CRYOSAT-2: STAR TRACKER ATTITUDE CALCULATION TOOL – FILE TRANSFER DOCUMENT

1. INTRODUCTION

This is the File Transfer Document for the executable routine that computes attitude data (quaternions, pitch, roll and yaw angles) from a given Cryosat-2 Star Tracker file.

1.1 Change History

Issue	Change Description
1.0	First issue

1.2 Distribution List

Project/Unit	Name	Project/Unit	Name	Project/Unit	Name

1.3 Reference Documents

[RD 01] Earth Observation Mission CFI Software. Conventions Document.
Ref. EO-MA-DMS-GS-0001. Issue 3.7.4 - 31/01/11

[RD 02] Earth Observation Mission CFI Software. EO_DATA_HANDLING Software User Manual.
Ref. EO-MA-DMS-GS-0007. Issue 3.7.4 - 31/01/11

2. ARCHIVE CONTENT

The following archive file has been delivered (generated with the zip utility):
EOCFI-FTD-019_1_0.zip

The archive has the following MD5 checksum:
fd682545733345fbaac1eb07c68bd6bf

The archive contains the following files:

```
./AttitudeStarTrackerFile_v1_0/INPUT/CS_OPER_DOR_NAV_0__20130601T034036_20130601T051836_0001.DBL
./AttitudeStarTrackerFile_v1_0/INPUT/CS_OPER_MPL_ORBPRE_20130601T000000_20130701T000000_0001.EEF
./AttitudeStarTrackerFile_v1_0/INPUT/CS_OPER_STR1ATT_0__20130601T034028_20130601T051837_0001.DBL
./AttitudeStarTrackerFile_v1_0/INPUT/CS_OPER_STR2ATT_0__20130601T034028_20130601T051837_0001.DBL
./AttitudeStarTrackerFile_v1_0/INPUT/CS_OPER_STR3ATT_0__20130601T034028_20130601T051837_0001.DBL
./AttitudeStarTrackerFile_v1_0/INPUT/cryosat_reference_frame_conf.xml
./AttitudeStarTrackerFile_v1_0/LINUX64/attitude_star_tracker_file
./AttitudeStarTrackerFile_v1_0/MACINTEL64/attitude_star_tracker_file
./AttitudeStarTrackerFile_v1_0/OUTPUT/output_attitude_data_20130601_034027_20130601_051837.txt
```

3. ARCHIVE CONTENT DESCRIPTION

File	Description
INPUT/ CS_OPER_DOR_NAV_0__20130601T034036_20130601T051836_0001.DBL	Cryosat DORIS Navigator file
INPUT/ CS_OPER_MPL_ORBPRE_20130601T000000_20130701T000000_0001.EEF	Cryosat Predicted Orbit File
INPUT/ CS_OPER_STR1ATT_0__20130601T034028_20130601T051837_0001.DBL	Cryosat Star Tracker file (Star Tracker #1)
INPUT/ CS_OPER_STR2ATT_0__20130601T034028_20130601T051837_0001.DBL	Cryosat Star Tracker file (Star Tracker #2)
INPUT/	Cryosat Star Tracker file (Star

CS_OPER_STR3ATT_0__20130601T034028_20130601T051837_0001.DBL	Tracker #3)
INPUT/cryosat_reference_frame_conf.xml	Star Tracker configuration file
LINUX64/attitude_star_tracker_file	Executable tools for Linux 64-bit
MACINTEL64/attitude_star_tracker_file	Executable tools for Mac Intel 64-bit
OUTPUT/output_attitude_data_20130601_034027_20130601_051837	Example of output file generated by the executable *attitude_star_tracker_file*

4. INSTALLATION

The archive can be expanded with the command unzip (in Linux/Mac Intel).

5. USAGE

5.1 Executable program *attitude_star_tracker_file*

The executable program *attitude_star_tracker_file* computes the relevant attitude data (with a given time step) from a given Cryosat-2 Star Tracker file. The attitude data is calculated for the time interval covered by the Star Tracker file. The executable tool expects also as input, among other parameters, an EO CFI-compatible orbit file (see [RD 02]). The orbit file has to cover the time period covered the Star Tracker file. The data generated by the executable is stored in an output file.

