A Monitoring and Warning System for Close Geosynchronous Satellite Encounters

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Outline

- Geosynchronous satellite failures
- Geosynchronous Monitoring and Warning System
- Preliminary results
- Summary and future work
Drifting Satellites in the Geopotential Well Centered at 105.3° W Longitude

• Telstar 401 failed January 11, 1997
  – Oscillates indefinitely from 97° to 115° W longitude with period ~ 800 days
  – Since failure, has encountered over 100 satellites with closest distances ~ 2 km
  – 27 close approaches predicted for 2001

• Solidaridad 1 failed August 29, 2000
  – Oscillates indefinitely from 101° to 109° W longitude
  – Encounters in Geopotential Well began in late January
  – 11 close approaches predicted for 2001
Galaxy 7

• Galaxy 7 failed November 24, 2000
• Galaxy 7 normally oscillates in Geopotential Well from 125 to 85° W longitude
  – It would have encountered a considerable number of satellites
• Galaxy 7 not completely dead, thrusting capability exists
• Operator performed boosting maneuvers in late November
  – Current perigee above GEO = 74 km
  – Current apogee above GEO = 286 km
  – Circulates moving West at about 2°/day
  – 26 satellites in the GEO belt are in the above Perigee to Apogee range, monitoring will look for any potential encounter
Galaxy 7 Encounter Population Before and After Boost

Galaxy 7 vs Active Population (without boost)

35 satellites

Galaxy 7 vs Active Population (after boost)

26 satellites
GEA CRDA Background

- MIT Lincoln Laboratory became involved in monitoring first encounters of Telstar 401 with Geopotential Well satellites
- Resources
  - Millstone Hill Radar with accuracy: 5 m range, 3 mm/s range rate, 5 – 10 mdeg azimuth and elevation
  - Space Based Visible telescope with 1 mdeg RA and DEC
  - High precision orbit determination DYNAMO (Force models to 1 m)
- MIT Lincoln Laboratory established Geosynchronous Encounter Analysis Cooperative Research and Development Agreement (GEA CRDA) with commercial satellite owners/operators
  - CRDA initially monitored the threat posed by Telstar 401, expanded to monitor threats to all CRDA partner satellites
  - GE Americom (18 Satellites), Loral Skynet (7 Satellites), SATMEX (3 Satellites), TELESAT Canada (6 Satellites)
- Operational aspect of CRDA
  - Monitor encounters of CRDA satellites with threatening RSOs
  - Calibrate CRDA partner range data either by processing the range data or providing high accuracy element sets to partners
Estimated Encounters vs. Distance of Closest Approach for 2001
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Geosynchronous Monitoring and Warning System (GMWS)

CRDA Partner Data → Orbit Determination System → Encounter Monitoring System → LL Analysts CRDA Partner → Encounter Warning System → LL Analysts CRDA Partner

SSN Catalog → Tracking data

ALERT (-60 days) → Encounter Tasking System

WARNING (-15 days)

MHR SBV
Encounter Determination for ALERTS (1)

- ALERTS determines encounters based on orbital plane intersection of two objects
  - $|a_1 - a_2| \leq a_1 e_1 + a_2 e_2$ requires Perigee of one object to be greater than the Apogee of the other (necessary but not sufficient condition)
  - Orbit planes are generally inclined, an object threatening the GEO belt must cross the equator near GEO radius
  - Due to typical sizes of GEO satellites an encounter is localized to point at which orbital planes intersect
Encounter Determination for ALERTS (2)

- Objects also need to be at point of intersection at same time
- At time one object is at point of intersection, compute longitudes and radial distances of both and check:

\[
\left| L_2 - L_1 \right| \leq L_{\text{threshold}} \quad \left| r_2 - r_1 \right| \leq r_{\text{threshold}}
\]

where \( L_{\text{threshold}} = 0.05 \) degrees

\( R_{\text{threshold}} = 50 \) km
Encounter Determination for WARNINGS

WARNINGS determine encounters based on 15 day DYNAMO ephemeris

- DYNAMO orbit propagated 15 days in ECI coordinates at 60 s spacing
- ECI vectors differenced, transformed to Radial, Along Track, and Cross Track Differences to show encounter distances in physically meaningful components
- Encounters tabulated and prioritized for tasking
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GMWS Validation

