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README - 4-Star Matching Algorithm

Guidance, Navigation and Controls Subsystem

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st_main_4SM_v2.m

Code Type: MATLAB - Script
Code author: KT Prajwal Prathiksh
Created on: 29/04/2020
Last modified: –/–/—-
Reviewed by: NOT YET REVIEWED!
Description:
This is the main script, which runs the 4-Star Matching Algorithm.
Note: This script can work with n-stars identified by *Feature Extraction block*
Formula & References:
Reference:
Dong, Ying Xing, Fei You, Zheng. (2006). *Brightness Independent 4-Star Matching Algorithm for Lost-in-Space 3-Axis Attitude Acquisition.* Tsinghua Science Technology. 11. 543-548. 10.1016/S1007-0214(06)70232-2.
Input parameters:

1. **st_constants_4SM.mat**: The contents of which are -
   (a) **Focal_Length** : (Float) The focal length of the optics system. Units in mm
   (b) **st_M_EPS** : (Float) The machine epsilon of the platform where the algorithm will be executed
   (c) **st_n_GC** : (Integer) The number of stars (= number of rows) in the Guide Star Catalogue
   (d) **st_n_RC** : (Integer) The number of star-pairs (= number of rows) in the Reference Star Catalogue
   (e) **st_DELTA** : (Float) The δ constant that determines the tolerance of the size window when searching for an angular distance value in the Reference Star Catalogue
   (f) **st_M** : (Float) The slope of the Z-vector line
   (g) **st_Q** : (Float) The y-intercept of the Z-vector line
   (h) **es_N_EST** : (Integer) The minimum number of pairs of body-frame (b_i and inertial-frame r_i vectors required by *Estimation block* to provide the attitude within the accuracy requirements

(i) **st_ITER_MAX_4SM** : (Integer) The max number of iterations of 4-Star Matching that will be allowed to execute irregardless of whether all the stars match or not - owing to the time constraint on the *Star-Matching block*

2. **st_input.mat**: The contents of which are -

   (a) **fe_output** : ((N, 3) - Matrix) - The output of Feature Extraction block - which contains the centroids of the identified stars as well ID of the identified star. The centroid is represented in (X, Y) format, with the origin at the center of the sensor. Unit of centroid: mm

   (b) **fe_n_str** : (Integer) - The number of stars identified by feature extraction

Output:

1. Writes the following output variables of Star-Matching in `./Star_Matching/4_Star_Matching/Output/st_output.mat` directory

   (a) **st_iter_total** : (Integer) - Counter variable which keeps track of the number of iterations of 4-Star Matching that has occurred

   (b) **st_Match** : ((st_N_Match, 5) - Matrix) - This matrix contains the entries of the stars that have been matched so far. The columns are as follows:

      i. 1^{st} column - Feature Extraction ID
      ii. $2^{nd}, 3^{rd}, 4^{th}$ columns - (X, Y, Z) unit body-frame vector
      iii. 5^{th} column - The matched SSP-ID

   (c) **st_N_Match** : (Integer) - Number of matched stars in st_Match matrix

   (d) **st_UnMatch** : ((st_N_UnMatch, 4) - Matrix) - This matrix contains the entries of the stars that are yet to be matched so far. The columns are as follows:

      i. 1^{st} column - Feature Extraction ID
      ii. $2^{nd}, 3^{rd}, 4^{th}$ columns - (X, Y, Z) unit body-frame vector

   (e) **st_N_UnMatch** : (Integer) - Number of stars yet to be matched in st_UnMatch matrix

   (f) **st_op_bi** : ((st_N_Match, 4) - Matrix) - The body-frame vectors b_i of the image stars that have been matched through Star-Matching. The columns include:

      i. 1^{st} column - Feature Extraction ID
      ii. $2^{nd}, 3^{rd}, 4^{th}$ columns - (X, Y, Z) unit body-frame vector

   (g) **st_op_ri** : ((st_N_Match, 4) - Matrix) - The corresponding inertial-frame vectors r_i of the matched stars obtained from the Guide Star Catalogue. The columns include:

      i. 1^{st} column - Corresponding SSP-ID of the matched star
      ii. $2^{nd}, 3^{rd}, 4^{th}$ columns - (X, Y, Z) unit inertial-frame vector

      NOTE:

      i. (N) in both cases should be equal!
      ii. The i^{th} body-frame and the i^{th} inertial-frame vector should correspond to the same star!