5.1.1 Command line input parameters description

The command line parameters of the executable routine are the following (provided in the order in which they have to be supplied):

INPUT PARAMETERS	Definition	Value
Satellite ID	Satellite identifier	CRYOSAT
Input Orbit File Supported types: Orbit Scenario File Predicted Orbit File Restituted Orbit File (also DORIS Preliminary and Precise) DORIS Navigator File	Filename (it may include the path to the file) See [RD 02] for further file format information	Given by the user
Input Star Tracker File	Filename (it may include the path to the file) See [RD 02] for further file format information	Given by the user
Input Star Tracker Configuration File	Filename (it may include the path to the file) See [RD 02] for further file format information	Given by the user
Time Step [s]	Time step (in seconds) for the computation of intermediate data	Given by the user

5.1.2 Output file format description

The executable program *attitude_star_tracker_file* generates as output a file. The filename of the output file is constructed automatically by appending the validity start and stop time of the input Star Tracker file to the string `output_attitude_data_`(see example in Section 5.1.3).

The output file includes comments (starting with the symbol #) describing the input and output data. The format of the output file is the following:

- Column 1: UTC Time in calendar format (CCSDS-A ASCII format "yyyy-mm-ddThh:mm:ss.uuuuuu")
- Column 2: UTC Time in MJD2000 reference [decimal days]
- Column 3: Absolute Orbit Number
- Column 4: Seconds since ANX
- Column 5: Geocentric Longitude [deg]
- Column 6: Geodetic Latitude [deg]
- Column 7: q0 component of attitude quaternion from Star Tracker Frame to Geocentric Mean of 2000 (J2000)
- Column 8: q1 component of attitude quaternion from Star Tracker Frame to Geocentric Mean of 2000 (J2000)
- Column 9: q2 component of attitude quaternion from Star Tracker Frame to Geocentric Mean of 2000 (J2000)
- Column 10: q3 component of attitude quaternion from Star Tracker Frame to Geocentric Mean of 2000 (J2000)
- Column 11: q0 component of attitude quaternion from Geocentric Mean of 2000 (J2000) to Satellite Attitude Frame
- Column 12: q1 component of attitude quaternion from Geocentric Mean of 2000 (J2000) to Satellite Attitude Frame
- Column 13: q2 component of attitude quaternion from Geocentric Mean of 2000 (J2000) to Satellite Attitude Frame
- Column 14: q3 component of attitude quaternion from Geocentric Mean of 2000 (J2000) to Satellite Attitude Frame
- Column 15: Pitch rotation angle from Satellite Orbital Frame to Satellite Attitude Frame [deg]
- Column 16: Roll rotation angle from Satellite Orbital Frame to Satellite Attitude Frame [deg]
- Column 17: Yaw rotation angle from Satellite Orbital Frame to Satellite Attitude Frame [deg]
- Column 18: Pitch rotation angle from Satellite Nominal Attitude Frame to Satellite Attitude Frame [deg]
- Column 19: Roll rotation angle from Satellite Nominal Attitude Frame to Satellite Attitude Frame [deg]
- Column 20: Yaw rotation angle from Satellite Nominal Attitude Frame to Satellite Attitude Frame [deg]

5.1.3 Example

5.1.3.1 Running the executable

The executable program can be called in the following way:

- From Linux/Mac shell

```
./attitude_star_tracker_file CRYOSAT ./INPUT/CS_OPER_MPL_ORBPRE_20130601T000000_20130701T000000_0001.EEF
./INPUT/CS_OPER_STR1ATT_0__20130601T034028_20130601T051837_0001.DBL ./INPUT/cryosat_reference_frame_conf.xml 10.0
```

The executable program shows the following messages:

```
attitude_star_tracker_file v1.0
--------------------------------

Input data:
Satellite: CRYOSAT
Orbit File: ./INPUT/CS_OPER_MPL_ORBPRE_20130601T000000_20130701T000000_0001.EEF
Star Tracker File: ./INPUT/CS_OPER_STR1ATT_0__20130601T034028_20130601T051837_0001.DBL
Star Tracker Configuration File: ./INPUT/cryosat_reference_frame_conf.xml
Time  Step: 10.000000 <s>


TIME INITIALIZATION
```

```
ATTITUDE INITIALIZATION


ORBIT INITIALIZATION


CALCULATION OF ATTITUDE DATA

Start UTC Time: 20130601_034027
Stop UTC Time : 20130601_051837


Output file created successfully: output_attitude_data_20130601_034027_20130601_051837.txt
```

