EVOLUTION OF SPACE DEBRIS MONITORING DATA ACQUISITION STANDARDS: THE TDM VERSION 2, OSDM, AND FUTURE PLANS

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ABSTRACT

ESA's SSA programme aims to contribute to data exchange formats and standards and support Space Debris Monitoring (SDmon) data acquisition. The need for timely and accurate SDmon data is increasing, driven by the recent launches of large numbers of small satellites and the announcements of several large constellations. Several SDmon standardisation gaps have been identified, including exchanging information about a sensor/observing system, and photometric and RCS data together with astrometric data. A new standard, the Observing System Data Message (OSDM) is in development with CEN/CENELEC. The CCSDS is preparing an updated version of the Tracking Data Message (TDM v2). This paper introduces ongoing and recent standardisation efforts relevant to SDmon. Future anticipated needs and current limitations will be discussed as well.

1 INTRODUCTION

Space Safety involves the exchange of data between various entities, including spacecraft operators, space agencies, service providers (eg space weather data, conjunction prediction), national authorities, etc. International standards are therefore needed to unambiguously exchange this data.

The ESA Space Safety/Space Situational Awareness (SSA) programme contains activities for space weather, near-Earth objects, and space debris monitoring. International partners include COSPAR, IADC (Inter-Agency Space Debris Coordination Committee), UN COPUOS (United Nations Committee on the Peaceful Uses of Outer Space), and ESO (European Southern Observatory) [1]; standardisation is key topic for the programme, with involvement in the Consultative Committee for Space Data Systems (CCSDS), International Organisation for Standardization (ISO), European Committee for Standardization (CEN), and European Committee for Electrotechnical Standardization (CENELEC). The Space Debris Office's expertise includes collision avoidance support, re-entry risk assessment, and the development of space debris environment models [2].

CCSDS was established by the major space agencies to develop "communications and data systems standards for spaceflight". The CCSDS Navigation Working group has produced several flight dynamics standard, such as the Orbit Data Messages (ODM), the Tracking Data Message (TDM), and the Conjunction Data Message (CDM) [3]. CCSDS is affiliated with ISO as TC20/SC13. CCSDS standards follow a very thorough development process, which includes review by member agencies, prototyping, and reviewing existing standards every 5 years.

CEN and CENLEC are two of the three pillars of European technical standardisation (the third being ETSI, the European Telecommunications Standards Institute). CEN and CENELEC share a mandate from the European Union to develop standards needed by the European space industry, which they are meeting through Technical Committee 5 'Space'. TC5/WG2 is responsible for developing standards related to SSA [4], including Space Weather, Near-Earth Objects, and Space Debris Monitoring (SDmon).

2 EXISTING SPACE DEBRIS MONITORING AND NEO STANDARDS AND APPROACHES

Standardised file formats are already in wide use in the SDmon and NEO communities. These standards include:

- FITS: the Flexible Image Transport System, the "standard data format used in astronomy" [5] and the near-universal image output format for SDmon and NEO telescopes.
- TDM: the Tracking Data Message, the standard format for astrometric (and soon photometric data) used in SDmon and flight dynamics.
- CDM: the Conjunction Data Message, used to warn spacecraft operators of close approaches that might require collision avoidance manoeuvres.
- ODM: the Orbit Data Messages, the standard formats to exchange orbit data used in SDmon and flight dynamics.
- CRD and CPF: the standard output and prediction format for Satellite Laser Ranging (SLR) [6].

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Ed. T. Flohrer, R. Jehn, F. Schmitz (http://neo-sst-conference.sdo.esoc.esa.int, January 2019)

3 STANDARDISATION GAPS IN SPACE DEBRIS MONITORING

Despite the very active SDmon standardisation community, several gaps in SDmon standards still exist. In the area of observation acquisition and catalogue build-up the following gaps have been identified:

- TDM v1 [7] does not contain any magnitude or radar cross-section (RCS) information, so attitude state or 'patterns-of-light' cannot be estimated. This is foreseen to be closed in TDM v2, discussed later in this paper.
- TDM v1 [7] lacks any signal-to-noise ratio (SNR) and 'confidence interval'-type information for the contained observations.
- There is no standard to describe the parameters of a sensor/observing system, for either orbit determination (OD) or observation planning. This gap is being closed by CEN/CENELEC TC5/WG2.
- The standardisation of observation requests and scheduling is fuzzy. There are several existing (eg Orbit Ephemeris Message [8] and Pointing Request Message [9]) and under development (CCSDS Events Message and Planning Information Format) standards to assist, but no coordinated approach or even widely-agreed approach. The SDmon and NEO subgroups in CEN/CENELEC TC5/WG2 are working towards closing this gap.

