Keystone (KSP) Class

Autonomous Satellite Laser Ranging (SLR) Systems

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1. Introduction

The Keystone system has been developed for measuringcrustal deformation in the Tokyo metropolitan area. The system is designed to allow an operator to control multiple SLR stations simultaneously and remotely. An operator can schedule remote stations to run autonomously to a prepared schedule or, at any time, take control of individual stations to carry out desired operations manually. To achieve these goals, the system provides facilities for:

- **remote operation** - stations can be controlled from remote locations across a Wide Area Network, dial-in phone lines, or the Internet. A remote operator can monitor and/or control multiple stations across the SLR network simultaneously.

- **mission planning** - high-level schedules of operations can be prepared many weeks in advance and downloaded to remote stations for automatic execution. The mission plan allows the operator to schedule such operations as satellite tracking, system calibration and maintenance tasks.

- **automatic tracking** - the system uses an operator-definable programming language to express algorithms for acquiring targets and optimising tracking behaviour. The system reads and actions these algorithms in real time. This approach allows system specialists to improve and test new automation algorithms in the fields without the need for software changes.

- **automatic post-processing** - the system is designed to perform automatic noise filtering, signal processing and generation of full-rate and normal point data files. Each station in the network will also transfer the data files to a remote central site for further analysis. The system provides automatic warnings for those passes that cannot be processed automatically and that may require manual processing.

- **system health and security monitoring** - the system automatically monitors the status of all sub-systems for safety, security and equipment failures. A set of conditional "business rules" is used to filter and present overall site status to the operator. At any time, an operator can retrieve detailed status relating to any of the station sub-systems. In addition, real-time event logging provides a detailed audit trail of system behaviour for operator analysis.

2. Mission Planning

All Keystone activities are controlled via the *site operations schedule.* The site operations schedule is a user-definable list of the operations that are to take place at the site over a specified time period. A schedule may contain such operations as satellite tracking, system calibration, file and data management activities, data analysis, equipment maintenance (e.g. dome window washing). A schedule may specify site operations for any time period, perhaps up to months in advance. Schedules may be created either locally at the site or remotely. The process of creating

schedules in advance for multiple stations across the Keystone SLR network is known as *mission planning*.

Mission planning is accomplished in Keystone systems as an off-line process in which operators can create a site operations schedule for multiple sites for weeks or months in advance. The schedule is then downloaded to the relevant stations across the Wide Area Network. The site control software at the stations will then read the downloaded schedule and automatically initiate the specified operations at the appropriate times. At any time, operators at the central station can monitor the remote stations and observe the operations in progress. Remote operators can also 'take over' control at any time and drive the stations manually.

