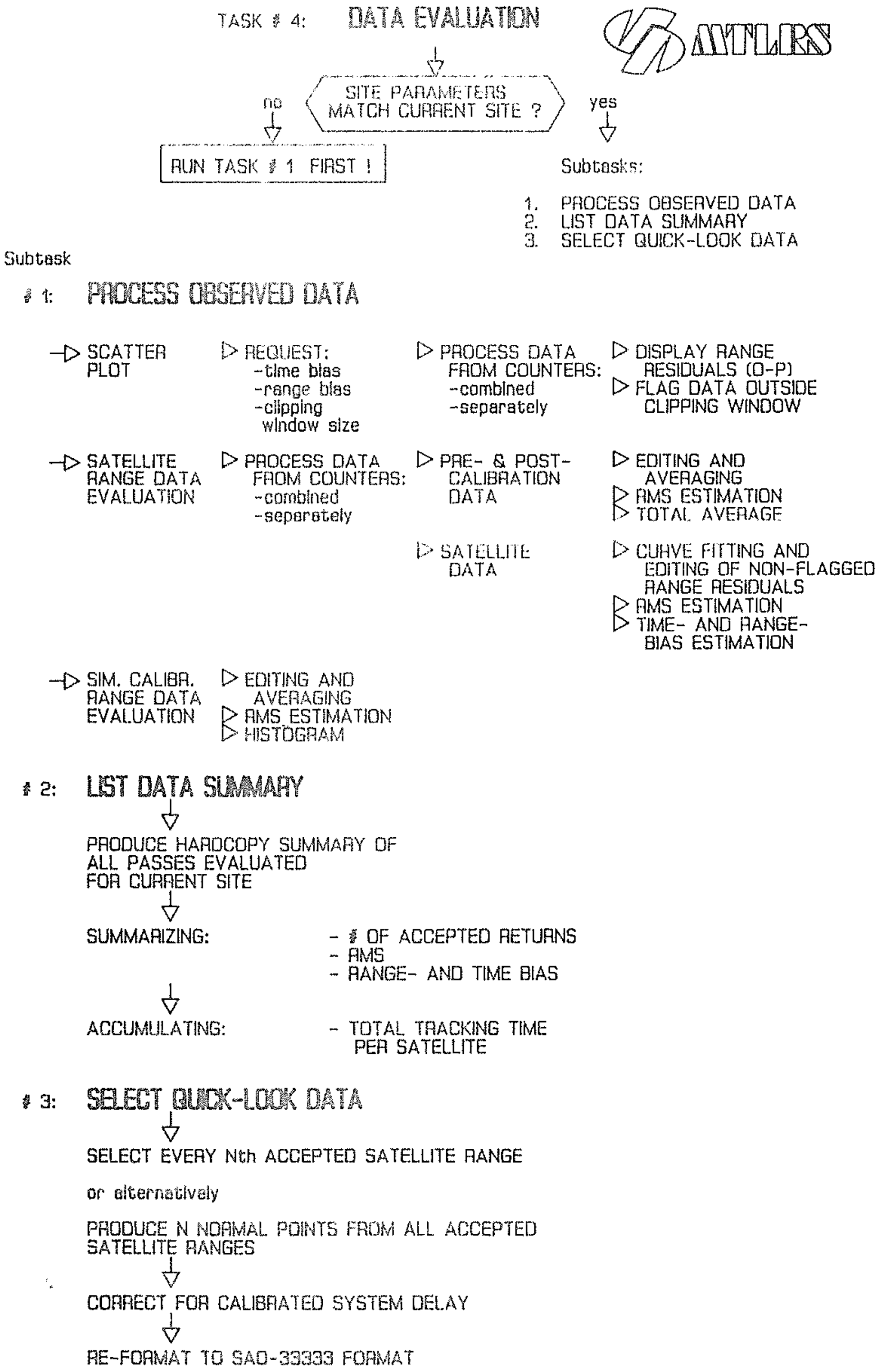


figure 7 Task-4: Diagram of the satellite-ranging and calibration data evaluation and the selection of quick-look data.

THE COMPUTER SYSTEM AT MLRS

R. L. Ricklefs
University of Texas
RLM 15.308
Austin, Texas 78712 USA

Telephone (512) 471 4462
TWX 910 874 1351

J.R. Wiant
McDonald Observatory
Fort Davis, Texas 79734 USA

Telephone (915) 426 3263
TWX 910 879 1351

ABSTRACT

The MLRS station computer firmware and software are described. Hardware that directly affects programming is highlighted.

COMPUTER SYSTEM

1 Introduction

The following document describes the computer system of the McDonald Laser Ranging System (MLRS) which was constructed by The University of Texas McDonald Observatory under NASA Contract NASW-3296. The station is located about 17 miles north of Fort Davis, Texas at longitude 255.9841, geodetic latitude 30.6770 N, and altitude 1963.41m. The system is a dual purpose installation designed for both artificial satellites and lunar targets. It takes advantage of many of the same design used in the 30 cm Transportable Laser Ranging System (TLRS) constructed earlier and the techniques developed in the 12 year old 2.7 meter lunar system about 800 meters away.

2 Functions Performed

Lunar and Satellite Position Determination: The computer must produce an ephemeris in both direction and range, suitable for tracking satellites and lunar sites in real time during each pass, Figure (◇a). These preprocessed initial conditions are produced either by integrating from a tape of Inter-Range Vectors (IRVs) (◇b) generated by an outside computer (for artificial satellites) or by internally computing an ephemeris based on either an MIT or JPL export lunar and planetary ephemeris (for the moon) (◇c). The preprocessed positions are produced at intervals which are commensurate with the apparent paths of the satellites and the moon to the required tracking precision.

Real Time Pointing and Tracking: In real time, the computer must perform 6th order interpolation of the pointing and ranging tables to generate rates for the 76 cm telescope, Figure(Δa), and range predictions to open the receive gate (Δb) and interpret the returning pulses (Δc). Real time tracking utilizes position dependent functions to correct for telescope mount orientation errors (◇e). The hand paddle (Δd) is used to input point angle offsets as well as time offsets, the latter modifying range as well as point angles. The system also responds to a number of interlocks and status word inputs. Tracking status, including point angles, are displayed on the Matrox monitor (Δe), while error messages appear on the system console (Δf).

Satellite pointing and tracking are accomplished by reading the absolute encoders (Δg) through the CAMAC interface (Δk). Lunar pointing is accomplished by visually pointing at known lunar features and then using differential offsets through the incremental encoder CAMAC interface (Δh).

Stellar Object Tracking: The computer is able to slew the telescope to the position of known stellar objects and begin tracking at stellar rates. In this mode the system is sensitive to position changes, via the handpaddle (Δd), and to focus commands only. An abridged version of the FK4 (◇d) supplies star positions, although positions may be entered manually by the operator (Δf). Stellar observations are used to determine the telescope orientation error model (◇e).

Telescope Servo System: The beam director servo system (Δi) is controlled by the NOVA 4X computer (Δj) via a CAMAC interface unit (Δh). Through the CAMAC unit the computer has continuous access to the positions of both the incremental encoder units (Δl) and the absolute encoders (Δg) and is able to select drive rates on each axis over the full rate capability of the system. As many as seventeen limit switches are available on both axis with which the computer may sense both the observing limits of the system as well as the mechanical stops in each axis. A manual handpaddle (Δm) is provided to move the beam director independently of the computer CAMAC system.

Laser Firing Control: During laser firing it is necessary for the computer to rotate the transmit-receive switch (▵n) and the attenuator to the appropriate positions, calculate the laser firing times, and fire the laser (▵o) at the correct repetition rate. During firing, the computer accesses the corrected returns, calculates the residual error between the observed and predicted flight times, and displays the results on the sceen (▵f) for operator interaction. Calibration data is automatically recorded and displayed (▵f) during the real time firing. All relevant data is saved (▵p) for later analysis.

Time of Flight: The time of flight system (TOF) is designed around a latchable timer (▵q), an EGG time digitizer (▵r) and a CMOS clock (▵D). The time digitizer (▵r) measures the interval between any event and the next pulse in a 5-megahertz pulse train with 100-picosecond accuracy. The latchable timer (▵q) records which pulse was used. The CMOS clock (▵D) contains the time of day from 1 second to 1000 days. The timer (▵q) and the time digitizer (▵r) are phased together with delay boxes to remove the one count uncertainty in the time of flight. The time latch on the timer (▵q) has five gateable inputs which are selectable from the computer. They are; four external TTL-compatible inputs (▵s, ▵s), and one internal, computer triggerable input. The timer (▵q) maintains the time standard from 200 nanoseconds to at least 53 seconds. It also has two computer-selectable outputs which occur upon the coincidence of the timer count train with a computer-loadable latch; one TTL laser firing output (▵t), and one variable width NIM compatible gate pulse (10 microseconds nominal width)(▵u).

