Consolidated Laser Ranging Prediction Format

By Randall L.Ricklefs
University of Texas
McDonald Observatory and Center for Space Research

Introduction

The ILRS Predictions Formats Study Group was created at the 12th International Workshop on Laser Ranging and tasked with creating a consolidated laser ranging prediction format that could accurately predict positions and ranges for a much wider variety of laser ranging targets than had been previously possible. While several complications arise in creating and implementing a format for such divergent targets, the opportunities for ranging exotic targets from ordinary ranging stations should compensate for any inconveniences.

Motivation

The SLR community of 40+ laser ranging stations has used the standard "Tuned IRV" prediction format for up to 20 years. This format consists of a satellite state vector (x,y,and z positions and velocities at a given time plus other parameters, one set per day per satellite) tuned to specific field integrator software and gravity field to provide maximum accuracy over the integration period. The format can be found at: ftp://cddisa.gsfc.nasa.gov/pub/formats/tirv.format.

The ranging ranging stations in the lunar community (2 stations routinely gathering data, at least 3 others lunar-capable, and 3 or more retired) have historically either developed their own prediction software or have ported others'. The software has used one of about 3 lunar and planetary ephemeris packages, each containing a multi-year ephemeris.

Thus, the SLR community has generally used standard integrator software and gravity field models with predictions supplied on a weekly or (now) daily basis. The lunar community has used a standard multi-year ephemeris, a mix of interpolation software, and weekly earth orientation parameter predictions.

Lunar ranging has been restricted to a few stations due in large part to the low return signal strengths involved. The distance to the moon (R), combined with the $1/R^4$ scaling of the return signal strength to that transmitted, means only a few photo-electrons per minute are seen by current ranging systems using available technology.

This state of affairs has existed since the 1970s. There are now, however, the possibility of several new missions that could change everything. For instance, CRL would like to put a laser transponder on the moon. Groups at NASA are proposing transponders combined with altimeters for future planetary and asteroid missions. Transponders have a laser transmitter at both ends of the ranging link. The receive signal strength therefore is proportional to $1/R^2$ times the transmit energy. Because of this, the downlink energy is high enough for most existing SLR stations (including SLR2000) to detect. This implies that there must soon be prediction procedures and formats in place for the moon, other solar system bodies, and transponders in transit.

This document represents the results of an effort to combine the prediction requirements of these various ranging techniques into a single laser ranging prediction format. The format presented is preliminary and will undoubtedly undergo some adjustments before it reaches the ranging stations.

Format Features

1. Tabular format

   The range to the environs of the moon and beyond cannot be simply calculated from the square root of the sum of the squares of the reflector's topocentric x, y, and z coordinates. The movement of the earth and moon during the approximately 2.5 second round trip is large enough that the range must be computed as the sum of the iteratively determined lengths of the outbound and inbound legs. Because of the distances and masses involved, there is also a non-negligible relativistic correction. The difference between the true range and the square root of the sum of the squares of coordinates gives a range error for the moon of a few to hundreds of microseconds. Omitting the relativistic correction causes a range error of about 50 nsec. Stellar aberration effects on pointing need to be considered since the aberration is a second or two of arc at the moon, 30 or more of arcseconds for Mars and asteroids, and possibly more for close in spacecraft in transmit (NEAR fly-by was around 30 arcseconds).

   The orbits of the moon and other major solar system objects can not be integrated easily on site as small earth satellites can. However, one can readily interpolate tables of geocentric coordinates for these and the other laser targets. The tabular format also benefits lower earth satellite ranging by removing the need to tune the predictions to a particular integrator. In addition, other non-integrable functions such as the drag can be included with a tabular format.

2. Multiple records

   The tabular format will need to include at least x, y, z and a corresponding time for each ephemeris entry. This and other specialized information will be spread over several records, the number and type depending on target class. The time between each entry will normally be constant and will be small enough to meet any reasonable precision requirements using the supplied interpolation software. The time should be large enough to avoid excessive file size. Typical values are 1 minute for low earth satellites, 15 minutes at the moon, and hours to a day for the planets. The choice depends on the prediction supplier.

3. Variable entry spacing

   To accomodate high eccentricity satellites like LRE, variable entry spacing is a possibility that is allowed for in the format and the interpolator.