The mission planning activity itself is carried out using a stand-alone application called the *Mission Planning System* (*MPS*). *Figure 1* below shows a schedule being created in *MPS*.
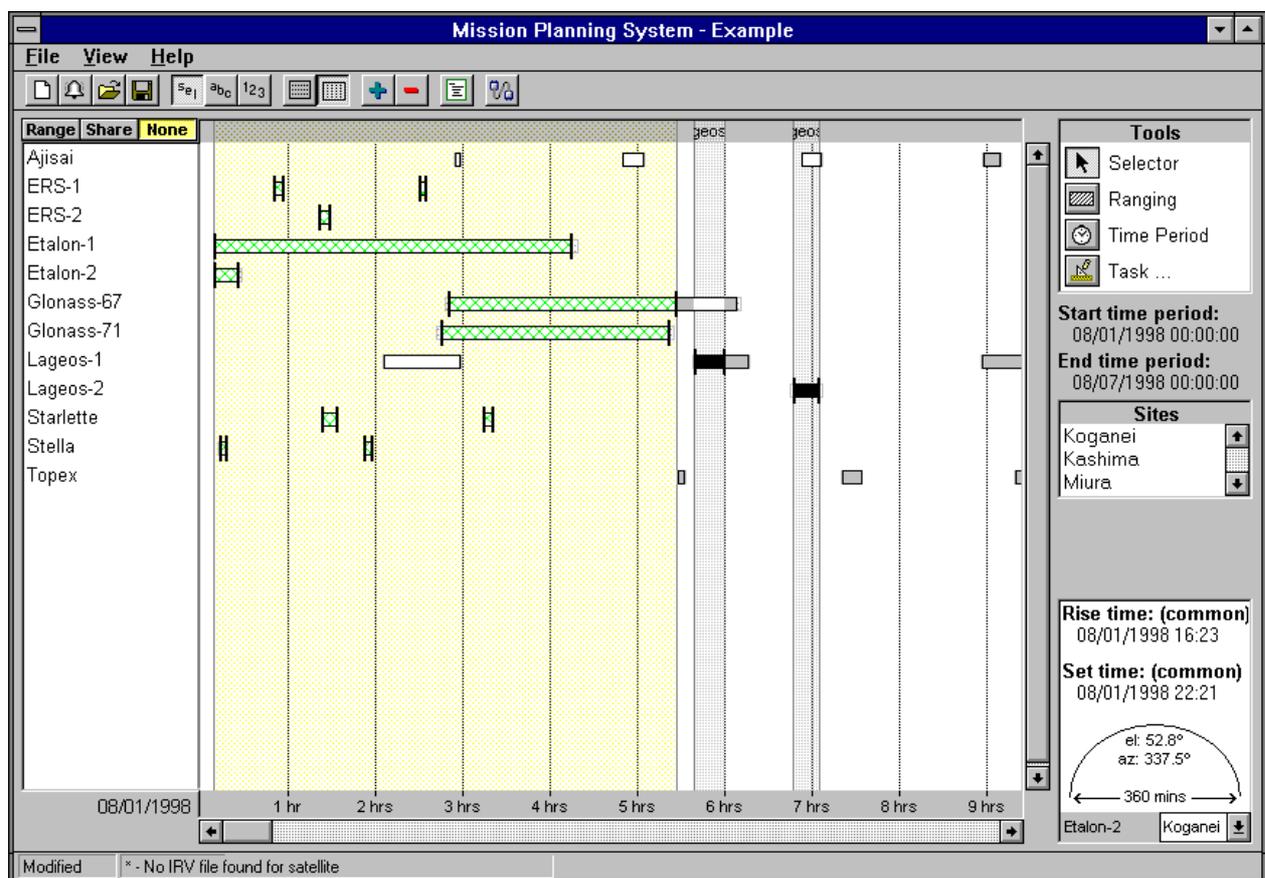
Figure 1: The Mission Planning System

The vertical pane at the left side of the screen shows all the satellites that are to be tracked by the station. The central pane shows time extending horizontally with the satellite tacks displayed as horizontal bars which stretch over the appropriate time spans. The vertical pane at the right side of the screen shows miscellaneous information relating to sites and satellites.

The user may select any number of the satellite tracks by clicking on them with the mouse, scrolling the timeline to the right or left as far as is desired. *MPS* will automatically prevent the user from creating an impossible schedule (e.g. track two satellites simultaneously). To assist in the selection of appropriate satellites, the user can click on any single satellite track and display a *polar plot* of the actual track as it will be visible from the remote station. *Figure 2* shows such a polar plot of *Etalon-2* as visible from the *Koganei* site. The plot shows the track across the sky,