Data Log Processing: The computer permits the entry of interactive log information (◇f), the editing of this information(◇n), the inclusion of internally regenerated sets of information, and allows for the storage on disk(▵p), or hard copy (▵B) and the subsequent review of the log information at a later time.

The Dynamic Process Monitoring: The dynamic processes in the system are monitored at all times (◇s). These processes include weather (◇g)(▵v), system interlocks, scaler data, clock frequency drift (◇h)(▵w), and the NASCOM line (◇i)(▵x).

System Operator Tutoring: The system is designed to tutor a non-sophisticated user such that he can access the proper commands, by answering a menu of questions at each phase (▵f).

Initialization Functions: Since nearly all of the ranging system dynamic processes are under computer control, a number of programs are needed to aid the operator to determine and input parameters required for laser ranging. These include the programs to develope the telescope orientation parameters from star observations (◇e), to input, check, and convert satellite and lunar ephemeris and stellar positions information (◇j,◇j), to set the hardware and software clocks, to enter new clock transfer information (◇k), site coordinates (◇l), and ground target positions.

Range Data Processing: Sometime after acquiring range data (◇m) and entering the pertinent log (◇f) information, the operator must generate files (◇v,◇w,◇x,◇y) containing this data for use elsewhere. The programs which the operator invokes (◇n) allow displaying (▵f) the old data, windowing it, and transferring it to disk (▵p), tape(▵y), etc., in the appropriate format for further use. In addition, a permanent archival copy is made of the raw data file itself.

NASCOM: The computer allows the easy preparation, editing and sending of all standard NASCOM messages including Status, TOR, and Quick Look (◇o). It also monitors the line (◇i)(▵z) for incoming messages and routes them to appropriate holding files on the disk (▵p).

Debugging: Several programs have been written to facilitate debugging the hardware and software unique to MLRS. These include programs to manually set parameters for the CAMAC modules, exercise the telescope drive, exercise the rotating mirror and attenuator, and to print binary data files in a useful format. These supplement a host of computer-vender supplied diagnostic programs.

3 Inputs to Computer

1. Telescope absolute axes encoders (◇p)(▵g)--from CAMAC (▵k)
2. Telescope incremental encoders(◇p)(▵l)--from CAMAC (▵h)
3. Handpaddle(◇q)(▵d)--from CAMAC (▵A)
4. User commands and response--from keyboard (▵f)
5. Epoch--from CAMAC (▵D,▵q,▵r)
6. Ephemeris data(◇b,◇c) for object (star, satellite,etc.)--from disc(▵p), keyboard(▵f)
7. Site constants--from keyboard (▵f)
8. Telescope orientation parameters--from disc (▵p)
9. Overrides, condition detectors and interlocks to the telescope--from CAMAC (▵h,▵A)
10. Weather (▵v) information--from CAMAC (▵E)
11. Previous return data(◇m)--from magnetic tape(▵y) and disc(▵p)
12. Status information from guiding (▵d) and detecting packages (▵q)--from CAMAC (▵A)
13. Orbit time coefficients--from managetic tape(▵y)

4 Outputs from Computer

1. Track rates to telescope axes(▵a)--through CAMAC (▵h)
2. Pulses to each telescope axis(▵a)--through CAMAC (▵h)
3. Slew commands to the telescope(▵a)--through CAMAC (▵h)
4. Keyboard (▵f) responses and prompts
5. Display of statistics (▵f)--CRT graph
6. Return information--disc(▵p), tape(▵y), printer(▵B)
7. Estimated fire times (▵t)--through CAMAC (▵q)
8. Transmit/receive control(▵G)--through CAMAC (▵A)
9. Dynamic information(◇r)--TV monitor (▵e)

5 Mode of Use

The MLRS operating system is disc resident (▵p) with a backup system on tape (▵y). Startup is initiated through a vendor-supplied operating system (RDOS) . After system initialization, the monitor program (◇s) begins to execute in the Forground partition (◇t) and the Command Line Interpreter (CLI) begins to execute in the Background partition (◇u) and awaits operator commands (▵f).

6 Environment

Hardware: The software system operates in a computer system configuration which can include any or all of the following:

1. One Nova 4X CPU with 128K 16 bit words of semi-conductor memory, power fail protect, a real-time clock, automatic program load, hardware arithmetic, and floating point options (▲j)
2. Two 10-megabyte disc subsystems, with removable 5-megabyte cartridges (▲p)
3. One 640X by 476Y point graphic/alphanumeric CRT terminal, 6.4" by 9" display area, with 75 to 9600 baud rate (9600 is used) (▲f)
4. One telephone modem, 300 baud rate, for NASCOM, RS232 (▲z)
5. A CAMAC interface (▲F) to the locally built hardware which includes a CRT monitor (▲e) for real time information displays
6. One 9-track, 800 BPI, 10-1/2" reel magnetic tape unit (▲y)
7. One line printer (▲B)

Operating System: The vendor-supplied operating system used is the Data General Real Time Disc Operating System (RDOS). This system provides software drivers for all vendor-supplied peripherals. It allows the user to compile, assemble and build the controlling software system on the single computer system. During real time operation, the system handles multiple priorities of user hardware interrupts on a task oriented basis. RDOS has been modified locally to handle the Matrox display (▲e) and TOF timers as system devices (▲q,▲r,▲D).

Note: On Figure ▲, the symbol

UT

indicates that these devices were designed and built by McDonald Observatory. Other device were available commercially.

7 Main Software

The following programs are available for routine operator usage and can be called by name by the operator from the system standby state (CLI). Indented entries are programs swapped in by the previous program.

BCDEPH	-Converts ASCII JPL Lunar and Planetary Export Ephemeris tape into NOVA-Compatible binary file
CALTD8	-Determines TD811 time digitizer calibration constants.
CLEANUP	-RDOS command file which cleans up debri after system crash
CLKCOR	-Allows operator to access clock data
CPYRDF	-Copies range data file between disk and tape
CYB9	-Writes blocked tapes for use by other computers such as the C.D.C. Cyber
FIXEPH	-Applies current time to ephemeris file for testing
FIXLEPH	-FIXEPH for lunar ephemeris files
FMAILER	-Creates ASCII laser mailing tape, quick look, and lunar Z & P files from windowed ranging data
GLOGGER	-Logs satellite passes
GTE	-Generates test ephemeris for range tests
INTRDF	-Initializes a range data file for (re)use
INITSAT	-Integrates IRV to produce satellite ephemeris
KEYCAMAC	-CAMAC diagnostic program
LMTCHECK	-Produces report of ASCII Laser Mailing Tape contents
LMTOP	-Converts FMAILER binary LMT to ASCII mag tape file
LUNRANGE	-Lunar range data acquisition program
MFORMIRV	-Reformats & verifies checksums on raw IRVS (Goddard & UT Metric)
MOUNT	-Telescope mount orientation data acquisition & fitting
MNTGRA	-Graphics program used by MOUNT
LSGFIT	-Least-squares fitting program used by MOUNT
MONITOR	-Foreground program to monitor & update time, clock differences, encoder, & environmental information
MSATPATH	-Prints listing of satellite positions (X,Y) from ephemeris file
MTAR	-Records fixed target positions for later use
NBRCMP	-NASCOM message number comparison
NCEDIT	-NASCOM message editor
PRECLI	-Setup program executed at system start-up
PREDCNTRL	-Lunar ephemeris generation program
PREDICT	-Produces intermediate lunar ephemeris
TABFORM	-Converts intermediate lunar ephemeris to MLRS lunar format
PRNTEPH	-Prints satellite positions (X,Y,Range) from ephemeris file
READX	-Read IRV format tape
RET	-Request for NASCOM re-transmission
RSCLK	-Re-syncs software clock to CAMAC CMOS clock
SATRANGE	-Satellite range data acquisition
SENDQL	-Sends Quicklook Data message
SITE	-Allows entry of site coordinates and eccentricities into system
STAT	-Writes status report (to Joe Miller, BFEC) onto NASCOM
TDUMP	-Dumps binary JPL ephemeris to line printer
TBR	-Sends time bias report over NASCOM
TOR	-Sends tracking observation report over NASCOM
XSHORT	-Creates short version of binary JPL ephemeris for routine use

In addition, the following is a list of files and file naming conventions for MLRS.