Gaps also exist for services aimed at SDmon users:

- There is no standard for sharing re-entry data: this gap is being actively closed by the CCSDS Navigation WG through the development of the Re-entry Data Message [10].
- There is no standard for sharing fragmentation detection data: the CCSDS Navigation WG is exploring closing this gap, but the activities have not progressed beyond a CCSDS White Paper and a second prototyping agency is needed before standardisation activities can commence.
- There are some gaps in the sharing of conjunction prediction data: the CDM development was driven by available data sources in 2011-2012. Since then the number of data providers has increased, as has coverage of the spacecraft operator needs. The CCSDS has approved a revision of the CDM.

The CCSDS Navigation WG and TC5/WG2 SDmon sub-group have taken the approach to only standardise the formats used for data exchange, not the way the data is produced or the mechanism used for exchange. Other CCSDS working groups (in the Cross-Support Services area) have prepared standardised services based around exchanging navigation messages.

One common pitfall in standardisation efforts is to develop an overly complex standard, in the attempt to satisfy the requirements of a large user base or to cover too many scenarios. This can lead to a protracted development process, even slower than the approx. 5 year timeframe of successful standardisation efforts, or to abandoned standards.

4 TRACKING DATA MESSAGE V2

The TDM version 2 is being developed to close some of the gaps identified in version 1:

- Lack of keywords for photometric data and RCS;
- Insufficient keywords for some tracking antennae.

The new keywords added to the metadata are listed in Tab. 1, while the new data keywords are listed in Tab. 2 [11].

Table 1 - New TDM v2 metadata keywords (all optional)

keyword	description	examples
DATA_TYPES	List of the types of data in the data section.	ANGLE_1, ANGLE_2, MAG ANGLE_1, ANGLE_2, RANGE, DOPPLER_INSTANTANEOUS, RCS
EPHEMERIS_NAME_n	External ephemeris file used in the tracking of PARTICIPANT_n.	SENTINEL-3A.OEM
INTERPOLATION	The interpolation method to be used to calculate a transmit phase count at an arbitrary time in tracking data where the uplink frequency is not constant.	HERMITE LAGRANGE LINEAR

INTERPOLATION_DEGREE	The recommended degree for the interpolating polynomial, as per INTERPOLATION.	3 12
DOPPLER_COUNT_BIAS	One way of giving Doppler is as a positive integer count. This requires a positive bias, so negative Doppler is still a positive integer, and a count scale, allowing for partial cycles in an integer number. If the count overflows the accumulator (due to a long track or high Doppler shift) a rollover occurs. The Doppler shift can be computed from the equation below, assuming no rollover: $DOPPLER = \frac{DOPPLER\_COUNT}{(DOPPLER\_COUNT\_SCALE - DOPPLER\_COUNT\_BIAS)}$	2.4E6
DOPPLER_COUNT_SCALE		1000 1
DOPPLER_COUNT_ROLLOVER		YES NO
CORRECTION_MAG	The corrections that have either been added to the data or should be added to the data (as indicated by the CORRECTIONS_APPLIED keyword). The units will match MAG and RCS respectively in the data.	
CORRECTION_RCS		

Table 2 - New TDM v2 data keyword

keyword	**unit**	**description**
DOPPLER_COUNT	n/a	Count of the number of times the phase of the received signals slips once cycle relative to the transmitted signal. Should be used in conjunction with DOPPLER_COUNT_BIAS, DOPPLER_COUNT_SCALE, and DOPPLER_ROLLOVER keywords in the metadata.
MAG	n/a	Apparent visual magnitude of the target.
RCS	m^2	Radar cross-section of the target.
RECEIVE_PHASE_CT_n	n/a	The number of phase cycles at the receiver/transmitter of PARTICIPANT_n.
TRANSMIT_PHASE_CT_n	n/a	