the rise, set times and the time of closes approach. In addition, the polar plot colour codes the track to illustrate the portions of the track that are sun illuminated or within the sun's halo.
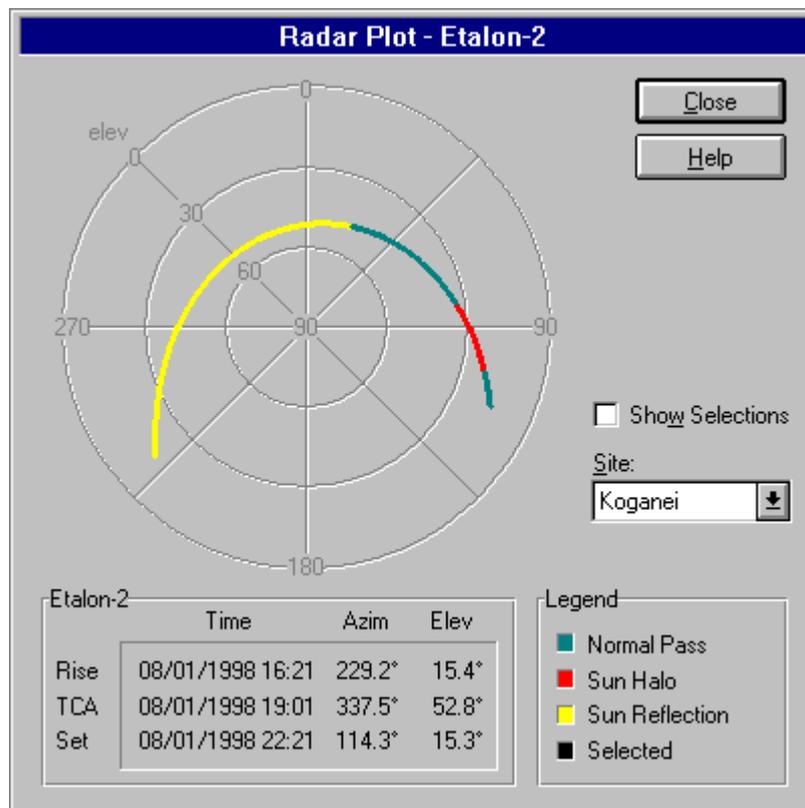
Figure 2: MPS Polar Plot of a Selected Satellite Track

MPS provides a number of shortcuts to make the creation of a complex schedule a simple process. For example, in *Figure 2* above, the user has 'time-shared' all the satellites between 0:15 and 5:30 hours by dragging a single marker of the desired time span. *MPS* has automatically selected all of the satellites within the indicated area (although the user may then 'unselect' specific satellites within the area). When the schedule executes at the remote station, the station will automatically 'share' tracking time among all of the selected satellites to achieve the most efficient collection of data from all of the satellites.

MPS also allows the user to schedule many other station operations other then satellite tracking, for example:

- ranging to ground targets for system calibration

- automatic washing of dome windows

- automatic processing (data analysis and signal processing of accumulated raw ranging data).

- file management (uploading of full rate and normal point files from the remote site to the central station for archival

3. Site Control

Keystone stations can be operated automatically and remotely via the site operations schedule which specifies all operations to be carried out at the site for weeks or months in advance. The schedules can be created by the *Mission Planning System*, as described above. Once a schedule is downloaded to a site, the site control software at the site will read the schedule and automatically initiate the required operations at the specified times. Up to this point, the station will be operating totally autonomously.

However, at any time, a remote operator can 'connect' to the remote station and monitor the operations currently in progress or initiate new operations. A connection to a remote site can be accomplished over a Wide Area Network, the Internet or even a low-bandwidth phone line. This capability was demonstrated live at the SLR Workshop at Deggendorf. Using a notebook PC, the demonstration showed a connection to the EOS SLR station at Mount Stromlo in Australia using a standard international phone line. The station was ordered to range to one of the ground targets (the weather being unfavourable for SLR) and live ranging data was relayed back to the notebook PC in real time and displayed to the Workshop audience.

Control and monitoring of a remote site is achieved using the *Site Operations Executive* application (*SOE*). *SOE* is the main user interface of Keystone systems. It is this application which was run on the notebook PC at the SLR Workshop demonstration. *SOE* allows the operator to

- connect to any number of remote sites
- monitor the operations in progress at multiple sites
- take over and control the operations at multiple sites.
- observe ranging statistics in real time.
- view low-level system diagnostics covering all of the instruments at the site (for example, telescope, laser, timing system, mets station etc)

SOE allows the operator to directly control any of the site operations, including

- ranging to satellites
- ranging to ground targets
- running the automatic data processing system that produces full rate and normal point files from raw ranging data
- running the file management system that uploads full rate and normal point files from the remote site to the central control station.

