Orbit Prediction for space debris tracking using laser ranging and angular data from encoder for Geochang DLT system

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KASI SLR Group
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Outline

1. Introduction
2. Encoder in Geochang system
3. OP Case and Result
4. Conclusion
Environment

Geochang SLR System is under test operation

**Debris Laser Tracking (DLT) system will be developed until 2020**

Tracking Space debris by DLT (One Station Tracking)

- Using TLE information for space debris acquisition/tracking
- Guide telescope (35min by 25min) can assist when sun-illuminated and visible time

...to acquisition space debris depending on operating condition and skill

Objective

Considering Time Critic/Sparse measurement Scenario

Predicting accurate orbit ephemeris of space debris to avoid collision event

- Accurate 1 day OP would be needed using only 1 day 3 passes window measurement data
Issues and Related Works

**Issues of space debris tracking with laser ranging**

1. Inaccuracy of initial orbit state → Limitation of Observation (Acquisition / Time)
   - Only using TLE information (1 km position error) for debris acquisition → sparse measurement
     Order of tens to hundreds of arcseconds
   - EO Sensor/Guide telescope (sun-illuminated and visible) is needed due to narrow laser beam

2. Range measurement error → Poor OP accuracy only using range measure
   - Uncertainty of debris size and attitude brings these errors
     Ref. Use of laser ranging to measure space debris, Zhang, Yang et al
   - Graz : 0.7m, Shanghai : 0.6 ~ 0.8m, Mt. Stromlo : better than 1.5 m RMS
     Ref. Laser measurement to space debris from Graz SLR station, Kirchner, Koidl et al
   - OD/OP only using range measurement brings limits in the achievable accuracy
     Ref. Fusion of laser ranges and angular measurement data for LEO and GEO Space debris OD, Cordelli, Vananti et al

**Related Works**

**Range + other data** (angular data of other optical system, TLE generated position…)
   - Other data also have measurement error (angular of EO : 2 ~ 5”, TLE Generated : hundreds of meter)
     Ref. very short arc OD for low Earth object using Sparse optical and laser data, Bennett, Sang et al
   - Improve OP accuracy and make **unaided laser ranging possible (Below 20 arcseconds)**
     * at least 50% of pass could be acquired with a diverged laser beam → **Overcome acquisition and time limitation**
Good Measurement for OP might come from

- Small measurement error / Small Noise
- Number of Observation → Enough / Dense data
- Geometry of observation → cover 3D position (Radial - In track - Cross track)

Ref. Fusion of laser ranges and angular measurement data for LEO and GEO Space debris OD, Cordelli, Vananti et al

Type of data for processing

- Optical Sensor : Angular Data
- Radar system : Range + Angular
  + Range Rate
- SLR/DLT : Range Data (Scalar)
  + **New Measurement** (Geometrical)

Angular data from Encoder

Select the angular data corresponding to full-rate data after data processing
Encoder in Geochang system

**Encoder**

One of main part in Tracking Mount System to track space object

- Can measure and collect Angular data (Azimuth and Elevation)

**Measurement Errors of Angular Data (Encoder)**

- C-SPAD FoV : 12 arcseconds
- Pointing and tracking accuracy of TMS : 10 arcseconds
  - Pointing/Tracking accuracy ≤ 2 arcseconds for star
- Time synchronization (neglectable)
  - About $10^{-7}$ sec
- Assuming worst case error : 7 arcseconds (Unthinkable)

→ Total 20 arcseconds (Most Worst Case)
Considerations

Considering Geochang DLT system Only with Range and Angular data from Encoder

Using AGI ODTK Simulation, Set Up Procedure followed by ODTK Guideline (Filter/Smoother)

Peroid of measurement : 3 Passes (only for night time) and Initial Orbit State Error : 1 km (TLE)

Gravity model : EGM08 100 by 100, Density Model : NRLMSISE-00

Targeted Space Debris : Norad ID 43031 (Apogee : 598km)