I. Satellite Ranging

-------.BI -Binary IRVs (output of FORMIRV, input to INITSAT)
-------.RC -Eye-readable recap of contents of BI file, including IRV number, date, & time
-------.EP -Ephemeris File (output of INITSAT, input to SATRANGE)
GEMION -Geophysical and physical constants input to INITSAT
RDFn -Range Data File (shared w/lunar)

II. Lunar Ranging

LSITES.PC -Lunar observatory site coordinate file
LFEAT.PC -Lunar surface feature file
LREFL.PC -Lunar reflector file
LMODEL.PC -Lunar model parameters file
LCONTOL.PC -Lunar control parameters file
PROCTRL.PC -Current lunar control parameter file

-------.IE -Intermediate lunar ephemeris file
-------.EP -Lunar ephemeris file (output from PREDCNTRL, input to LUNRANGE)
RDFn -Range data file (shared w/ satellite)
DE111S -Shortened binary JPL lunar and planetary ephemeris

III. Star Pointing

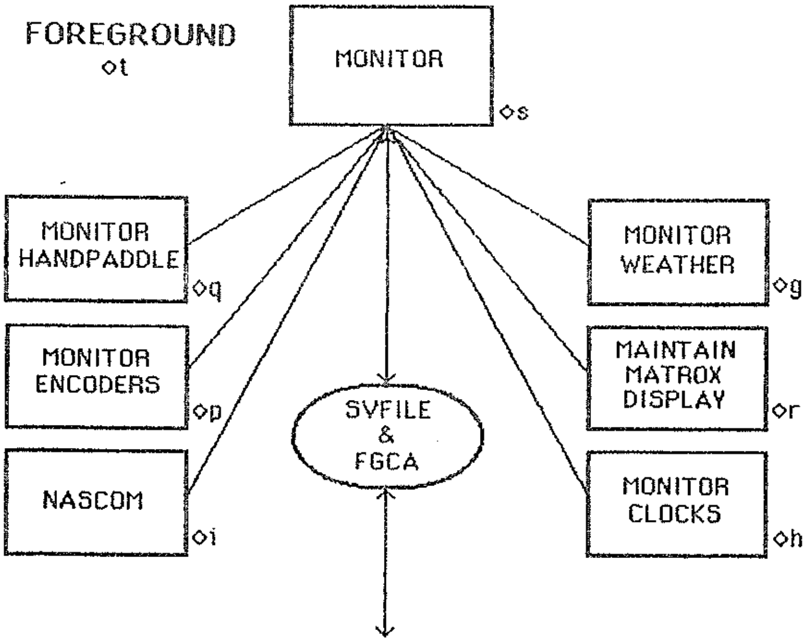
FK4PKD -FK4 star catalog edited and packed as a binary file
STARS -Eye-readable list of brightest stars and corresponding numbers

IV. NASCOM

RLOG -Receive log; lists message number, file where placed, date/time received
NASCOM -All other messages
TLOG -Transmit log

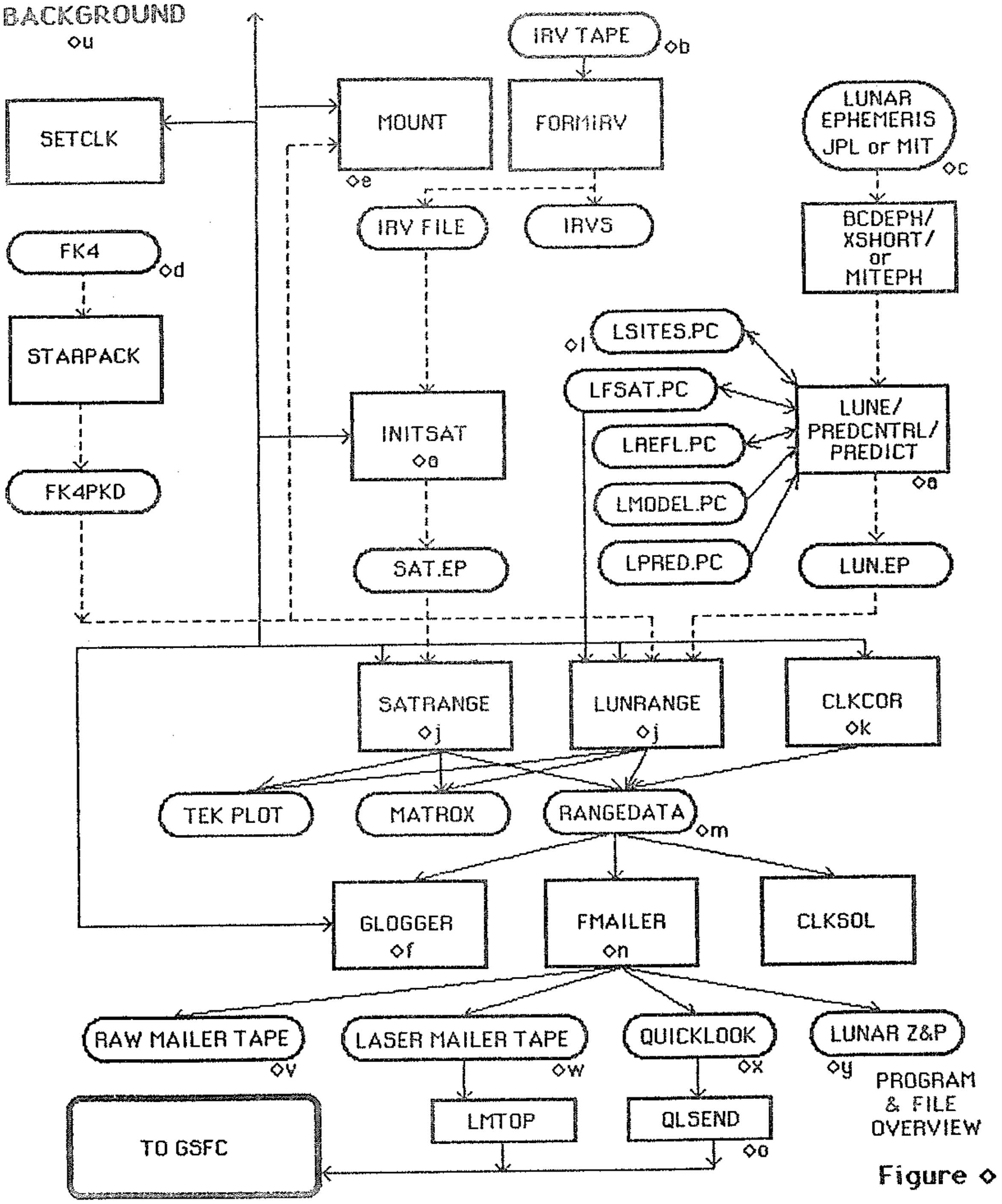
V. Others

SVFILE -Station variables files. Used by monitor and most user programs
FEATPKD -Ground target position file
FILES -List of file names and naming conventions (this list)