5.1.3.2 *Output File*

The output file S3A_*output_data.txt* is created. Excerpt of the example output file:

```
# Generated with executable tool attitude_star_tracker_file v1.0
# Satellite: CRYOSAT
# Predicted orbit file: ./INPUT/CS_OPER_MPL_ORBLPR_20120619T120000_20130622T190000_0001.EEF
# Star Tracker file: ./INPUT/CS_OPER_STR1ATT_0__20130601T034028_20130601T051837_0001.DBL
# Star Tracker configuration file: ./INPUT/cryosat_reference_frame_conf3.xml
# Time  Step: 10.000000 <s>
# Output Filename: output_attitude_data_20130601_034027_20130601_051837.txt
#
# Calendar UTC Time    MJD2000 UTC Time    Geocentric Longitude [deg]  Geodetic Latitude [deg]
Attitude Quaternion (q0 q1 q2 q3) from STR to GM2000 Attitude Quaternion (q0 q1 q2 q3) from GM2000 to
Sat Attitude   (Pitch, Roll, Yaw) [deg] from Sat Orbital to Sat Attitude   (Pitch, Roll, Yaw) [deg]
from Sat Nominal to Sat Attitude
# ---------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------
----------------------------------------------------------------------------------------------------
-----------------------
20130601_034026982000 4900.153090069444 16683 +1646.269560 +091.601975 +080.110147 +0.036693305 -
0.077613326 -0.202706379 +0.975469065 +0.031043116 +0.080974692 +0.835458996 +0.542667201 +000.056131
+000.017436 -000.584457 -000.001791 +000.008240 +000.080246
20130601_034036982000 4900.153205810185 16683 +1656.269560 +090.885864 +079.520227 +0.037901883 -
0.082678604 -0.202016217 +0.975149806 +0.033789921 +0.085397219 +0.834737593 +0.542935270 +000.061390
+000.016882 -000.645100 +000.000058 +000.007757 +000.060654
20130601_034046982000 4900.153321550926 16683 +1666.269560 +090.240926 +078.929023 +0.039100926 -
0.087787392 -0.201461809 +0.974770553 +0.036574249 +0.089843840 +0.834069047 +0.543064668 +000.061984
+000.017458 -000.688915 -000.002744 +000.008346 +000.057812
20130601_034056982000 4900.153437291667 16683 +1676.269560 +089.656458 +078.336726 +0.040286395 -
0.092858912 -0.200953693 +0.974357143 +0.039341601 +0.094254672 +0.833408885 +0.543137114 +000.066891
+000.018395 -000.726781 -000.001212 +000.009354 +000.060834
[…]
```