<table>
<thead>
<tr>
<th>Debris</th>
<th>InclinaCZ-2C R/B (PRC)</th>
<th>43031U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected Mass</td>
<td>5000kg</td>
<td>Cylinder</td>
</tr>
<tr>
<td>Expected Size</td>
<td>Radius 3.5m, length : 8m</td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td>50 Square meter</td>
<td></td>
</tr>
</tbody>
</table>

1st pass : sun-illuminated and visible time

3 Pass / 1 night

<table>
<thead>
<tr>
<th>Pass</th>
<th>Start Time (UTCG)</th>
<th>Stop Time (UTCG)</th>
<th>Duration (min)</th>
</tr>
</thead>
</table>

Measurement Error and Time set up

<table>
<thead>
<tr>
<th>Measurement Type</th>
<th>Measurement Error</th>
<th>Time Span</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>Range (1m)</td>
<td>0.5 sec</td>
</tr>
<tr>
<td>Angular (Encoder)</td>
<td>20 arcseconds ≈ 0.005 Deg</td>
<td>0.5 sec</td>
</tr>
<tr>
<td>Angular (Electro Optic)</td>
<td>5 arcseconds ≈ 0.001 Deg</td>
<td>10 sec</td>
</tr>
</tbody>
</table>
Flow of Case Study

1st Pass
Sun-illuminated and visible time

Op Case 1
Check Unaided Laser Ranging Possibility
Increasing possibility of successful acquisition and allowable observing time without any optics aid under no sun-illuminated/visible condition

Time span 90 min

Using Guide Telescope
Acquisition and Tracking
TLE data

Generate Measurement Range + Angular from Encoder

OP using Generated Measurement
Determine OP accuracy after 90 min (the time span until 2nd pass start)

OP Result

Unaided Laser Ranging Possibility

Using OP Result

Using TLE data

No
Sun-illuminated and visible time

No
Sun-illuminated and visible time

Increasing possibility of successful acquisition and allowable observing time without any optics aid under no sun-illuminated/visible condition

20 arcseconds ≈ 132m @ beginning of 2nd pass

2nd Pass

Acquisition and Tracking Without Guide Telescope

Using TLE data

Using OP Result

No
Unaided Laser Ranging Possibility

Yes

Entire 3 passes OD window determine OP accuracy after 1 day

OP Case 2

3rd Pass

Generate Measurement Range + Angular from Encoder

OP using Generated Measurement

OP Result

Unaided Laser Ranging Possibility

Using OP Result

Using TLE data

No

The data contained in this document, without the permission of KASI, shall not be used, duplicated or disclosed, in whole or in part, for any purpose other than Geochang SLR/DLT development.
OP Case 1 (1 Pass)

OP Case 1: Check the possibility of **unaided laser ranging (20 arcseconds) of 2nd pass**

Ref. very short arc OD for low Earth object using Sparse optical and laser data, Bennett, Sang et al

1-1: Range + Angular (Encoder) / 50% of 1st pass – 90 min OP (for next pass)

1-2: Range + Angular (Electric Optic Sensor) 100% of 1st pass → Assuming other EO sensor support

**Remind**

(Sun-illuminated and visible time)

1**st pass** with TLE / Guide Telescope/ EO Sensor

**Goal**

Solve limitation of Observation Issue (Acquisition and Time)

**Unaided Laser Ranging**

- Increasing possibility of successful acquisition and allowable observing time without any optics aid under no sun illuminated and visible condition

1. At least 50% of pass could be acquired with a diverged laser beam without other sensors (Solve the Acquisition limitation)

2. No Sun-illuminated and visible time can laser ranging (Solve the Time Limitation)

140m @ beginning of 2nd pass (slant range 1450km)

140m @ beginning of 2nd pass (slant range 1450km)
OP Case 2 (3 Passes)

OP Case 2 : Check the Range + Angular(Encoder) measurement benefit

2-1 : Range (DLT) + Angular data (from Encoder of DLT) for 3 passes
2-2 : Range (DLT) for 3 passes + Angular data (from other EO Sensor) for 1 pass (sun and visible)
    → Assuming other EO sensor support for 1 pass
2-3 : Range (DLT) for 3 passes / 1 night + Angular (Encoder) for 3 passes + Angular (EO) for 1 pass