4. Line length limits and method of transmission
   The length of each prediction record is 72 characters or less to allow for easy email transmission without line wrap or truncation. No mode of distribution is assumed, so email, ftp, and scp should be usable.

5. Free format read, fixed format write
   Due to the large dynamic range in the target positions and velocities, the non-header data should be read in free format. The prediction providers should write with a fixed format so that all fields line up for a given satellite. Doing so will allow easy visual reading of the files for debugging.

   The format in appendix A show width and significant digits for each field. For the free format records, this represents a typical or worst case width for planning purposes.

6. True body fixed system of date and earth rotation parameters
   The coordinate system used in the TIVS is pseudo-body-fixed. The new format is in the true-body-fixed of date system. In this reference system, the earth X and Y pole positions have been included in the predicted positions. EOP X and Y were included in the tuned IRV files to rotate from pseudo-body-fixed to body-fixed system in the field. The IRVs could be months old and the X an Y predictions could have been stale, requiring replacement of the included values with new ones. Since fresh EOP predictions are now easily available to the prediction suppliers and since the predictions are usually supplied daily, there is no need to apply the EOP information on site nor to back out values used in predictions. In addition, the excess length of day was rarely used at the ranging stations. Therefore, earth orienation X, Y, and excess length of day are not needed and are not included in the format.

7. Multiple days per file
   As with current IRVs, the prediction file for a particular satellite will contain several days worth of data. This should help interpolating over day boundaries, which could otherwise cause problems. Header records appears only once per file.

8. Integration past end of file
   Current IRVs permit integration well past the epoch of the last IRV in a prediction set. This benefits stations that are cut off from a supply of IRVs for a moderate period of time. The predictions show steadily increasing runoff, but can still allow data to be taken, especially with higher satellites. In addition, it is also possible to extend the integrations several months into the future for the purpose of scheduling. The latter use has fairly low accuracy requirements. It may be possible for the site to extrapolate a tabular file or (only for sub-lunar satellites) integrate the last state in a prediction file. This may not help with transponders in transit.

9. Elimination of drag message
   Since the drag information can be built into the tabular state vectors, there should be no need for separate drag messages. Drag could not be easily incorporated into tuned IRVs.

10. Compression

Common compression software such as compress, gnu zip, and others could reduce the files size. If file size is still too onerous, it is possible to create smart compression software based on numerical difference between successive file entries as is done with RINEX data.

12. File naming conventions

While there appears to be a wide range of file naming conventions used, the following is suggested for the new prediction format, based on conventions used on the ILRS and prediction center websites:

aaa_table_yymmdd[_n].bbb

where

aaa is the satellite name, any reasonable number of characters;
table is a literal indicating the new tabular format;
yy is 2-digit year;
mm is 2 digit-month;
dd is 2-digit day of month;
n is optional and refers to the sequential number of predictions set for this date, starting with 0; and
bbb is a typically 3-4 digit prediction center identifier.

Format Field Comments

1. SIC, NORAD and COSPAR ID's

SIC, COSPAR, and possibly NORAD IDs will be included in the prediction headers as a convenient cross reference.

2.Estimated accuracy

These records give an estimate of the expected accuracy at certain points during the day. This will be based on the experience of the prediction provider. The desire is to use this information to suggest or automatically set a station's range gate. This will especially be valuable to automated stations so that excessive time is not spent in searching for an optimal range gate setting.

3. Leap second

Application of leap seconds has always been a source of some confusion. In the new format, each ephemeris record contains a leap second flag. In prediction files spanning the date of a leap second, those records having leap second applied will have this flag set to '1'. In other words, a 3-day file starting the day before a leap second is introduced will have the leap second flag set to '0' for the first 24 hour segment and '1' in the last 48 hours. If the leap second is not applied by the supplier, then the flag is '0' for all records.

Predictions starting at 0 hours immediately after the leap second has been introduced will have the leap second flag set to '0'.

4.Correction fields

As noted above, several complications arise in predicting ranges and point angles of solar system targets. These are essentially relativity and aberration. The aberration can be broken into light-time aberration which applies to all targets and stellar aberration which applies to those targets (such as moon and planets) which are computed from solar system ephemerides. Near-earth artificial satellites are usually computed in the geocentric system and do not require the so-called stellar aberration. Light time aberration is already applied implicitly in the state vectors supplied in the new format. Stellar aberration corrections are applied in computing point angles on site, while the relativistic corrections are applied to the ranges.