6. TECHNICAL DETAILS AND ASSUMPTIONS

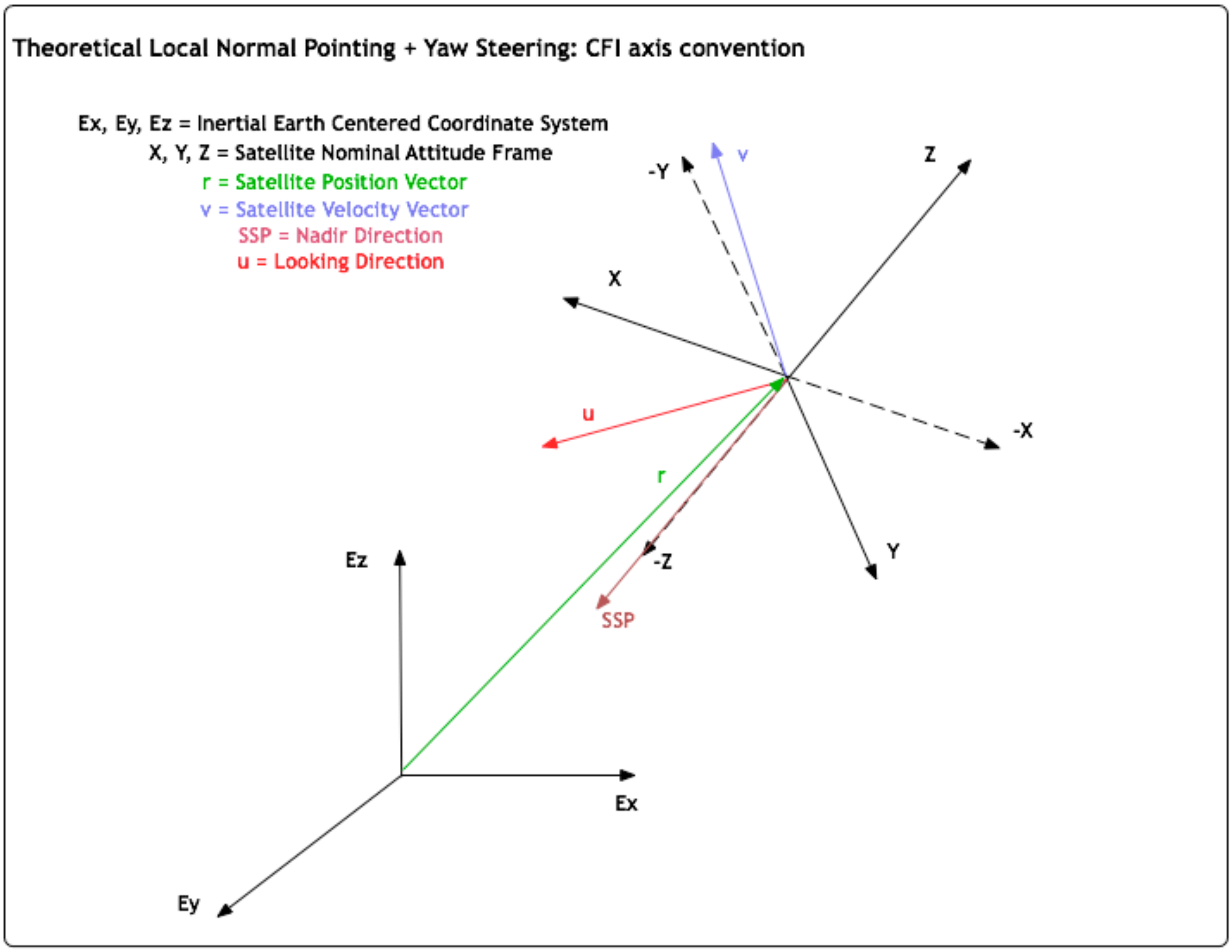
6.1 Coordinate Systems and Attitude Frames

The geodetic coordinates of the satellite are defined with respect Earth Ellipsoid WGS 84.

The following reference frames have been used for the calculation of the attitude quaternions:

- Geocentric Mean of 2000 (J2000)
  The definition of the Geocentric Mean of 2000 can be found In Section 5 of [RD 1].
- Satellite Orbital Frame:
  - Z = Unit vector from Earth Center to satellite
  - X = Unit cross product Z x satellite inertial velocity
  - Y = Z x X

- Satellite Nominal Attitude Frame: Local Normal Pointing + Yaw Steering Law
  - Z = Unit vector from geodetic nadir to satellite. It is calculated on-board by scaling the Z component of the satellite position with a coefficient
  - X = Unit cross product Z x satellite inertial velocity corrected for Earth's rotation
  - Y= Z x X
- Satellite Attitude Frame: Measured attitude frame. Star Tracker measured attitude including misalignment of the Star Tracker Frame.



6.2 Quaternion Definition

The following quaternion definition is used:

$$Q = \begin{bmatrix} q_0 & q_1 & q_2 & q_3 \end{bmatrix}$$

with

$$q_0 = e_x \cdot \sin\left(\frac{\theta}{2}\right)$$

$$q_1 = e_y \cdot \sin\left(\frac{\theta}{2}\right)$$

$$q_2 = e_z \cdot \sin\left(\frac{\theta}{2}\right)$$

$$q_3 = \cos\left(\frac{\theta}{2}\right)$$

where (e_x, e_y, e_z) are the direction cosines of the rotation axis (vector part) and θ is the rotation angle (real part).

6.3 Rotation Matrix Definition

The rotation matrix $M_{A \to B}$ transforms a vector in Frame A into a vector in Frame B, i.e.