Goal

Objective : Accurate 1 day OP would be needed using only 1 day window measurement data

If the OP Case 2-1 result is accurate as much as other case
→ Solve Poor OP Accuracy issue through OP with range and angular data from encoder measurement
### Result of OP Case 1 (1 Pass)

#### Position Uncertainty / Position Difference /

#### Comparison between true orbit and determined orbit (OP Accuracy)

#### How much can we trust OP result

<table>
<thead>
<tr>
<th>OP Case 1 (1 Pass)</th>
<th>Data type</th>
<th>3D</th>
<th>R</th>
<th>I</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1-1) DLT + Encoder (2m30s)</td>
<td>Range + Angular</td>
<td>2.7</td>
<td>1.7</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>(1-2) DLT + Angular EO (5min)</td>
<td>Angular</td>
<td>10.5</td>
<td>5.6</td>
<td>6.1</td>
<td>6.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OP Case 1 (1 Pass)</th>
<th>Data type</th>
<th>3D</th>
<th>R</th>
<th>I</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1-1) DLT + Encoder (2m30s)</td>
<td>Range + Angular</td>
<td>147.4</td>
<td>39.6</td>
<td>133.6</td>
<td>48.2</td>
</tr>
<tr>
<td>(1-2) DLT + Angular EO (5min)</td>
<td>Angular</td>
<td>193.1</td>
<td>30.3</td>
<td>160.9</td>
<td>102.4</td>
</tr>
</tbody>
</table>
Result of OP Case 1 (1 Pass)

Radial

In-track

Crosstrack

DLT + Encoder (1 pass) Position Difference

More detailed view → Appendix
## Result of OP Case 2 (3 Passes)

### Position Uncertainty (m) - Mean Value -

<table>
<thead>
<tr>
<th>Position Uncertainty (m) - Mean Value -</th>
<th>OP Case 2 (3 Pass)</th>
<th>Data type</th>
<th>3D</th>
<th>R</th>
<th>I</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2-1) DLT + Encoder</td>
<td>Range + Angular</td>
<td>1.2</td>
<td>0.2</td>
<td>0.3</td>
<td>1.16</td>
<td></td>
</tr>
<tr>
<td>(2-2) DLT + Angular EO</td>
<td>Range + Angular</td>
<td>3.1</td>
<td>0.5</td>
<td>0.6</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td>(2-3) DLT + Angular Encoder + Angular EO</td>
<td>Range + Angular</td>
<td>0.5</td>
<td>0.09</td>
<td>0.1</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>

### Position Difference (m) – RMS –

<table>
<thead>
<tr>
<th>Position Difference (m) – RMS –</th>
<th>OP Case 2 (3 Pass)</th>
<th>Data type</th>
<th>3D</th>
<th>R</th>
<th>I</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2-1) DLT + Encoder</td>
<td>Range + Angular</td>
<td>56.8</td>
<td>6.8</td>
<td>55.6</td>
<td>9.3</td>
<td></td>
</tr>
<tr>
<td>(2-2) DLT + Angular EO</td>
<td>Range + Angular</td>
<td>98.9</td>
<td>3.3</td>
<td>94.3</td>
<td>29.7</td>
<td></td>
</tr>
<tr>
<td>(2-3) DLT + Angular Encoder + Angular EO</td>
<td>Range + Angular</td>
<td>35.5</td>
<td>2.4</td>
<td>35.4</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>
Result of OP Case 2 (3 Passes)

Radial

In-track

Crosstrack

DLT + Encoder (3 Pass) Position Difference

More detailed view → Appendix
**Conclusion**

**Geochang Debris Laser Tracking Operation**

**Objective**
Predicting accurate orbit state of space debris to avoid collision event
- Accurate 1 day OP would be needed using only 1 day 3 passes measurement

**Issues**

| Limitation of Observation (Acquisition / Time) | Poor OP accuracy using range measurement |

**Solution**

Novel Idea: Using Angular Data from Encoder of DLT with Range data

**Results**

- Limit of Observation (Acquisition / Time) issue
  → Increasing possibility of Acquisition and Laser Ranging Time without optics aid
- Poor OP Accuracy issue → Improve OP (1 day) accuracy as much as other cases