- GMWS system runs daily
  - Updates orbits based on new tracking
  - Generate ALERTS and WARNINGS
  - Generates necessary tasking to improve encounter estimation
- A number of system checks are made to ensure that all components are running properly
- Validating the results:
  - Examine age of element sets
  - Examine orbit and encounter prediction accuracy
    - Orbits overlapped over semi independent (10% overlap) fit spans
    - Predicted orbit accuracy assessed by predicting backwards
  - Track with radar during closest approach to confirm predicted encounter distance and time
Element Set Ages for the GMWS Catalogue

Element Set Age vs. Number of Objects

- Number of Objects
- Element Set Age

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GMWS: Orbit Accuracies by Overlap

- **GMWS Deep Space Catalog**
  - 477 orbits computed
    - 443 inactive
    - 34 active
  - 472 DYNAMO orbits
  - 408 objects have orbits determined from optical observations only

- **GMWS Inactive Objects**
  - 443 inactive objects
  - 346 (78%) have overlap errors measured
    - 331 (96%) have errors < 50 km
    - 256 (74%) have errors < 10 km
    - 189 (55%) have errors < 5 km
    - 52 (15%) have errors < 1 km

**Overlap Errors For All GMWS Inactive Objects**

- Overlap error (km)
  - 0
  - 100
  - 200
  - 250
- Number of objects
  - 0
  - 50
  - 100
  - 150
  - 200
  - 250

- Overlap error (km)
  - 0
  - 1
  - 2
  - 3
  - 4
  - 5
  - 6
  - 7
  - 8
  - 9
  - 10
- Number of objects
  - 0
  - 5
  - 10
  - 15
  - 20
  - 25
  - 30
  - 35
  - 40
  - 45
  - 50

- Color Legend:
  - radial
  - along
  - cross
  - total
GMWS Along-Track Error Distribution

Along-track errors with and without radar tracks

- No radar tracks
- Some radar tracks

Along-track overlap error (km)

Number of orbits
SBV capable of generating high accuracy GEO orbits

SBV Only High Accuracy GEO Orbits
SBV and Radar Data Fusion

- Two week observation span
  - 6 SBV tracks
  - 3 Millstone (MH) tracks
- Optical and radar data are complementary
- Optimize data collection to achieve a given accuracy
Effect of Accurate Radiation Pressure Modeling

- Radiation parameter error significant source of prediction error
## Orbit Accuracy Improvement by Adding CRDA Partner Range Data

<table>
<thead>
<tr>
<th>Tracking Case</th>
<th>$\Delta$Rad RMS (m)</th>
<th>$\Delta$Cross RMS (m)</th>
<th>$\Delta$Along RMS (m)</th>
<th>$\Delta$RSS (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Millstone Only</td>
<td>132</td>
<td>1236</td>
<td>268</td>
<td>1272</td>
</tr>
<tr>
<td>Millstone + Telesat</td>
<td>9</td>
<td>61</td>
<td>17</td>
<td>64</td>
</tr>
</tbody>
</table>

- Orbit Accuracy Assessment of Anik E1 (Telesat Canada) by Overlap
Encounter Validation
With Millstone and Haystack Radars

- Millstone and Haystack each track one of the encountering objects
- Observations are later combined, giving a three-dimensional picture of the encounter (in azimuth, elevation, and range)
- If Haystack is unavailable, Millstone alternates between objects
Single-Radar Encounter Validation

Anik E1 (object A) with B = Solidaridad 1 (object B) on 2001/01/25

- Rng-357.86 (km)
- El (°)
- Az (°)
- Separation (km)

GMWS Prediction (17:31 14 km)

21222 = Anik E1
22911 = Solidaridad 1
12 km
Summary and Future Work

- GMWS is currently monitoring a catalogue of ~ 450 inactive and 34 CRDA partner satellites
  - GMWS generates close encounter ALERTS 60 days out followed by WARNINGS 15 days out
  - MHR and SBV tasking requested as needed to enhance accuracy of encounter prediction

- Accuracy measures from GMWS currently show 75% with errors < 10 km and 50% with errors < 5 km
  - Enhanced using radar, radiation pressure scale factor, longer arcs if optical only

- Calibrated CRDA partner range and timely maneuver information important to enhance tracking resources

- Accuracy assessment, maneuver detection, active vs. active, and precision longitude monitoring are current priority Research and Development components for GMWS