The in-bound and out-bound relativistic corrections are due to geodesic curvature. The time-scale correction converts a solar system barycentric range (elapsed time) into an elapsed time which would be observed at a station. This correction can be 200 m for a round trip range to Mars and is necessary because the vectors are computed in the solar system barycentric frame using a solar system ephemeris. The former is included in the format while the later is site-dependent and is computed in the sample on-site code.

5. Lunar fields

Lunar predictions may include lunar features for offset pointing. These features do not have SIC or COSPAR IDs since they are not ranging targets. The ID for these objects will be given bogus IDs, perhaps negative numbers. A list of targets, names, and IDs will be supplied.

6. Transponder fields

Transponders can either be synchronous or asynchronous. Synchronous transponders fire when a laser pulse has been received from a ground station. The delay between receiving and transmitting the return pulse must be accounted for in both the prediction and data flow. Asynchronous transponders fire continuously for some period of time, as does the ground station. Both the spacecraft and ground station record transmit and receive time based on a local clock, which must be tied with an offset and rate to a master clock.

Transponders need various time, frequency and range rate fields in the format. With the exception of the oscillator relativity correction, these are slowly changing with time, so they can be included in the data header records. (Alternatively, some quantities could be distributed in separate files.) These fields are as follows.

- Pulse Repetition Frequency (PRF) - 1e-5 to 1e6 Hz
    - Asynchronous transponders only.
- Transponder transmit delay - 10sec to 1 msec
    - Synchronous transponders: delay between receive and fire
    - Asynchronous transponders: delay between fire command and fire
- Transponder UTC offset - 10 nsec to 1 second
    - Asynchronous transponders only
- Oscillator Frequency Drift – TBD-TBD parts in 10e9
    - Asynchronous Transponders orbitting a solar system body
    - Corrects for the drift of the satellite's on-board oscillator.
- Relativity Correction to Satellite Oscillator Time Scale for 1 Way Range Rates – 1.5m/sec - 1cm/sec (5 nsec/sec – 0.03 nsec/sec)

- Asynchronous Transponder orbitting a solar system body
- Corrects for range rate change due to satellite orbitting in a different gravitational field.
- Range rate is also needed to an estimated accuracy of 15 cm/sec, but this is computable from positions and/or velocities given a small enough time between vectors (5-10 sec).

7. Tracking Restrictions

There are 2 satellites which will fly soon whose detectors could be damaged by laser light from ground stations: ADEOS-2, and ICESat. Currently there is no method to control when a certain station ranges to a given satellite except by vigilance at the station or not distributing the predictions. Neither of these is a general solution. An additional tool could be fields in the prediction format that describe and enforce conditions under which a satellite could not be ranged to. The latter would only be effective if the format completely described the types of restrictions required and the sample code were used at each station and updated regularly. The tracking restriction fields shown in the format are not fully developed and could either be dropped or changed in the final format.

Interpolator definition

Interpolation of the new format predictions will require an 8 point interpolation scheme that allows for variably spaced grid point times. A suggested interpolator has been written to accompany the new format. Recent investigations of study group members show the following record spacing to be reasonable, using position (X, Y, and Z) only. Note that the MGS (Mars Global Surveyor) results are identical with the step size of the Integration of the satellite's orbit. If the target had been on Mars, the interval would have been much larger.

Satellite	Interval (min)	
	Degree 7	Degree 9
CHAMP (LEO)	2	3
GFO-1	3	4
TOPEX	4	5
LAGEOS	5	10
GPS	15	30
Moon	30	60
MGS at Mars	0.3	

It will be the responsibility of the prediction providers to insure that the time step between prediction records will provide adequate ranging and pointing accuracy.

Sample code

Sample station implementation code incorporating the new interpolator is being developed and will be supplied in FORTRAN and C. This computer software handles the computation of topocentric ranging predictions rigorously, meaning that it can be used for artificial satellites near or distant, the moon, and other solar system bodies.