2. Writes the following output variables of Star-Matching as input for Estimation in `./Estimation/Input/es_input.mat` directory

   (a) **st_N_Match** : (Integer) - Number of matched stars in st_Match matrix

(b) **st_op_bi** : ((st_N_Match, 4) - Matrix) - The body-frame vectors b_i of the image stars that have been matched through Star-Matching. The columns include:

i. 1^{st} column - Feature Extraction ID

ii. $2^{nd}, 3^{rd}, 4^{th}$ columns - (X, Y, Z) unit body-frame vector

(c) **st_op_ri** : ((st_N_Match, 4) - Matrix) - The corresponding inertial-frame vectors r_i of the matched stars obtained from the Guide Star Catalogue. The columns include:

i. 1^{st} column - Corresponding SSP-ID of the matched star

ii. $2^{nd}, 3^{rd}, 4^{th}$ columns - (X, Y, Z) unit inertial-frame vector

NOTE:

i. (N) in both cases should be equal!

ii. The i^{th} body-frame and the i^{th} inertial-frame vector should correspond to the same star!

st_gnrt_bi.m

Code Type: MATLAB - Function
Code author: KT Prajwal Prathiksh
Created on: 26/04/2020
Last modified: 29/04/2020
Reviewed by: NOT YET REVIEWED!
Description:
This function generates the body-frame vectors of the stars from the centroids identified through means of Feature Extraction
Formula & References:
Reference:
Appendix B - Erlank, Alexander O.. *"Development of CubeStar : a CubeSat-compatible star tracker."* (2013).
Input parameters:

1. **fe_output** : ((N, 3) - Matrix) - The output of Feature Extraction block - which contains the centroids of the identified stars as well ID of the identified star. The centroid is represented in (X, Y) format, with the origin at the center of the sensor. Unit of centroid: mm
2. **fe_n_str** : (Integer) - The number of stars identified by feature extraction
3. **Focal_Length** : (Float) The focal length of the optics system. Units in *mm*

Output:

1. **st_bi** : ((N, 4) - Matrix) - Generates the body-frame vectors for all the stars identified by Feature Extraction using the centroids. The body-frame vectors are unit-vectors represented in (X, Y, Z) format, with the origin at the center of the sensor and positive z-axis pointing out of the lens. The columns of matrix are as follows:

   (a) 1^{st} column - Feature Extraction ID

   (b) $2^{nd}, 3^{rd}, 4^{th}$ columns - (X, Y, Z) unit body-frame vector

st_4SM.m

Code Type: MATLAB - Function
Code author: KT Prajwal Prathiksh
Created on: 29/04/2020
Last modified: –/–/—-
Reviewed by: NOT YET REVIEWED!
Description:
This function runs the 4-Star Matching Algorithm. It executes the algorithm to match stars, and returns the result.
Formula & References:
Reference:
Dong, Ying Xing, Fei You, Zheng. (2006). *Brightness Independent 4-Star Matching Algorithm for Lost-in-Space 3-Axis Attitude Acquisition.* Tsinghua Science Technology. 11. 543-548. 10.1016/S1007-0214(06)70232-2.
Input parameters:

1. **st_4SM_input** : ((4, 4) - Matrix) - The input to 4-Star Matching Algorithm - four stars identified by Feature Extraction, along with their body-frame vectors (a unit-vector represented in (X, Y, Z) format, with the origin at the center of the sensor and positive z-axis pointing out of the lens). The columns of the matrix are as follows:
   (a) 1^{st} column - Feature Extraction ID
   (b) $2^{nd}, 3^{rd}, 4^{th}$ columns - (X, Y, Z) unit body-frame vector
2. **st_RF_SC** : ((st_n_RC, 3) - Matrix) - The Reference Star Catalogue, which has the following columns:
   (a) **SSP_ID_1** - The SSP-ID of i^{th} star
   (b) **SSP_ID_2** - The SSP-ID of j^{th} star
   (c) **K_Vec** - The K-Vector value determined uniquely using the dot product of the Cartesian unit vector corresponding to the i^{th} and j^{th} star $(i \neq j, \forall\, i, j)$
3. **st_4SM_constants** : ((4, 1) - Matrix) - An array that contains the following constants:
   (a) **st_n_GC**
   (b) **st_M**
   (c) **st_Q**
   (d) **st_DELTA**

Output:

1. **st_n_match** : (Integer) - The number of stars that have been matched
2. **st_result** : ((4,2) - Matrix) - Output of 4-Star Matching. The columns of the matrix are as follows:
   (a) 1^{st} column - Feature Extraction ID
   (b) 2^{nd} column - The matched SSP-ID (*If no match was made* - 0 *is assigned*)

st_gnrt_ip_4SM.m

Code Type: MATLAB - Function
Code author: KT Prajwal Prathiksh
Created on: 26/04/2020
Last modified: 29/04/2020
Reviewed by: NOT YET REVIEWED!
Description:
This function generates the input for 4-Star Matching Algorithm, using the body-frame vectors of 4 identified stars from the image
Formula & References: –
Input parameters:

1. **st_4SM_input** : ((4, 4) - Matrix) - The input to 4-Star Matching Algorithm - four stars identified by Feature Extraction, along with their body-frame vectors (a unit-vector represented in (X, Y, Z) format, with the origin at the center of the sensor and positive z-axis pointing out of the lens). The columns of the matrix are as follows:
   (a) 1^{st} column - Feature Extraction ID
   (b) $2^{nd}, 3^{rd}, 4^{th}$ columns - (X, Y, Z) unit body-frame vector

Output:

1. **st_c_img_AngDst** : ((6,1) - Matrix) - Has the angular distances (in $\cos(\theta)$) between those of four stars in the following order:
   $(S_1, S_2); (S_1, S_3); (S_1, S_4); (S_2, S_3); (S_2, S_4); (S_3, S_4);$
   NOTE: THE ABOVE ORDER IS IMPORTANT, AND SHOULD BE FOLLOWED!
2. **st_c_fe_ID** : ((4,1) - Matrix) - Has the Feature Extraction IDs of stars that are used to generate st_c_img_AngDst, in the following order:
   $[S_1; S_2; S_3; S_4]$

st_gnrt_SIM.m

Code Type: MATLAB - Function
Code author: KT Prajwal Prathiksh
Created on: 26/04/2020
Last modified: 29/04/2020
Reviewed by: NOT YET REVIEWED!
Description:
This function generates the the Star Identification Matrix (SIM) from a given array of angular distances between those of four stars, using the Reference Star Catalogue and the Guide Star Catalogue
Formula & References: –
Input parameters:

1. **st_c_img_AngDst** : ((6,1) - Matrix) - Has the angular distances (in $\cos(\theta)$) between those of four stars in the following order:
   $(S_1, S_2); (S_1, S_3); (S_1, S_4); (S_2, S_3); (S_2, S_4); (S_3, S_4)$
   NOTE: THE ABOVE ORDER IS IMPORTANT, AND SHOULD BE FOLLOWED!

2. **st_RF_SC** : ((st_n_RC, 3) - Matrix) - The Reference catalogue, which has the following columns:
   (a) **SSP_ID_1** - The SSP-ID of i^{th} star
   (b) **SSP_ID_2** - The SSP-ID of j^{th} star
   (c) **K_Vec** - The K-Vector value determined uniquely using the dot product of the Cartesian unit vector corresponding to the i^{th} and j^{th} star $(i \neq j, \forall\, i, j)$
3. **st_4SM_constants** : ((4, 1) - Matrix) - An array that contains the following constants:
   (a) **st_n_GC**
   (b) **st_M**
   (c) **st_Q**
   (d) **st_DELTA**

Output:

1. **SIM** : ((st_n_GC, 6) - Matrix) - The Star Identification Matrix (SIM). The i^{th} row of the matrix corresponds to the i^{th} SSP-ID star. There are thus as many rows in SIM as there are in the Guide Star Catalogue = (st_n_GC). The j^{th} column corresponds to a boolean value. If an element SIM_{ij} is 1 $\implies$ S_j^{th} input star matched to the i^{th} star of the Guide Star Catalogue

st_gnrt_CSPA.m

Code Type: MATLAB - Function
Code author: KT Prajwal Prathiksh
Created on: 26/04/2020
Last modified: 29/04/2020
Reviewed by: NOT YET REVIEWED!
Description:
This function generates the candidate star pair array (CSPA) from the value of angular distance calculated between two image stars
Formula & References:
Reference:
Refer 2. '4-Star Matching Strategy' - Dong, Ying Xing, Fei You, Zheng. (2006). *Brightness Independent 4_Star Matching Algorithm for Lost-in-Space 3-Axis Attitude Acquisition.* Tsinghua Science Technology. 11. 543-548. 10.1016/S1007-0214(06)70232-2.
Input parameters:

1. **st_AngDst** : (Float) - The angular distance calculated between two stars (in $\cos(\theta)$)
2. **st_DELTA** : (Float) The δ constant that determines the tolerance of the size window when searching for an angular distance value in the Reference Star Catalogue
3. **st_M** : (Float) The slope of the Z-vector line
4. **st_Q** : (Float) The y-intercept of the Z-vector line
5. **st_RF_SC** : ((st_n_RC, 3) - Matrix) - The Reference Star Catalogue, which has the following columns:

(a) **SSP_ID_1** - The SSP-ID of i^{th} star

(b) **SSP_ID_2** - The SSP-ID of j^{th} star

(c) **K_Vec** - The K-Vector value determined uniquely using the dot product of the Cartesian unit vector corresponding to the i^{th} and j^{th} star $(i \neq j, \forall\, i, j)$

Output:

1. **st_CSPA** : ((X,1) - Matrix) - The possible SSP-ID matches for given angular distance
2. **st_INDEX** : ((1,2) - Matrix) - The start and stop indices of possible matches generated for given angular distance

st_gnrt_SMM.m

Code Type: MATLAB - Function
Code author: KT Prajwal Prathiksh
Created on: 26/04/2020
Last modified: 29/04/2020
Reviewed by: NOT YET REVIEWED!
Description:
This function evaluates the Star Identification Matrix to identify the stars that have been matched through the 4-Star Matching Algorithm to generate the Star Matched Matrix (SMM).
Of the four stars that are provided as input to the 4-Star Matching Algorithm, the S_i star is said to have been matched, if only one such row of the Star Identification Matrix as given below is present:

1. $S_1 - [1, 1, 1, 0, 0, 0]$
2. $S_2 - [1, 0, 0, 1, 1, 0]$
3. $S_3 - [0, 1, 0, 1, 0, 1]$
4. $S_4 - [0, 0, 1, 0, 1, 1]$

This pattern arises out of the fact that angular distances that are provided as input follow the order: $(S_1, S_2); (S_1, S_3); (S_1, S_4); (S_2, S_3); (S_2, S_4); (S_3, S_4)$
Formula & References:
Reference:
Refer 2. '4-Star Matching Strategy' - Dong, Ying Xing, Fei You, Zheng. (2006). *Brightness Independent 4_Star Matching Algorithm for Lost-in-Space 3-Axis Attitude Acquisition.* Tsinghua Science Technology. 11. 543-548. 10.1016/S1007-0214(06)70232-2.
Input parameters:

1. **st_SIM** : ((st_n_GC, 6) - Matrix) - The Star Identification Matrix (SIM)
2. **st_n_GC** : (Integer) The number of stars (= number of rows) in the Guide Star Catalogue
3. **st_c_fe_ID** : ((4,1) - Matrix) - Has the Feature Extraction IDs of stars that are used to generate st_c_img_AngDst, in the following order:

   $[S_1; S_2; S_3; S_4]$

Output:

1. **st_SMM** : ((4,3) - Matrix) - The Star Matched Matrix. The columns of the matrix are as follows:
   (a) 1^{st} column - Feature Extraction ID
   (b) 2^{nd} column - The matched SSP-ID (*If no match was made* - 0 *is assigned*)
   (c) 3^{rd} column - The number of rows in SIM that matched the condition of S_i star
2. **st_mtch_rows** : ((4, X) - Cell Array) - The columns of the cell array are as follows:
   (a) 1^{st} column - Feature Extraction ID
   (b) 2^{nd} column - i^{th} element consists of a (X,1) - Matrix, that stores the SSP-IDs that matched the i^{th} condition

st_update_match_matrix.m

Code Type: MATLAB - Function
Code author: KT Prajwal Prathiksh
Created on: 29/04/2020
Last modified: –/–/—-
Reviewed by: NOT YET REVIEWED!
Description:
This function updates the Match Matrices associated with 4-Star Matching Algorithm
Formula & References: –
Input parameters:

1. **st_result** : ((4,2) - Matrix) - Output of 4-Star Matching. The columns of the matrix are as follows:
   (a) 1^{st} column - Feature Extraction ID
   (b) 2^{nd} column - The matched SSP-ID (*If no match was made* - 0 *is assigned*)
2. **st_Match** : ((st_N_Match, 5) - Matrix) - This matrix contains the entries of the stars that have been matched so far. The columns are as follows:
   (a) 1^{st} column - Feature Extraction ID
   (b) $2^{nd}, 3^{rd}, 4^{th}$ columns - (X, Y, Z) unit body-frame vector
   (c) 5^{th} column - The matched SSP-ID
3. **st_UnMatch** : ((st_N_UnMatch, 4) - Matrix) - This matrix contains the entries of the stars that are yet to be matched so far. The columns are as follows:
   (a) 1^{st} column - Feature Extraction ID
   (b) $2^{nd}, 3^{rd}, 4^{th}$ columns - (X, Y, Z) unit body-frame vector
4. **st_N_Match** : (Integer) - Number of matched stars in st_Match matrix
5. **st_N_UnMatch** : (Integer) - Number of stars yet to be matched in st_UnMatch matrix