PROGRAM
&
FILE
OVERVIEW

FIGURE ◇



PROGRAM
& FILE
OVERVIEW

Figure ◇

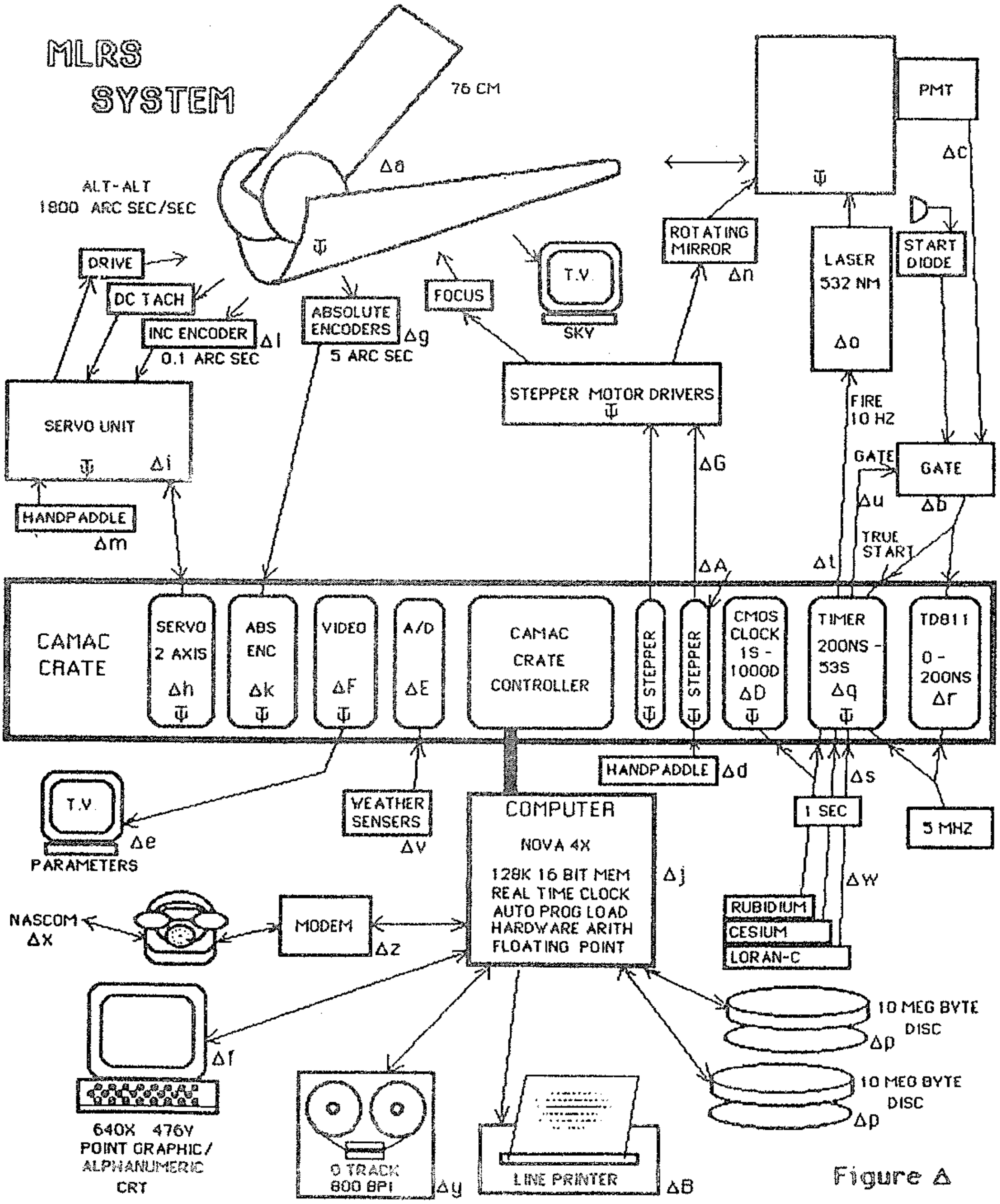

MLRS
SYSTEM
76 CM
Δa
ALT-ALT
1800 ARC SEC/SEC
Ψ
DRIVE
DC TACH
INC ENCODER
Δl
0.1 ARC SEC
ABSOLUTE ENCODERS
Δg
5 ARC SEC
FOCUS
T.V.
SKY
ROTATING MIRROR
Δn
Ψ
PMT
Δc
LASER
532 NM
Δo
START DIODE
STEPPER MOTOR DRIVERS
Ψ
FIRE
10 HZ
GATE
GATE
Δu
Δb
TRUE START
Δt
ΔG
ΔA
SERVO UNIT
Ψ
Δi
HANDPADDLE
Δm
CAMAC CRATE
SERVO
2 AXIS
Δh
Ψ
ABS
ENC
Δk
Ψ
VIDEO
ΔF
Ψ
A/D
ΔE
CAMAC
CRATE
CONTROLLER
STEPPER
Ψ
STEPPER
Ψ
CMOS
CLOCK
1S -
1000D
ΔD
Ψ
TIMER
200NS -
53S
Δq
Ψ
TD811
0 -
200NS
Δr
HANDPADDLE
Δd
Δs
1 SEC
5 MHZ
T.V.
Δe
PARAMETERS
WEATHER SENSERS
Δv
COMPUTER
NOVA 4X
128K 16 BIT MEM
REAL TIME CLOCK
AUTO PROG LOAD
HARDWARE ARITH
FLOATING POINT
Δj
ΔW
RUBIDIUM
CESIUM
LORAN-C
NASCOM
ΔX
MODEM
Δz
10 MEG BYTE
DISC
Δp
10 MEG BYTE
DISC
Δp
Δf
640X 476Y
POINT GRAPHIC/
ALPHANUMERIC
CRT
9 TRACK
800 BPI
Δy
LINE PRINTER
ΔB

Figure Δ

A DESCRIPTION OF THE MT. HALEAKALA SATELLITE AND LUNAR LASER RANGING SOFTWARE

E. Kiernan, M.L. White
Institute for Astronomy
University of Hawaii
P.O. Box 209
Kula, HI 96790

Telephone (808) 244 9108
Telex 7238459

ABSTRACT

The Mt. Haleakala Satellite and Lunar Laser Ranging System utilizes a LSI-11/23 processor manufactured by the Digital Equipment Corporation. The satellite and lunar software programs are written in Fortran and Macro-11. The RSX-11M, version 3.2 operating system is used for both program development and real time execution. This operating system allows several programs to execute concurrently and to interact with each other in real time by means of global system flags ans shared regions of memory.

A DESCRIPTION OF THE
MT. HALEAKALA SATELLITE AND
LUNAR LASER RANGING SOFTWARE

1.0 INTRODUCTION

This paper describes SATCAL version 6.0, satellite laser ranging software, and the LURE version 7.0, lunar laser ranging software used at the University of Hawaii, Haleakala Observatory. The SATCAL and LURE systems consist of several programs which run on an LSI-11/23 processor manufactured by the Digital Equipment Corporation. The processor has 128K words of memory, the upper 2K being used for the video graphics display. The RSX-11M operating system, version 3.2, is used to execute the tasks and control inter-task communication and synchronization. The SATCAL and LURE software has been written in FORTRAN and MACRO-11 languages.

2.0 SATCAL

The SATCAL version 6.0, satellite ranging software consists of the following programs:

1. SATCAL is a small task which prompts the operator for the desired activity, performs initializations, and starts execution of the DESIGN task.

2. DESIGN is the main program for satellite and target board ranging. It starts up all of the other tasks, goes into a one-second real-time ranging loop, and exits when ranging is done.

3. INLIZE is started up by DESIGN, and initializes the variables needed for satellite and target board ranging.

4. RANGE runs only during the real-time ranging cycle. It contains a loop which runs N times a second, N being a number set by the operator. N can be any number from 1 to 10, but due to the structure of the laser, the only numbers which can be used are 1, 5, or 10. 5 is the number used at present for satellite ranging. RANGE fires the laser and arms the Event Timer for the return pulse.

5. UTIPR is the task which interfaces with the Hewlett Packard 5370A Universal Time Interval Counter (referred to henceforth as the UTI). It contains a loop which is activated whenever a return pulse is expected, up to N times per second. It reads the UTI and arms it for the next return.

6. INTEG runs during the real-time cycle. It contains a loop which is executed every 2 seconds. Every other loop (i.e. every 4 seconds) it integrates the IRV vector in order to get the current azimuth, elevation, and range for the satellite. It also performs the necessary corrections for refraction, mirror offsets, etc.

7. IOPRG runs during the real-time cycle and prompts the operator for commands such as: fire laser, record the data, etc.

8. SYSCOM is a common region which is shared by all of the tasks. It contains constants, inter-task semaphores (called "event flags" by RSX-11M), and variables shared by the tasks.

9. VIDCOM is a system common region which corresponds to the video graphics display memory. Once a second, DESIGN writes to this region, in order to update the display.

These tasks are described in detail in the following paragraphs.

SATCAL is a small task which is invoked directly by the operator by the command RUN SATCAL. It initializes the display on the operator's VT100 console. It also initializes the video graphics display. It reads the file CONFIL. DAT, which contains several SYSCOM constants, such as current temperature, humidity, telescope tiltmeter readings, etc. CONFIL. DAT is edited by the operator to update the appropriate values, before the start of each satellite run. SATCAL prompts the user for the activity desired (range to a satellite, range to the target board only, range to the corner cube, or exit program). SATCAL starts up (i.e., spawns) the DESIGN task, and then waits patiently for DESIGN to exit. It then goes back and prompts the user for the next activity.

DESIGN is the main task for satellite and target board ranging. It starts up the INLIZE task, which initializes SYSCOM values and prompts the operator for several parameters. DESIGN waits for INLIZE to finish, and then proceeds to create and open the output data file. It asks the operator if target board ranging is desired. If so, it calls the subroutine CALIBR, which performs real-time target board ranging. (CALIBR is described in detail below).