Most relevant for SDmon is the addition of the MAG and RCS keywords, that allow the creation of pattern-of-light plots for GEO objects and help planning observations. An example TDM v2 containing the MAG keyword can be seen in Fig. 1.

```
CCSDS_TDM_VERS = 1.0
CREATION_DATE  = 2017-07-25T13:47:42.0
ORIGINATOR     = ESA
META_START
DATA_TYPES       = ANGLE_1, ANGLE_2, MAG
TIME_SYSTEM      = UTC
START_TIME       = 2017-05-21T23:10:35.3
STOP_TIME        = 2017-05-21T23:12:41.9
PARTICIPANT_1    = SHOT Teplice
PARTICIPANT_2    = TITAN 3C TRANSTAGE
DEB
MODE             = SEQUENTIAL
PATH             = 2,1
ANGLE_TYPE       = RADEC
REFERENCE_FRAME = EME2000
META_STOP
DATA_START
ANGLE_1 = 2017-05-21T23:10:35.3 234.503
ANGLE_2 = 2017-05-21T23:10:35.31
20.473
MAG     = 2017-05-21T23:10:35.3  15.940
ANGLE_1 = 2017-05-21T23:10:56.1 234.571
ANGLE_2 = 2017-05-21T23:10:56.1  20.486
MAG     = 2017-05-21T23:10:56.1  15.460
DATA_STOP
```

Figure 1 - Example of TDM v2 in KVN with the MAG keyword

The Tracking Data Message v2 successfully completed its CCSDS Agency Review in August 2018 and is being prototyped. ESA/SSA is prototyping the implementation of the MAG and RCS keywords. The TDM v2 Blue Book should be published in mid-2019. The CCSDS Navigation WG is already gathering ideas for version 3, which might be a more thorough reengineering of the standard.

5 OBSERVING SYSTEM DATA MESSAGE

The Observing System Data Message (OSDM) is a standard message format being developed by CEN/CENELEC TC5/WG2 for the exchange of optical telescope, satellite laser ranging stations, or radar (collectively termed observing systems) information. The message contains the observing system parameters needed to be exchanged by producers and consumers of astrometric and/or photometric data [12].

The goal of the message is to allow an observing system owner/operator to send the information needed by SSA operators for proper orbit determination configuration or the simulation of observing system performance (eg for scheduling). For this purposes, the OSDM contains the following information for one observing system:

- OSDM message/file information: creation date, originator, message ID;
- identifiers and general information (name, ID, owner, operator);
- "reference" performance (MTBF, MTTR, success rate);
- location (coordinates or pointer to an external ephemeris file);
- pointing performance parameters (pointing restrictions);
- optical telescope, radar, or SLR station parameters (eg CCD type and size for an optical telescope).

The OSDM has the same look and feel as existing CCSDS Navigation Data Messages, with both plain text (called KVN, or Keyword Value Notation) and XML versions. The OPM (Orbit Parameters Message) is the most similar in the terms of structure.

Fig. 2 shows an example OSDM in KVN for an optical telescope. The information contain includes the output data types (right ascension, declination, and apparent visual magnitude), the formats used for input and output, the coordinates and some performance parameters.

```
CEN_OSDM_VERS = 1.0
CREATION_DATE = 2018-03-15T11:03:36
ORIGINATOR    = ESA
MESSAGE_ID    = 20180315ESA/01
```

```
SYSTEM_NAME         = OGS TELESCOPE
SYSTEM_ID           = J04
SITE_NAME           = TEIDE OBSERVATORY
SYSTEM_TYPE         = PASSIVE OPTICAL
SYSTEM_OWNER        = ESA
SYSTEM_OPERATOR     = IAC/SPAIN

OUTPUT_DATA_TYPES   = RADEC, MAG
OUTPUT_FORMAT       = TDM
INPUT_FORMAT        = OEM
CORRECTIONS_APPLIED = ANNUAL
ABERRATION, TIME BIAS

LOCATION_TYPE   = GROUND-BASED
CENTER_NAME     = EARTH
REF_FRAME       = WGS84
REFERENCE_POINT = CCD CENTER
LON             = -16.512         [deg]
LAT             =  28.301         [deg]
ALT             = 2513              [m]

MIN_ELEVATION   =  10.0           [deg]
MAX_ELEVATION   =  90.0           [deg]
MIN_AZIMUTH     =   0.0           [deg]
MAX_AZIMUTH     = 360.0           [deg]

TELESCOPE_APERTURE_DIAMETER = 1.0    [m]
TELESCOPE_FOCAL_LENGTH      = 13.3   [m]

MIN_SNR_DETECTION           = 5.0
MIN_SNR_ASTROMETRY          = 6.0
MIN_SNR_PHOTOMETRY          = 9.0
ANGULAR_SIGMA               = 1.0
[deg]
VM_SIGMA                    = 0.5
TIME_PRECISION              = 0.001 [s]
TIME_BIAS                   = 0.0   [s]
TIME_DRIFT                  = 0.0 [s/s]
```