Conclusion

It is the intent to fulfill the requirements established for this study group for improved prediction accuracy and inclusion of exotic targets through the ILRS tabular prediction format. The consolidated prediction format includes 4 different target types in one prediction format and sample software set. It opens up opportunities for most stations to range a wider variety of targets and will naturally solve several difficulties in current SLR predictions. The format will comes at the expense of some software retooling and larger file transfers. It will, however, provide a flexible platform for laser ranging predictions into the foreseeable future.

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A. Preliminary Prediction Format Version 0.6

1) Data headers

Header type 1 Basic information - 1 (required)

1-2	A2	Record Type (= "H1")
4-6	A3	"IRV"
8-17	A10	Ephemeris Source (e.g., "HTSI ", "UTX")
19-28	A10	Notes (e.g., "041202","DE-403")

Header type 2 Basic information - 2 (required)

1-2	A2	Record Type (= "H2")
4-11	I8	COSPAR ID
13-16	I4	SIC
18-22	I5	Ephemeris Sequence number
24-27	I4	Starting Year
29-30	I2	Starting Month
32-33	I2	Staring Day
35-36	I2	Starting Hour
38-39	I2	Starting Minute
41-42	I2	Starting Second
44-45	I2	Ending Day
47-48	I2	Ending Hour
50-51	I2	Ending Minute
53-54	I2	Ending Second
56-60	I5	Time between table entries (seconds)(=0 if variable)
62	I1	Compatibility with TIVs = 1 (=> integratable)
64	I1	Format Version
66	I1	Target type 1=passive artificial satellite 2=passive lunar reflector 3=synchronous transponder 4=asynchronous transponder

Header type 3 Expected accuracy (highly recommended)

1-2	A2	Record Type (= "H3")
4-8	I5	Along-track run-off after 0 hours (meters)
10-14	I5	Cross-track run-off after 0 hours (meters)
16-20	I5	Radial run-off after 0 hours (meters)
22-26	I5	Along-track run-off after 6 hours (meters)
28-32	I5	Cross-track run-off after 6 hours (meters)
34-38	I5	Radial run-off after 6 hours (meters)
40-44	I5	Along-track run-off after 24 hours (meters)
46-50	I5	Cross-track run-off after 24 hours (meters)
52-56	I5	Radial run-off after 24 hours (meters)

Header type 4 Transponder information

1-2	A2	Record Type (= "H4")
4-15	F12.5	Pulse Repetition Frequency (PRF) in Hz
17-26	F10.4	Transponder transmit delay in microseconds
28-38	F11.2	Transponder UTC offset in microseconds
40-50	F11.2	Tranponder Oscillator Drift in parts in (TBD)

Header type 5 Tracking restrictions (repeat as needed)

1-2	A2	Record Type (= "H5")
4	A1	Restriction type (e.g., No ranging above maximum elevation)
6-15	F10	Restriction information (e.g. Maximum elevation)

Header type 9 Last header record

1-2	A2	Record Type (= "H9")

2) Ephemeris entry (repeat as needed)

Record type 1 Position (transmit required for all targets; receive for distant targets and transponders)

1	I1	Record Type (= '10')
2	I1	Direction flag (transmit = 1; receive = 2)
	I5	Modified Julian Date (MJD)
	I6	Seconds of Day
	I1	Leap second flag (=1 if new leap second introduced)
	f17.3	Geocentric X position in meters
	f17.3	Geocentric Y position in meters
	f17.3	Geocentric Z position in meters

Record type 2 Velocity (tranmit required for all targets; receive for distant targets and transponders)

1	I1	Record Type (= '20')
2	I1	Direction flag (transmit = 1; receive = 2)
	f18.6	Geocentric X velocity in meters/second
	f18.6	Geocentric Y velocity in meters/second
	f18.6	Geocentric Z velocity in meters/second

Record type 3 Corrections (all targets computed from a solar system ephemeris)

1-2	I2	Record Type (= '30')
	F7.0	X stellar aberration correction in meters
	F7.0	Y stellar aberration correction in meters
	F7.0	Z stellar aberration correction in meters
	F5.1	Relativistic range correction in nsec (transmit)

F5.1 Relativistic range correction in nsec (receive)

Record type 4 Transponder specific (Tranponders)

1-2	I2	Record Type (= '40')
	F5.2	Oscillator relativity correction in meters/second

Record type 9 Last ephemeris record

1-2	I2	Record Type (= "99")

3) Comments

1	A1	Record Type (="#")
2-72	A	Free format comments