After target board ranging is complete, if the operator has requested satellite ranging, DESIGN starts up INLIZE again, this time to compute the initial telescope positions and range for the satellite for a time a minute or two from now. After INLIZE is done, DESIGN points the telescope to this initial position, using the telescope's "position" mode. It then starts up the following tasks: RANGE, IOPRG, INTEG, and UTIPR. Then it goes into a loop, which is executed once a second. In this loop, during which all of the tasks are executing and performing the necessary activities for laser ranging, DESIGN does the following:

1. Wait for an event flag to be set by the RANGE task, and then clear it.
2. If the current time is less than the initial time, then go back to step 1 and wait again.
3. Point the Lunastat, in telescope "digital rate" mode. If using the Lurescope to receive ranges (this is rarely done), point it too.
4. Write the previous second's data to the data file.
5. Point the dome if necessary. (Is done every 10 degrees of azimuth).
6. Every 2 seconds, set a flag for the INTEG task to begin its loop.
7. Every 4 seconds, take the values just calculated by INTEG, and put them in the interpolation tables.
8. Interpolate the az, el, and range for 2 seconds from now.
9. Update the video graphics display.
10. Go back to the first step and wait.

This loop will continue indefinitely until the operator has indicated "exit" to the system via IOPRG.

At the termination of this loop, DESIGN asks the operator if target board post-calibration is desired, and if so, calls CALIBR again. Then, it closes the data file, stops the telescopes, sets several event flags to ensure that all of the other tasks have stopped, sets a flag to signal to SATCAL that it is done, and exits.

CALIBR is a subroutine called by DESIGN, to perform target board ranging. It also does corner cube ranging, which is exactly like target board ranging, except that the telescope is pointed to a slightly different position. CALIBR first initializes the appropriate local and common variables, points the telescope to the target board, and starts up the tasks RANGE, UTIPR, AND IOPRG. It then enters a one-second real-time ranging loop, which is very similar to the one in DESIGN.

INLIZE is executed before a satellite and/or target board ranging run. It calls routines which read in SYSCOM values from various files, and other routines which prompt the operator for ranging parameters. For satellites, it calculates the initial satellite position and range from the IRV vector. It corrects these values for refraction, the mount model, and mirror offsets. It also checks if the satellite is too near the sun, and calls sun avoidance routines if necessary. It sets up and initializes tables which will be later used by INTEG to interpolate the azimuth, elevation, and range.

RANGE runs only during the real-time ranging cycle. It connects to an interrupt card which provides interrupts at N times a second. N is set by the operator, and is usually set to 5, for satellite ranging. It executes a loop N times a second, during which the following things are done:

1. Wait for an event flag to be set by the interrupt card, and then clear it.

2. Fire the laser.

3. Read the time of laser fire (start diode time).

4. Compute the time at which to open the range gate. The range gate is opened just before the satellite return pulse is expected back, and closed just after.

When the range gate is open, the return pulse can be detected by the receive equipment.

5. Arm the Event Timer to open the range gate at the proper time.

6. Calculate the predicted range for the next cycle.

7. After the range gate has been opened, set an event flag to signal to the task UTIPR. UTIPR will read the UTI for the range value.

8. Go back to the first step and wait.

UTIPR is a task which interfaces to the UTI. When it is first started up, it connects to the UTI, initializes it, and arms it to receive the first satellite range. It then goes into a loop, which is executed every time a flag has been set by RANGE. RANGE sets this flag whenever it has gotten a laser start and is expecting a return pulse. Therefore UTIPR's loop is executed up to N times a second. During this loop, the following happens:

1. Wait for the flag to be set by RANGE, then clear it.

2. Check event flags which indicate whether or not a return range has been received. Continue checking until we time-out, in which case we haven't gotten a return pulse.

3. If a range has been received, read it from the buffer.

4. If a range has been received, read the Receive Energy Module (REM) and save this value in SYSCOM.

5. Clear out the buffer.

6. Re-arm the UTI to receive the next range.

IOPRG runs during the real-time cycle. It simply displays a prompt on the VT100 console, and waits for the operator to type in a command. The commands can be abbreviated. The following is a list of the available commands. The upper case letters indicate the minimum possible abbreviation, and the lower case letters are optional. (In the actual program, the commands consist of all upper case letter).

1. Fire - Start to fire the laser.
2. NOFire - Stop the laser firing.
3. Record - Record the data on the data file.
4. NORecord - Stop recording.
5. WRITEall - Write to the data file, whether or not there have been any return ranges.
6. LScan - Change Lunastat scanning mode. Available modes are:
    1. PADdle - Read the paddles and calculate the cross-track and long-bias, based on the readings.
    2. SPiral - Change the cross-track and the long-bias automatically, in a spiral pattern.
    3. TIMscan - Use the paddle readings to calculate the cross-track and the time-bias.
    4. STop - Stop the spiral.
    5. CLear - Set the cross-track and long-bias offsets to zero.
7. MLtscan - Change the scanning mode for the Lurescope. The modes are the same as for the Lunastat.
8. EXit - Stop the real-time ranging cycle.
9. Carriage return - same as a "nofire".
10. RBias - Change the range bias.
11. TBias - Change the time bias.

INTEG runs only during the real-time ranging cycle. It contains a loop which is activated every two seconds. During this loop, it does the following:

1. Wait for an event flag to be set by DESIGN, then clear it.
2. If the operator is using the hand paddles to change vector time bias, then read the paddles and calculate the time bias.
3. Read the Analog-to-Digital Card for environmental information, such as temperature, etc. (However, at this writing, the A-to-D card is disabled).

Every other cycle, i.e., every 4 seconds, INTEG also does the following:

1. Integrate the IRV vector to 4 seconds in the future.
2. De-inertialize the vector.
3. Modify the vector cross-track and/or long-bias, either by reading the hand paddles or changing them in a spiral pattern. (The operator selects which mode to use for cross-track and long-bias scanning).
4. Calculate the azimuth, elevation, and range for 4 seconds from now.
5. Checks the azimuth and elevation of the sun. If the satellite position is within 15 degrees of the sun, then modify the satellite position to go around the sun, and stop firing the laser. It is necessary to avoid pointing the telescope directly at the sun, since it could be destructive to the receive equipment.
6. Correct the elevation and range for refraction.
7. Convert the azimuth and elevation from satellite angles to Lunastat mirror angles.

8. Correct the azimuth and elevation for the mount model.
9. Place the calculated values in the interpolation tables.

3.0 LURE

The LURE version 7.0, lunar ranging software consists of the following programs:

1. SYSCOM is a common region of shared memory.
2. MOON is a main control program for lunar ranging.
3. INITSK initialized values in syscom.
4. POINT fires the laser and points the telescope.
5. ETINT arms and reads the event timer.
6. IOPRG updates the video display and accepts user commands.
7. HISTO displays residuals on the histogram.

These tasks are described in detail in the following paragraphs.

SYSCOM is a common region of memory which is shared by all of the programs. It contains values which are used by all of the programs, such as constants. It provides a means for the programs to pass values to each other. VIDCOM is another shared region of memory, however, it is only used by the IOPRG program. It corresponds to a region of the memory which is connected to a MATROX video display card, therefore, writing to this region will update the display.

MOON is the main program which initiates the lunar ranging sequence. Its first task is to start up the program INITSK. MOON suspends its own execution until INITSK is done. After INITSK has completed and exited, MOON proceeds to open the output data file on the disk. If target board pre-calibration ranging is requested by the operator, the calibration routine is called. MOON reads in the lunar ephemeris, which is calculated by another program prior to the lunar run. MOON uses the ephemeris to calculate an initial position and range for the moon for a time a couple of minutes in the future. It then points the two telescopes to this initial az and el, using "position drive" mode. MOON now starts up the program POINT, IOPRG, and HISTO. Then, MOON enters a software loop which is executed once a second. This loop will be referred to as the "real-time ranging cycle". So, once a second, MOON does the following:

1. Wait for a flag to be set by the POINT program. This flag is set once a second, to signal to MOON that it is time to do its loop.

2. See if any lunar data has been obtained. If so, write it to the data file.

3. If there was lunar data, also signal the HISTO program so it can be plotted.

4. Predict the lunar position (az, el) and range, for 2 seconds from now. This is done by interpolating the ephemeris values.

5. Correct the az, el, and range for the following: refraction, Lunastat mirror angles, and mount model.

6. Go back to the first step and wait.

This loop will continue indefinitely, until the operator indicates that the lunar run is over. When the loop is terminated in this manner, the POINT, IOPRG, and HISTO programs all exit. MOON now will perform a post-cal on the target board if the operator so requests, and then closes all of the input and output files and exits.

INITSK, as mentioned above, is started up by MOON. Its only function is to initialize the values in SYSCOM. It obtains these values from user input and several disk files.