Preliminary Study is Completed → Go to Future Work

OP Accuracy OP Case 1-1 : 147.4 m
(20” ≈ 140m @ beginning of 2nd pass)

OP Accuracy OP Case 2-1 : 56.8 m

Much better than TLE
Future Work

1. System Implementation to extract encoder value in Geochang SLR station

2. Validation of Encoder Angular Data Measurement from real observing data (Ajisai, Satellite POD available)

3. OP with real observation data (Range and Angular) Using Geochang SLR
   - OP using 1 pass measurement data (Unaided Laser Ranging Check)
   - OP using 3 pass measurement data (OP Accuracy improvement Check)
   - OP with other EO sensor data (Bohyun Mt. OWL EO system)
   - Comparison with Simulation Result
Thanks for your attention !!!
Any Question ???

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Appendix
Result of OP Case 1-1

(Target-Reference) Radial Position Difference

Satellite(s): STKEphemeris_Satellite
Target: Ephemeris
Reference: Ephemeris

Time of First Data Point: 29 May 2018 18:31:23.966000 UTCG

Radial

DLT + Encoder (1 pass) Position Difference
Result of OP Case 1-1

In-track

DLT + Encoder (1 pass) Position Difference
Result of OP Case 1-1

Crosstrack

DLT + Encoder (1 pass) Position Difference
Result of OP Case 1-2

DLT + EO (1 pass) Position Difference

Radial Position Difference

Satellite(s): STKEphemesis_Satellite
Target: Ephemeris
Reference: Ephemeris

Time of First Data Point:
29 May 2018 18:29:05.146000 UTCG
Result of OP Case 1-2

DLT + EO (1 pass) Position Difference

In-track
Result of OP Case 1-2

(Target-Reference) Crosstrack Position Difference

Satellite(s): STKEphemeris_Satellite
Target: Ephemeris
Reference: Ephemeris

Time of First Data Point:
29 May 2018 18:20:05 UTC

Crosstrack

DLT + EO (1 pass) Position Difference
Result of OP Case 2-1

DLT + Encoder (3 Pass) Position Difference

Radial
Result of OP Case 2-1

In-track

DLT + Encoder (3 Pass) Position Difference
Result of OP Case 2-1

DLT + Encoder (3 Pass) Position Difference

Crosstrack
Result of OP Case 2-2

(D Target-Reference) Radial Position Difference

Satellite(s): STK Ephemeris_Satellite
Target: Ephemeris
Reference: Ephemeris

Time of First Data Point:
29 May 2018 18:29:05.146000 UTC/G

Radial

DLT + EO (3 Pass) Position Difference

2018 May 29 Tue
21:00 30 Wed 3:00 6:00 9:00 12:00 15:00 18:00 21:00

STKEphemeris_Satellite Difference (Target-Reference)
STKEphemeris_Satellite Target +2 Sigma
STKEphemeris_Satellite Reference +2 Sigma
STKEphemeris_Satellite Target -2 Sigma
STKEphemeris_Satellite Reference -2 Sigma
Result of OP Case 2-2

In-track

DLT + EO (3 Pass) Position Difference
Result of OP Case 2-2

DLT + EO (3 Pass) Position Difference

Crosstrack
Result of OP Case 2-3

DLT + Encoder + EO (3 Pass) Position Difference

(Target-Reference) Radial Position Difference

Satellite(s): STKEphemeris_Satellite
Target: Ephemeris
Reference: Ephemeris

Time of First Data Point:
29 May 2018 10:29:05 UTC

STKEphemeris_Satellite Difference (Target-Reference)
STKEphemeris_Satellite Reference +2 Sigma
STKEphemeris_Satellite Target +2 Sigma
STKEphemeris_Satellite Reference -2 Sigma
STKEphemeris_Satellite Target -2 Sigma
Result of OP Case 2-3

In-track

DLT + Encoder + EO (3 Pass) Position Difference
Result of OP Case 2-3

DLT + Encoder + EO (3 Pass) Position Difference