Figure 3 below shows an actual screen dump of the *SOE* main screen as the station at Tateyama tracks *Ajisai*.
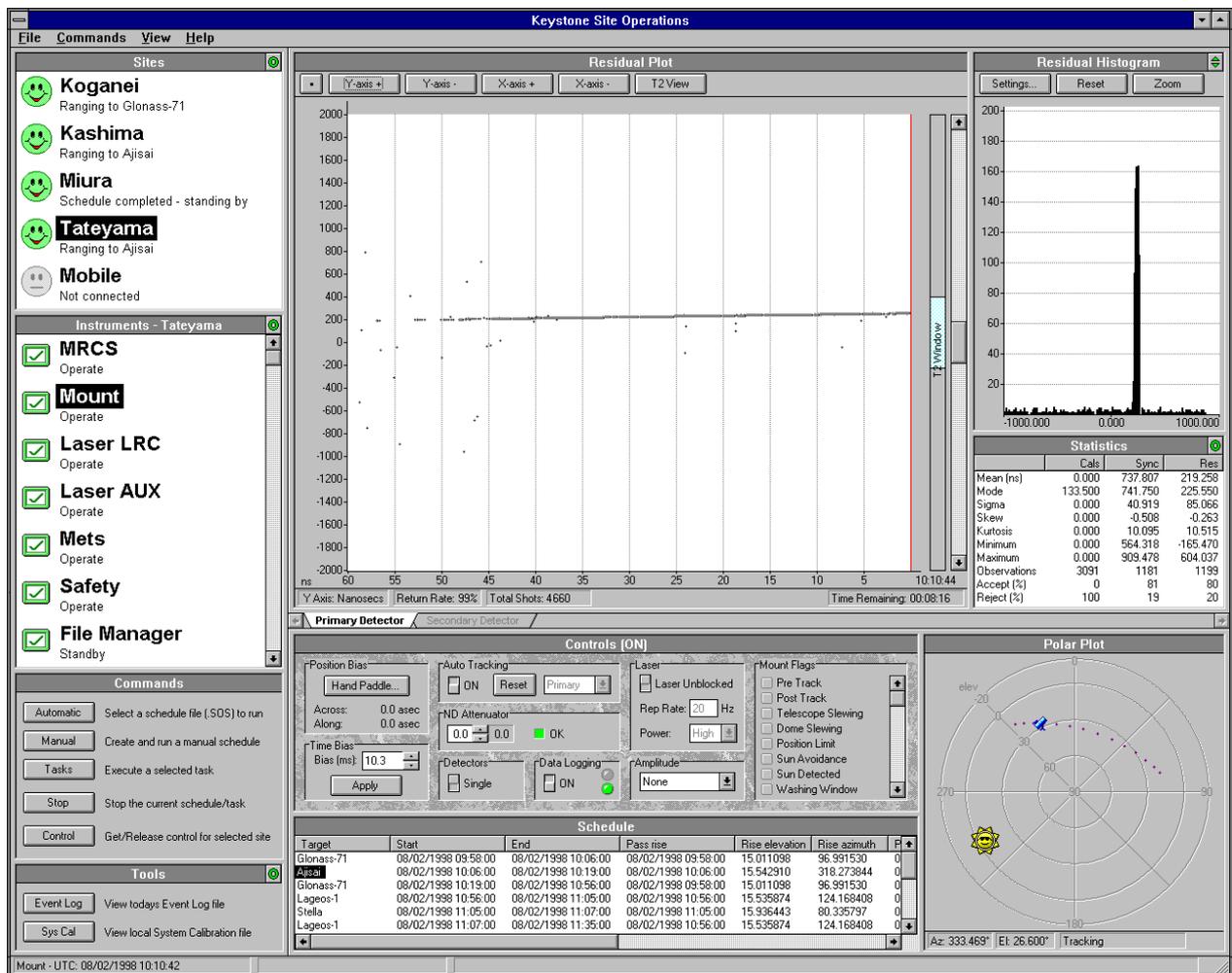
Figure 3: SOE - Keystone's Main User Interface

The upper pane on the left side of the screen, the *Sites Pane*, shows all of the remote sites in the network. The 'smiley face' icons display the overall status of the sites by their colour - green (ok), yellow (warning) or red (error or site down). The user 'connects' to any of the sites by clicking on the required site icon. The other panes on the *SOE* screen then display information from the selected site. For example, in *Figure 3* above, the user has clicked on the Tateyama site icon to display the current satellite track and other site related information.