POINT is a program which runs only during the real-time ranging loop. It starts up the ETINT program, then enters a loop which is executed 5 times a second. This loop does the following things:

1. Wait for an interrupt to come in from the interrupt card. The card is connected to the Cesium clock, and can be programmed to give an interrupt at 1 to 10 times a second.
2. If the range gate is open, wait until it is closed. This is done to avoid any possible conflicts between the laser fire and the lunar return coming back, since the same event timer is used for both events. The range gate is usually open for 1 microsecond.
3. If the "laser fire" flag has been set to "Yes" by the operator, fire the laser and read the start time.
4. If there is a return coming in during this cycle, send a signal to the ETINT program.
5. Once every 5 cycles, (or once a second) point the telescopes. The current position of the telescope is compared against the position at which it should be in one second, and the corresponding rate command is sent to the telescope.
6. Once every second, set event flags to start up the MOON and IOPRG programs.
7. Calculate whether or not a return is coming in during the next cycle.
8. Go back to the first step and wait.

ETINT is a small program which runs only during the real-time cycle. It is active only when a return range is expected during the 200 millisecond cycle. Therefore, it usually runs 5 times a second. It waits for a flag from POINT. When the flag is set, it arms the Event Timer for the expected range. After the range has been received, it processes the Event Timer readings and places the results in a buffer. It then goes back and waits for another flag from POINT.

IOPRG only runs during the real-time cycle. It is activated once a second by the POINT program. It updates the video display, which contains current values for az, el, range, time, number of data obtained thus far, and other values useful to the operator. IOPRG also interacts with the operator at the console, accepting the various commands such as fire the laser, stop firing, exit from the lunar run, etc.

HISTO is activated only when the MOON program has determined that some lunar data has been received. Therefore, HISTO runs once a second or less. It takes the residual values (Observed range minus Calculated range) and plots them on the histogram display. This provides real-time feedback to the operator, since many returns in the same bin of the histogram would indicate possible lunar ranges.

4.0 DISCUSSION

The LSI-11/23 with 128 kilowords of memory using the RSX-11M operating system has proven adequate for satellite and lunar laser ranging at 5 p.p.s. However, due to the somewhat elaborate executive overhead of the RSX-11M operating system,program execution timing conflicts can arise on lower orbit satellites such as Starlette and BE-C.

REFERENCES

Documentation Kit RSX-11M Version 3.2, Digital Equipment Corporation, Maynard, Massachusetts, 1979.

Microcomputer Interface Handbook, Digital Equipment Corporation, Maynard, Massachusetts, 1980.

Microcomputer Processor Handbook, Digital Equipment Corporation, Maynard, Massachusetts, 1979.

AN OVERVIEW OF THE NLRS RANGING SOFTWARE

R.J. Bryant*, J.P. Guilfoyle**
Division Of National Mapping
Department of Ressources and Energy
Canberra, Australia

Telephone *62 52 52 77 ** 62 35 72 85
Telex 62230

ABSTRACT

The Division of National Mapping in co-operation with NASA have undertaken an upgrade of the National Mapping ranging facility to enable Satellite Laser Ranging as well as a Lunar Ranging to be performed at the site. Because the new system was to be so dramatically different from what existed, this upgrade provided a unique opportunity to design from basics a complete integrated system to fulfil this dual role. This paper provides a brief outline of the ranging system hardware used and an overview of the software system to control it. It should not be taken as a recipe for instant success or necessarily the best way but as an outline of the approach taken by National Mapping to achieve the goal of routine high accuracy ranging.

AN OVERVIEW OF THE NLRS RANGING SOFTWARE

Introduction

The Division of National Mapping in co-operation with NASA have undertaken an upgrade of the National Mapping ranging facility to enable Satellite Laser Ranging as well as a Lunar Ranging to be performed at the site.

Because the new system was to be so dramatically different from what existed, this upgrade provided a unique opportunity to design from basics a complete integrated system to fulfil this dual role.

This paper provides a brief outline of the ranging system hardware used and an overview of the software system to control it. It should not be taken as a recipe for instant success or necessarily the best way but as an outline of the approach taken by National Mapping to achieve the goal of routine high accuracy ranging.

Ranging System Hardware

Telescope and Telescope Control:

> The telescope is a 60 inch clear aperture Cassegrain telescope mounted in an X-Y configuration. The telescope control electronics consists of a Contraves-Goerz MPACS system with an absolute encoding system providing a resolution of 0.36 arc seconds. The telescope's position can be read under computer control and it can be driven in both position and rate modes.
>
> The MPACS system is interfaced to the computer system through a locally designed and built interface (MPACS Interface).
>
> Automated dome control is implemented by means of this interface together with a guiding handpaddle which provides a manual offset of the computed telescope position. Four push buttons provide long and cross track corrections for satellite ranging. These same push buttons provide X and Y corrections when used for Flexure Mapping of the telescope. Incorporated in the Handpaddle is an 'on target' switch which is also used for Flexure Mapping.

Laser Ranging Controller:

The NLRS uses epoch determination rather than time interval measurements for establishing the time-of-flight. Coarse epoch consisting of days, hours, minutes, seconds and decimal seconds to the 100 nanosecond level is obtained from a locally designed and built Laser Ranging Controller. Fine resolution epochs to ten picoseconds are obtained by merging the coarse epoch with readings taken from 2 Lecroy 4202 Time to Digital converters which are controlled by the same pulses as the Laser Ranging Controller's clock. The Lecroy modules are housed in a standard Camac crate.

The LRC provides a) the Range Gate function for the system; b) in conjunction with a Hewlett Packard 5359A Time Synthesiser two software selectable off-line system calibration modes; c) a T/R system monitor; d) a Station Clock which can be used under computer control to determine epochs of selected events other than ranging operations together with Laser Control, Diode/PMT gating logic and the necessary computer hardware interface.

CAMAC Crate:

A standard CAMAC crate is used to house the following modules:

a) Kinetic Systems crate controller

b) Locally developed computer Interface

c) Dataway display module for diagnostic purposes

d) Discriminator and Logic modules for Timing System

e) Lecroy 4202 TDC modules

f) T/R stepping motor controller

g) A/D Converter module for Meteorological system.

Transmit/Receive System:

A T/R system of the same design employed by the McDonald Observatory MLRS is used in the NLRS. A spinning disc mirror with 2 diametrically opposed holes is used to switch the optical path between laser transmission from the telescope and returning signal into the PMT. A spinning 'dog-bone' is used as a protective shield for the PMT. The mirror disc and the 'dog-bone' have to be synchronised and rotated at the same speed for system operation.

Locally developed hardware is used to detect that the T/R system is in position for the Laser to fire. This is used in conjunction with a master Laser Enable signal generated by the computer through the LRC to fire the laser.

The T/R system is controlled by the computer via a module in the CAMAC crate.

Computer Hardware:

There are two Hewlett Packard A-Series computers on site.

The Ranging is currently run on the A-700 system which is configured with 1Mb of memory, hardware floating point, 65Mb Winchester disc drive, 400 lpm printer, 1600 BPI magnetic tape drive, graphics VDU, system console VDU.

The second system comprises an A-900 system with 1.5Mb memory, hardware floating point, 132Mb Winchester disc, 1600 BPI magnetic tape drive, 200 LPM printer, 2 graphics VDU's and a system console VDU.

All non-standard peripherals on both systems are interfaced using Hewlett Packard 16 bit parallel interface cards. Although Hewlett Packard supply a software driver for this card our approach has been to develop our own. This has allowed us to customise the drivers and provide a means whereby the complexity of the hardware control and interrupt routines are removed from the actual ranging and utility programs.

Both computer systems run the standard Hewlett Packard RTE-A Real Time operating system which is unmodified in any way. The relevant software drivers for the locally developed hardware interfaces are 'generated' into the system and these devices are accessed from then on as any other standard peripheral using high level language calls.

All locally developed drivers are written in Assembler language (H.P. MACRO). The Ranging software and all other utility software is written in FORTRAN 77.

Ranging System Software

Satellite Prediction System:

The NLRS prediction software is based on that used at McDonald Observatory. Ephemeris data arrives at the site on magnetic tape in the form of daily IRV's for about a 6 month period. They are read from tape and stored in a variable record length disc file.

As required program FORMIRV is run against this disc file to create a random access binary file or IRV's to cover the desired period. FORMIRV performs checksum verification and the necessary reformatting. It is capable of accepting IRV data from either Goddard or U. of T. Experience at the McDonald site leads us to believe that the U. of T. IRV's have a better long term stability.

Periodically the SATPREDICT program is run to produce an ALERT file for a period as well as a PREDICTION file for each satellite pass where the satellite will rise above a 20 degree horizon. Data in the prediction file consists of a file header containing the relevant IRV from which it was generated, daily time bump information as supplied by the network (U. of T.) and for every 1 minute point in the pass a satellite position in Azimuth, Elevation and Range.