Output:

st_check_ID_err.m

Code Type: MATLAB - Function
Code author: KT Prajwal Prathiksh
Created on: 29/04/2020
Last modified: –/–/—-
Reviewed by: NOT YET REVIEWED!
Description:
This function evaluates the result of Star-Matching with one of the input stars having already been matched, and checks for discrepancy error (if any) in the previously matched SSP-ID, and newly generated SSP-ID
Formula & References: –
Input parameters:

1. **st_result** : ((4,2) - Matrix) - Output of 4-Star Matching. The columns of the matrix are as follows:
   (a) 1^{st} column - Feature Extraction ID
   (b) 2^{nd} column - The matched SSP-ID (*If no match was made* - 0 *is assigned*)
2. **st_ref_ID** : ((4,2) - Matrix) - This matrix is stores the previously matched SSP-IDs of the stars taken from st_Match matrix. This is used to check if the newly matched SSP-ID is the same as the previous SSP-ID. The columns of this matrix are as follows:
   (a) 1^{st} column - Feature Extraction ID
   (b) 2^{nd} column - The previously matched SSP-ID (The unmatched stars have 0 as their ID)
3. **st_N** : (Integer) - Number of previously matched stars used as input

Output:

1. **st_flag_ID_err** : (boolean) - Returns 1 if the previous and the new SSP-ID do not match, or if the previously matched star was not matched in st_result. Returns 0 only if they match!

st_gnrt_op_4SM_v2.m

Code Type: MATLAB - Function
Code author: KT Prajwal Prathiksh
Created on: 26/04/2020
Last modified: 29/04/2020
Reviewed by: NOT YET REVIEWED!
Description:
This function evaluates the Star Matched Matrix (SMM), to generate the output in the format required by Estimation - Body-frame vectors, and Inertial-frame vectors of the matched stars
Formula & References: –
Input parameters:

1. **st_Match** : ((st_N_Match, 5) - Matrix) - This matrix contains the entries of the stars that have been matched so far. The columns are as follows:
   (a) 1^{st} column - Feature Extraction ID

(b) $2^{nd}, 3^{rd}, 4^{th}$ columns - (X, Y, Z) unit body-frame vector

(c) 5^{th} column - The matched SSP-ID

2. **st_GD_SC** : ((st_n_GC, 4) - Matrix) - The Guide Star Catalogue, which has the following columns:

   (a) **SSP_ID** - The SSP-ID of Guide Stars

   (b) **X** - X component of the unit vector, corresponding to the star

   (c) **Y**- Y component of the unit vector, corresponding to the star

   (d) **Z**- Z component of the unit vector, corresponding to the star

Output:

1. **st_op_bi** : ((st_N_Match, 4) - Matrix) - The body-frame vectors b_i of the image stars that have been matched through Star-Matching. The columns include:

   (a) 1^{st} column - Feature Extraction ID

   (b) $2^{nd}, 3^{rd}, 4^{th}$ columns - (X, Y, Z) unit body-frame vector

2. **st_op_ri** : ((st_N_Match, 4) - Matrix) - The corresponding inertial-frame vectors r_i of the matched stars obtained from the Guide Star Catalogue. The columns include:

   (a) 1^{st} column - Corresponding SSP-ID of the matched star

   (b) $2^{nd}, 3^{rd}, 4^{th}$ columns - (X, Y, Z) unit inertial-frame vector

st_pseudo_input.m

Code Type: MATLAB - Script
Code author: KT Prajwal Prathiksh
Created on: 26/04/2020
Last modified: 29/04/2020
Reviewed by: NOT YET REVIEWED!
Description:
This script generates fictitious input, that resembles the output expected out of Feature Extraction.
NOTE: The values are random, and therefore should not be treated as test-cases
Formula & References: –
Input parameters:

1. **fe_n_str** : (Integer) - The number of stars identified by feature extraction

Output:

1. Writes the following output variable in `./Star_Matching/4_Star_Matching/Input/st_input.mat` directory:

   (a) **st_input.mat**: The contents of which are -

      i. **fe_output** : ((N, 3) - Matrix) - The output of Feature Extraction block - which contains the centroids of the identified stars as well ID of the identified star. The centroid is represented in (X, Y) format, with the origin at the center of the sensor. Unit of centroid: mm

      ii. **fe_n_str** : (Integer) - The number of stars identified by feature extraction

st_main_4SM.m

Code Type: MATLAB - Script
Code author: KT Prajwal Prathiksh
Created on: 26/04/2020
Last modified: –/–/—-
Reviewed by: **NOT YET REVIEWED!**
Description:
This is the main script, which runs the 4-Star Matching Algorithm.
Note: This script can only work with 4-stars identified by *Feature Extraction block*
Formula & References:
Reference:
Dong, Ying Xing, Fei You, Zheng. (2006). *Brightness Independent 4-Star Matching Algorithm for Lost-in-Space 3-Axis Attitude Acquisition.* Tsinghua Science Technology. 11. 543-548. 10.1016/S1007-0214(06)70232-2.
Input parameters:

1. **st_constants_4SM.mat**: The contents of which are -
   (a) **Focal_Length** : (Float) The focal length of the optics system. Units in mm
   (b) **st_M_EPS** : (Float) The machine epsilon of the platform where the algorithm will be executed
   (c) **st_n_GC** : (Integer) The number of stars (= number of rows) in the Guide Star Catalogue
   (d) **st_n_RC** : (Integer) The number of star-pairs (= number of rows) in the Reference Star Catalogue
   (e) **st_DELTA** : (Float) The δ constant that determines the tolerance of the size window when searching for an angular distance value in the Reference Star Catalogue
   (f) **st_M** : (Float) The slope of the Z-vector line
   (g) **st_Q** : (Float) The y-intercept of the Z-vector line
   (h) **es_N_EST** : (Integer) The minimum number of pairs of body-frame (b_i and inertial-frame r_i vectors required by *Estimation block* to provide the attitude within the accuracy requirements
   (i) **st_ITER_MAX_4SM** : (Integer) The max number of iterations of 4-Star Matching that will be allowed to execute irregardless of whether all the stars match or not - owing to the time constraint on the *Star-Matching block*
2. **st_input.mat**: The contents of which are -
   (a) **fe_output** : ((N, 3) - Matrix) - The output of Feature Extraction block - which contains the centroids of the identified stars as well ID of the identified star. The centroid is represented in (X, Y) format, with the origin at the center of the sensor. Unit of centroid: mm
   (b) **fe_n_str** : (Integer) - The number of stars identified by feature extraction

Output:

1. Writes the following output variables of Star-Matching in `./Star_Matching/4_Star_Matching/Output/st_output.mat` directory

(a) **n_st_strs** : (Integer) - The number of stars matched by Star Matching

(b) **st_mtch_rows** : ((4, X) - Cell Array) - i^{th} element consists of a (X,1) - Matrix, that stores the SSP-IDs of the rows that match the i^{th} condition

(c) **st_op_bi** : ((N, 3) - Matrix) - The body-frame vectors - (X, Y, Z), of the matched stars

(d) **st_op_ri** : ((N, 3) - Matrix) - The inertial-frame vectors - (X, Y, Z), of the corresponding matched stars

(e) **st_SIM** : ((st_n_GC, 6) - Matrix) - The Star Identification Matrix (SIM). The i^{th} row of the matrix corresponds to the i^{th} SSP-ID star. There are thus as many rows in SIM as there are in the Guide Star Catalogue = (st_n_GC). The j^{th} column corresponds to a boolean value. If an element SIM_{ij} is 1 $\implies$ S_j^{th} input star matched to the i^{th} star of the Guide Star Catalogue

(f) **st_SMM** : ((4,3) - Matrix) - The Star Matched Matrix. The first column consists of the Feature Extraction IDs of the stars, the second column consists of matched SSP-ID (if there is no match: 0 is updated), and the third column consists of the number of rows in SIM that matched the condition of S_i^{th} star

2. Writes the following output variables of Star-Matching as input for Estimation in `./Estimation/Input/es_input.mat` directory

(a) **n_st_strs** : (Integer) - The number of stars matched by Star Matching

(b) **st_op_bi** : ((N, 3) - Matrix) - The body-frame vectors - (X, Y, Z), of the matched stars

(c) **st_op_ri** : ((N, 3) - Matrix) - The inertial-frame vectors - (X, Y, Z), of the corresponding matched stars