The pane immediately below the site selection pane on the left side of the screen is the *Instruments Pane*. This pane shows all of the major 'instruments' at the selected site and the current overall status of each instrument (this is a scrollable list - some of the instruments are therefore not visible in *Figure 3*). The instruments are

- **MRCS** - ranging timing system

- **Mount** - telescope and dome

- **Laser LRC** - main ranging laser

- **Laser AUX** - auxiliary laser table instruments (e.g. energy meter)

- **Mets** - local site mets station

- **Safety** - security and safety system (safety interlocks, warning lights, security cameras etc)

- **File Manager** - file management system

- **ADL** - Aircraft Detection Laser

In a similar manner to the smiley face site icons, the individual instrument icons are also colour-coded green (ok), yellow (warning) or red (error or failure). The overall status of each instrument is also displayed next to their icon (e.g. Standby, Operate). The user can obtain more information about each instrument by double-clicking on the instrument to display a detailed status screen for that instrument. The instrument status screen shows the low-level condition of the instrument and the most recent errors or warnings, if any, that occurred with that particular instrument.

The large display area in the central portion of the *SOE* screen displays range residuals as a time series that scrolls from right to left across the screen as the raw ranging data is received. The straight line shown in above Figure 3 is the track of an *Ajisai* pass. The residuals plot can be zoomed in and out on both axes by clicking the buttons along the top of the display. The track is *Figure 4* is a solid line because the display is shown at minimum zoom. Zooming in further can display the individual shots as they are received.

The pane below the residuals pane is the *Control Pane*. Here the operator is presented with the controls that can be used to carry out site operations manually. Immediately below the Control Pane is the *Schedule Pane*. This pane lists all the operations that are in the current schedule. The highlighted line represents the specific operation that is currently running, in the case of *Figure 4* above, an *Ajisai* pass. This list scrolls upward automatically as the site progresses through the schedule.

At the top right of the *SOE* screen is the *Histograms Pane*. This pane displays a histogram of the ranging data that is continually updated in real time. Immediately below this pane is the *Stats Pane*, which calculates and displays statistics on the same ranging data.

Finally, at the bottom right of the *SOE* screen is the *Polar Plot*, which displays the satellite track currently being followed. The current position of the telescope is shown on the track as a small telescope icon. The current position of the sun is also shown.

In summary, the *SOE* application provides all of the tools and displays required for an operator to monitor and control any number of remote stations.

4. Automatic Tracking

A vital part of operating an SLR station autonomously is the ability of the system to acquire and track satellites with no human intervention. The *auto tracking* capability of the Keystone system performs this task. In real-time, auto tracking will

- continually process the ranging returns to extract the satellite signal from the noise

- if no signal is seen, initiate a search pattern by biasing the telescope in a pre-determined pattern around the predicted track

- once the satellite is acquired, continually adjust the position of the detector gates to eliminate the noise received in advance of the signal and maintain the maximum return rate

Auto tracking in Keystone systems provides a high degree of flexibility by providing a proprietary programming language and compiler that is used to specify the algorithms that the system will use during the tracking process. The auto track language allows an SLR specialist in the field to

change search patterns, signal analysis and many other factors to fine tune auto tracking behaviour using pseudo-language relevant to acquisition algorithms.

5. *Data Analysis*

When running the Keystone system autonomously, automatic processing of accumulated range data is provided, although manual processing can be undertaken at any time. Both manual and automatic applications allow for processing of both satellite and ground target data. Reduction of ground target data produces system calibration values that are stored and available for use as pre and post calibration data when analysing satellite passes, and for use as system quality checks.

When analysing satellite range data, the system will

- obtain calibration data from current internal (spiderretro) calibration data or pier range results taken before and after the satellite pass

- read the range data file and apply system calibrations

- extract the signal from noise using a variety of filtering and curve fitting techniques

- generate normal point values and

- generate full rate and normal point files in MERIT II and CSTG formats.