Operator inputs to program SATPREDICT are:

a) File name of checked daily IRV's

b) Starting date and number of days predicts required

c) Whether program can expect a new IRV for each day's processing or has to extrapolate from only one IRV

d) Whether PREDICT files are required

e) Whether an ALERT file is required.

Where there is a missing IRV the program can extrapolate across the gap.

Ranging Software:

The Ranging system comprises 3 separate programs, INITIAL, RANGE and CLEANUP.

Program INITIAL performs the following sequence of operations:

a) Initialise the inter-program communication memory area.

b) Access the ALERT's file to determine which pass is the relevant one, obtain the name of the PREDICT file and create and initialise the observation data file.

c) Read in from a disc file the current flexure parameters for the telescope.

d) Obtain the current weather parameters from the meteorological system.

e) Loop through the PREDICTION file data applying refraction corrections to predicted elevation and range; azimuth corrections for dome positioning; corrections for X-Y axes offset and optical path lengths to system fundamental point; corrections for telescope flexure.

f) Store in the inter-program communication area the corrected prediction data together with all other default parameters such as range gate window width, firing repetition rate, real time display parameters etc.

EMPTY PAGE

Program RANGE is the actual data acquisition program. It is basically a supervisory program which directs the various hardware systems to perform the requested actions in a sequential fashion. This sequence is as follows:

a) Initialise all hardware modules, position dome for start of pass.

b) Synchronise T/R stepping motors.

c) Initialise real time display.

d) Verify all variable parameters with user.

e) Ramp up the T/R system to require repetition rate.

f) Determine theoretical telescope and dome positions. Output them to MPACS. Wait 100msec then read in telescope position from MPACS. Evaluate new theoretical position and calculate error vector. If error vector is less than 0.02 degrees then proceed otherwise repeat this step.

g) Issue the Master Laser Enable signal to the LRC.

h) Read in from the LRC and CAMAC timing modules the epoch of the laser diode pulse and PMT calibration pulse.

i) Evaluate predictions for theoretical range.

j) Output Range Gate Epoch to LRC.

k) Read in from MPACS the current telescope position, time and handpaddle data.

l) Determine theoretical position, drive rates and dome azimuth.

m) Calculate actual drive rate for ensuing period by adding in to base rate corrections for handpaddle.

n) Output pointing information to MPACS.

o) Read in current weather details from CAMAC module.

p) Read in from the LRC and CAMAC timing modules the epoch/s of returning photons.

q) Calculate and display Residuals on real time display.

r) Journal data to disc file.

Steps (h) through (r) are repeated for the duration of the pass. The system can be halted at any time to enable the user to vary such things as firing rate, range gate window width, range gate offset, real time display parameters and also to display a histogram of the current real time calibration data. Once this is done control goes back to step (h) and ranging is resumed.

The one minute IRV's held in the inter-program communication area are interpolated using Bessel's Central-Difference Formula of degree 5 to provide theoretical range at step (i) and telescope position and dome azimuth at steps (f) and (l).

Steps (h) and (p) are the only occasions when the software system has to wait for a hardware interrupt from an external device.

Program CLEANUP is true to its name. Essentially it filters the ranging data and reformats it to make up the QUICKLOOK, MAILING and ARCHIVING files. It operates in the following manner:

Low noise passes

Three iterations of a two step stripping process are employed on each 1 minute block of returns. The two steps are:

a) Residuals are histogrammed (at a bin width of 16 nanoseconds on the first iteration an 1/2 sigma on subsequent iterations). The highest bin is determined. Data in bins of height less than a nominated fraction (typically 25%) of this maximum are rejected.

b) A straight line is fitted through the remaining residuals. Results more than 3 standard errors away are rejected.

In practice this procedure converges satisfactorily and the final histogram has a reasonably normal distribution out to 3 sigma. The standard error is often 0.3 nanoseconds and 67 - 80% of all data points are accepted.

High Noise Passes

A preliminary estimate of the starting point and slope of the real trace in the first minute of the data has to be obtained from the real time ranging display. All data points more than 32 nanoseconds away from this line are then stripped out. The low noise procedure outlined above is then performed. The resulting straight line is then used as the reference for the next 1 minute of data.

Future Development

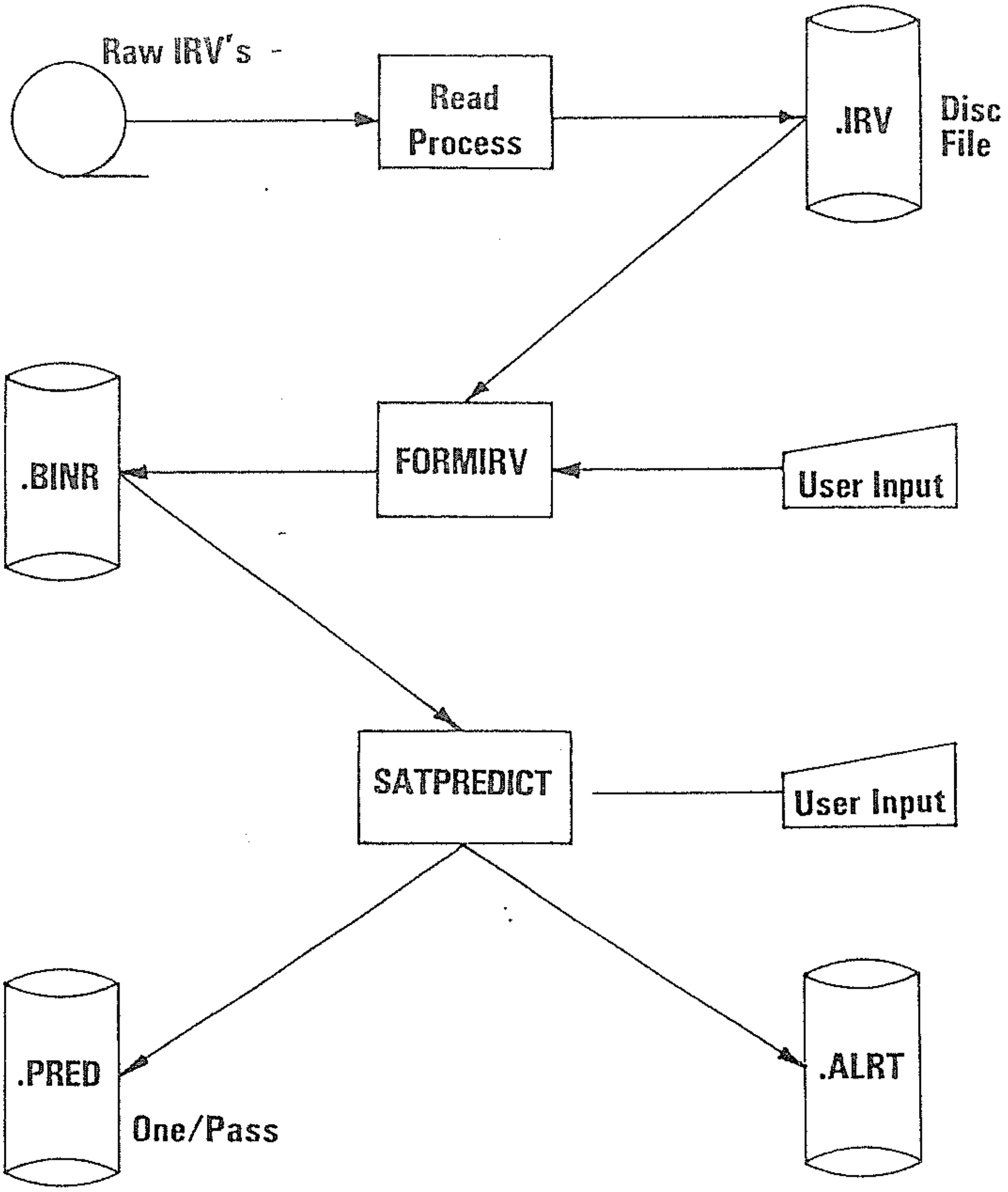
The system described is the satellite ranging software system. For Lunar ranging the same concepts - indeed almost the same programs - are being used. The inter-program communication area will be expanded to hold data for the several lunar targets, some of the internal loops of program RANGE will need to be modified to allow for multiple photons in flight and the user will be given the ability to switch from one target to the other without having to reinitialise the system. The hardware will require no modification nor will the software drivers that interface them to the computer. It is intended to include into the system one or two video monitors for the real time display instead of using the graphics VDU. This will enable the display of both residuals and calibration simultaneously.