Figure 2 - Example OSDM in KVN for an optical telescope

Fig. 3 shows and example OSDM in XML for a radar. It includes the output data (range only), formats used for input and output, which corrections are applied to the output data (none), the location, and that the information in the message only applies to the receiver of a bi-static radar. The "one observing system per message" restriction means that each component of a multi-static system should be described in its own OSDM. The OSDM is currently going through the CEN/CENELEC review process and should be published at some point in 2019.

```
<?xml version="1.0" encoding="utf-8"?>
<osdm id="CEN_OSDM_VERS" version="1.0" xmlns="urn:cen:space:ssa:osdm">
    <header>
        <CREATION_DATE>2018-03-16T15:35:17</CREATION_DATE>
        <ORIGINATOR>ESA</ORIGINATOR>
        <MESSAGE_ID>20180316ESA/04</MESSAGE_ID>
    </header>
    <body>
        &lt;segment&gt;
```

```
            <metadata>
                <SYSTEM_NAME>EISCAT SODANKYLA</SYSTEM_NAME>
                <SYSTEM_ID>E-RX/SGO</SYSTEM_ID>
                <SITE_NAME>SODANKYLA GEOPHISICAL OBSERVATORY</SITE_NAME>
                <SYSTEM_TYPE>RADAR</SYSTEM_TYPE>
                <SYSTEM_OWNER>N/A</SYSTEM_OWNER>
                <SYSTEM_OPERATOR>N/A</SYSTEM_OPERATOR>
            </metadata>
            <data>
                <refPerformance>
                    <OUTPUT_DATA_TYPES>RANGE</OUTPUT_DATA_TYPES>
                    <OUTPUT_FORMAT>TDM</OUTPUT_FORMAT>
                    <INPUT_FORMAT>OEM</INPUT_FORMAT>
                    <CORRECTIONS_APPLIED>NONE</CORRECTIONS_APPLIED>
                </refPerformance>
                <location>
                    <LOCATION_TYPE>GROUND-BASED</LOCATION_TYPE>
                    <CENTER_NAME>EARTH</CENTER_NAME>
                    <REF_FRAME>WGS84</REF_FRAME>
                    <REF_POINT>ANTENNA PHASE CENTER</REF_POINT>
                    <GEODETIC_COORDINATES>
                        <LON units="deg">31.127</LON>
                        <LAT units="deg">70.367</LAT>
                        <ALT units="m">202.0</ALT>
                    </GEODETIC_COORDINATES>
                </location>
                <pointingPerformance>
                    <MIN_ELEVATION units="deg">30.0</MIN_ELEVATION>
                    <MAX_ELEVATION units="deg">150.0</MAX_ELEVATION>
                    <MIN_AZIMUTH units="deg">0.0</MIN_AZIMUTH>
                    <MAX_AZIMUTH units="deg">0.0</MAX_AZIMUTH>
                </pointingPerformance>
                <radar>
                    <RADAR_TYPE>BISTATIC RX</RADAR_TYPE>
                    <RADAR_SCANNING>MECHANICAL</RADAR_SCANNING>
                </radar>
                <observationAccuracy>
                    <MIN_SNR_DETECTION units="dB">10.0</MIN_SNR_DETECTION>
                </observationAccuracy>
            </data>
        &lt;/segment&gt;
    </body>
</osdm>
```

Figure 3 - Example OSDM in XML for a radar

6 SUMMARY AND CONCLUSIONS

The SDmon standardisation community is very active and closing the gaps identified in existing data exchange standards. The CCSDS Tracking Data Message v2 will offer better functionality for optical and radar observations and be published in 2019. The CEN/CENELEC Observing System Data Message will be a standard format for the exchange of data about optical telescopes, satellite laser ranging stations, and radars. It should also be published in 2019.

7 REFERENCES

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https://ilrs.cddis.eosdis.nasa.gov/data_and_products/formats/

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