- provide a summary of processing status for operator review

- provide a log of processing events and errors

- transfer output data files across the WAN to the central control centre for use by analysts

- compress and archive range data files

The extraction of signal from noise data relies on a set of automatic and manual filtering and curve fitting techniques. These techniques include

- the ability to generate residuals using orbit predictions with manually defined time bias,

- the ability to find the time bias that optimises the residual trend,

- a filter of sparse noise data,

- a filter that searches for and extracts trended signals,

- a filter that removes noise from relatively clean signals

- polynomial curve fitting to all data and to manually set data

- spline curve fitting to manually set data

- normal point bin trend and rms checks.

Figure 4 shows the main screen of the *Profits* application which provides the manual processing capability. *Profits* uses the same algorithms and calculations as the automatic processing but allows greater flexibility in the sequencing and control of the processing steps.
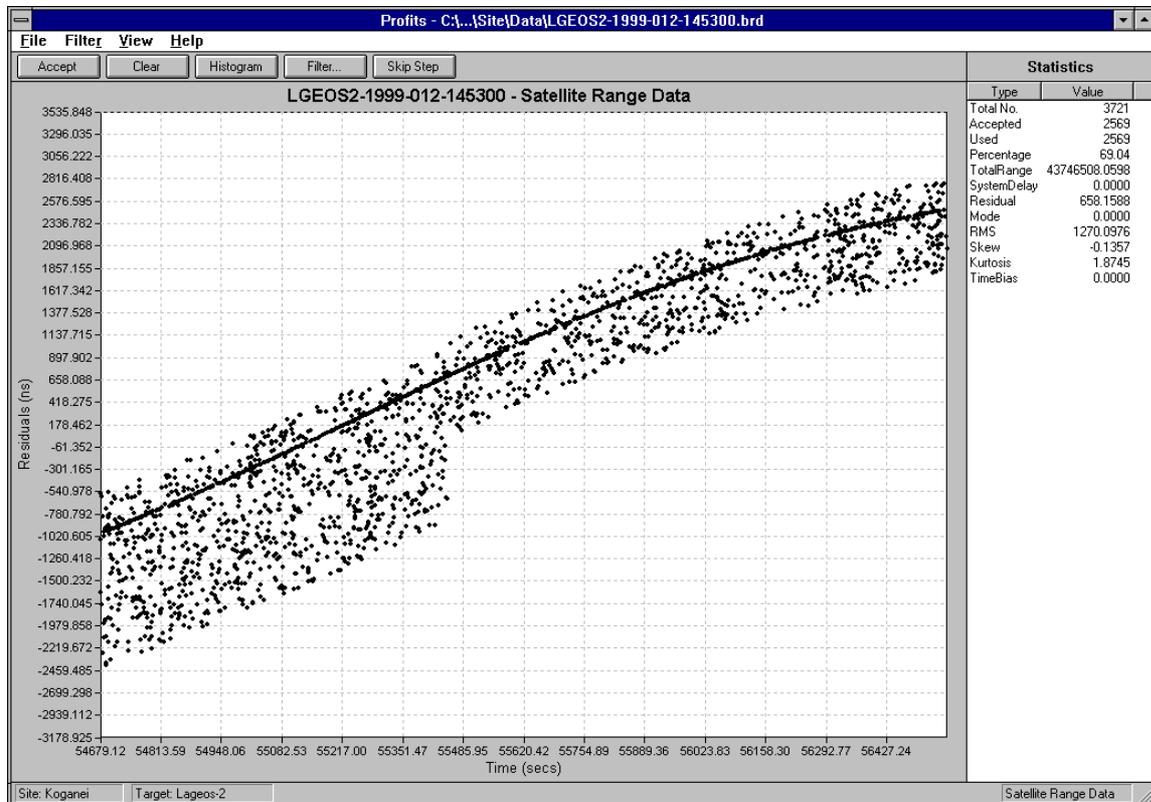
Figure 4: Post Processing of Range Data for Lageos

6. Conclusions

The KSP-Class tracking system software allows remote or autonomous operation of multiple tracking sites, operating cohesively as a network.