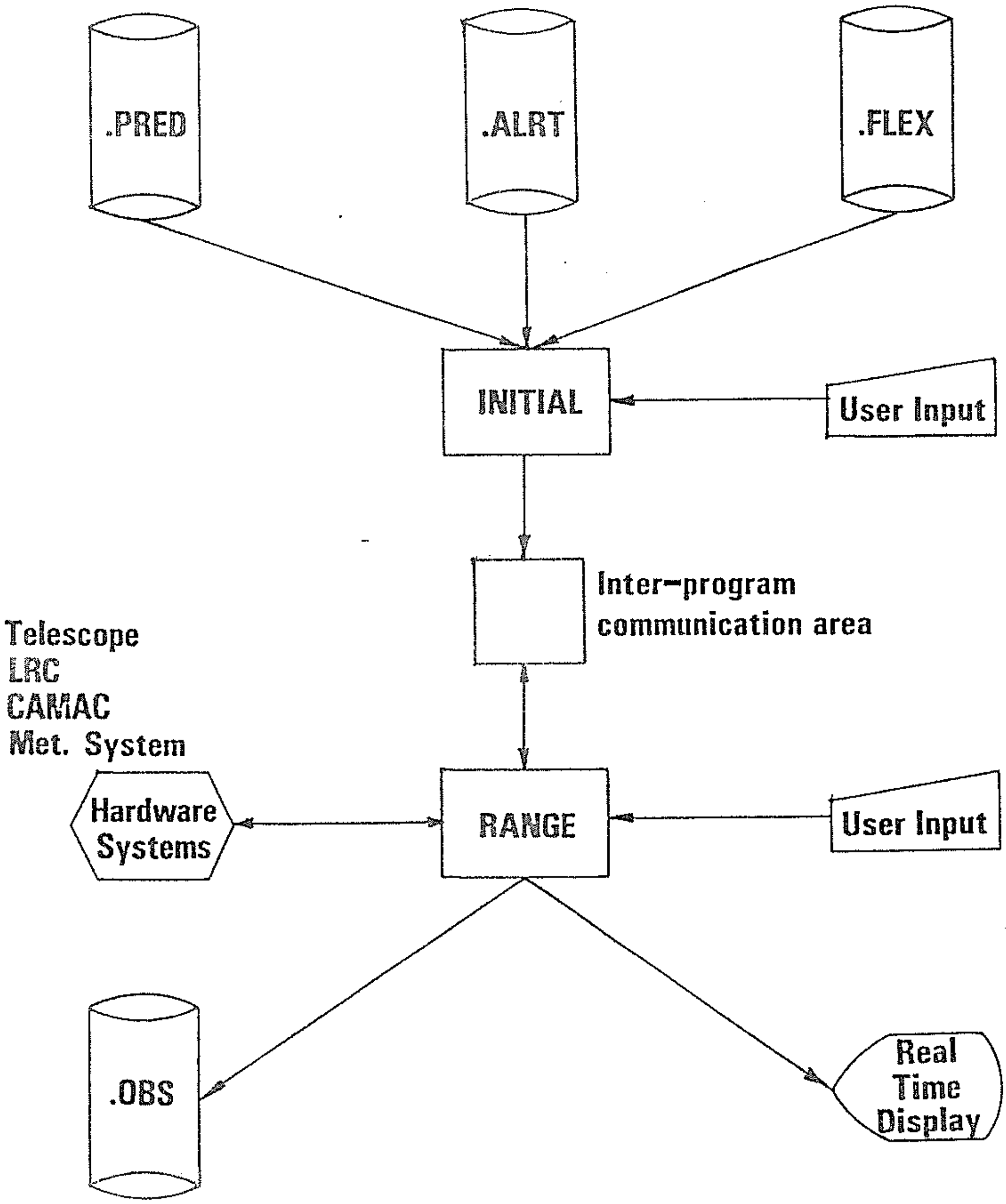
Conclusions

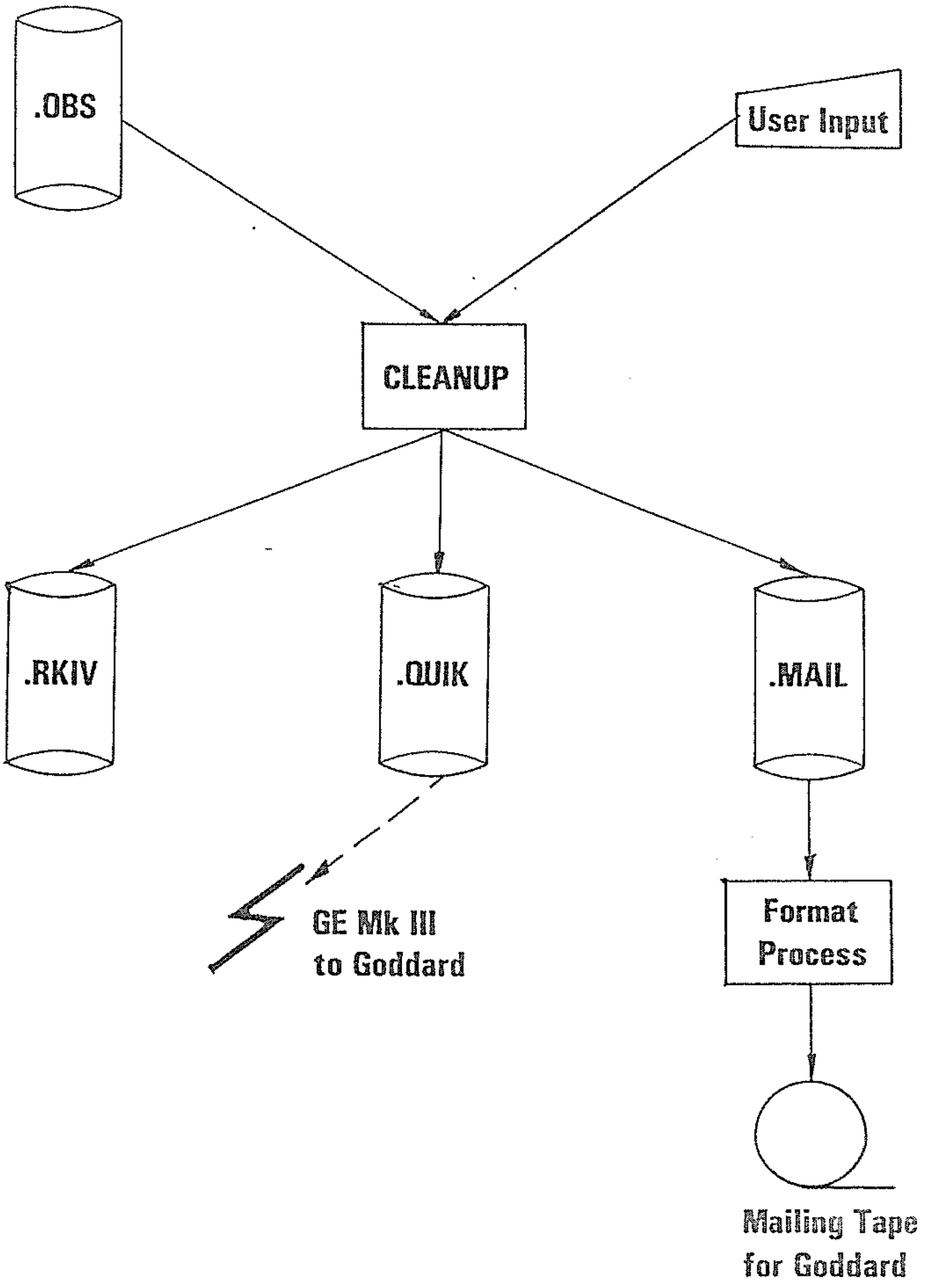
The Hewlett Packard computer system used has proven adequate. Once an integrated hardware/software design for the system was reached both streams were able to proceed in parallel. The ability to 'hide' the complex hardware control within the operating system makes the high level code easy to write and maintain. If software drivers need to be changed then a new system has to be generated but since this takes on average half an hour it is not seen as a problem. It facilitates the testing of individual parts of the system using various locally written high level utility routines which proved extremely helpful in the debugging phase of the project.

One of the main design aims in the software has been to make the system user friendly to the extent that specialists are not required for the routine operation of the site. For satellite ranging this goal has been achieved and National Mapping's Laser Ranging System is now in full production.

NLRS Data Flow




.PRED
.ALRT
.FLEX
INITIAL
User Input
Inter-program
communication area
Telescope
LRC
CAMAC
Met. System
Hardware
Systems
RANGE
User Input
.OBS
Real
Time
Display


.OBS
User Input
CLEANUP
.RKIV
.QUIK
.MAIL
GE Mk III
to Goddard
Format
Process
Mailing Tape
for Goddard