$x_B = M_{A \to B} x_A$

where

$$M_{A \to B} = \begin{bmatrix} x_0 & y_0 & z_0 \\ x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \end{bmatrix}$$

(x_0, x_1, x_2) is the unitary direction vector along X-axis of Frame A (expressed in Frame B)

(y_0, y_1, y_2) is the unitary direction vector along Y-axis of Frame A (expressed in Frame B)

(z_0, z_1, z_2) is the unitary direction vector along Z-axis of Frame A (expressed in Frame B)

6.4 Quaternion and Rotation Matrix

Two quaternion sets are given in the output attitude data files:

- quaternions that represent the transformation from Star Tracker Frame to Geocentric Mean of 2000 (J2000)
- quaternions that represent the transformation from Geocentric Mean of 2000 (J2000) to Satellite Attitude Frame

In both cases, the following convention applies (the equations below use the notation for the quaternion from Geocentric Mean of 2000 (J2000) to Satellite Attitude Frame):

$$Q_{J2000 \to ATT} = \begin{bmatrix} q_0 & q_1 & q_2 & q_3 \end{bmatrix}$$

The quaternion $Q_{J2000 \to ATT}$ is associated to the rotation matrix $M_{J2000 \to ATT}$ as follows:

$$Q_{J2000\to ATT}=\begin{bmatrix}q_0\\q_1\\q_2\\q_3\end{bmatrix}\Leftrightarrow M_{J2000\to ATT}=\begin{bmatrix}q_0^2-q_1^2-q_2^2+q_3^2 & 2(q_0\cdot q_1+q_2\cdot q_3) & 2(q_0\cdot q_2-q_1\cdot q_3)\\ 2(q_0\cdot q_1-q_2\cdot q_3) & -q_0^2+q_1^2-q_2^2+q_3^2 & 2(q_1\cdot q_2+q_0\cdot q_3)\\ 2(q_0\cdot q_2+q_1\cdot q_3) & 2(q_1\cdot q_2-q_0\cdot q_3) & -q_0^2-q_1^2+q_2^2+q_3^2\end{bmatrix}$$

where $M_{J2000\to SATATT}$ transforms a vector in J2000 into a vector in Satellite Attitude Frame, i.e. $x_{SATATT}=M_{J2000\to SATATT}\,x_{J2000}$

6.5 Rotation Angles

Note that in EO CFI (see [RD 01]) whenever a transformation is expressed as a sequence of rotations, the following expressions apply (the angle w is regarded positive):

$$R_X(w)=\begin{bmatrix}1&0&0\\0&\cos w&\sin w\\0&-\sin w&\cos w\end{bmatrix}\quad R_Y(w)=\begin{bmatrix}\cos w&0&-\sin w\\0&1&0\\\sin w&0&\cos w\end{bmatrix}\quad R_Z(w)=\begin{bmatrix}\cos w&\sin w&0\\-\sin w&\cos w&0\\0&0&1\end{bmatrix}$$

The Earth Observation CFI applies the following convention when using Euler angles roll-pitch-yaw to rotate one reference frame to another.
In the output attitude data file, two sets of roll, pitch, yaw angles are given:

- rotation from Satellite Orbital Frame to Satellite Attitude Frame
- rotation from Satellite Nominal Frame to Satellite Attitude Frame

In both cases the following definition applies (the notation for the case from Satellite Orbital Frame to Satellite Attitude Frame is used):

$$M_{SATORB\to SATATT}=R_Z(yaw)\cdot R_X(-pitch)\cdot R_Y(-roll)=$$

$$=\begin{bmatrix}\cos(y)\cdot\cos(r)+\sin(r)\cdot\sin(y)\cdot\sin(p) & \sin(y)\cdot\cos(p) & \cos(y)\cdot\sin(r)-\cos(r)\cdot\sin(y)\cdot\sin(p)\\ -\sin(y)\cdot\cos(r)+\sin(r)\cdot\sin(p)\cdot\cos(y) & \cos(y)\cdot\cos(p) & -\sin(y)\cdot\sin(r)-\sin(p)\cdot\cos(y)\cdot\cos(r)\\ -\sin(r)\cdot\cos(p) & \sin(p) & \cos(r)\cdot\cos(p)\end{bmatrix}$$

where $M_{SATORB\to SATATT}$ transforms a vector in Satellite Orbital Frame into a vector in Satellite Attitude Frame, i.e.
$x_{SATATT}=M_{SATORB\to SATATT}\,x_{SATORB}$

6.6 Earth Observation CFI Software Version

The executable tools have been generated using EO CFI v3.7.4.