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README - 4-Star Matching Algorithm

Guidance, Navigation and Controls Subsystem

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st_main_4_str_mtch.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.
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_4_str_mtch.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) **n_rw_GC** : (Integer) The number of stars (= number of rows) in the Guide Star Catalogue
   (d) **n_rw_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
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) **n_fe_strs** : (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** : ((n_rw_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 = (n_rw_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

st_gnrt_bi.m

Code Type: MATLAB - Function
Code author: KT Prajwal Prathiksh
Created on: 26/04/2020
Last modified: –/–/—-
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. **n_fe_strs** : (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) - The body-frame vector of each corresponding star. It is 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 first column corresponds to the index of the star as denoted in fe_output

st_gnrt_ip_4_str_mtch.m

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

1. **st_bi** : ((N, 4) - Matrix) - The body-frame vector of each corresponding star. It is 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 first column corresponds to the index of the star as denoted in fe_output

2. **n_fe_strs** : (Integer) - The number of stars identified by feature extraction. **NOTE:** (n_fe_strs) ≥ 4 !

Output:

1. **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. **c_fe_IDs** : ((4,1) - Matrix) - Has the Feature Extraction IDs of stars that are used to generate 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: –/–/—-

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. **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** : ((N, 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. **n_rw_GC** : (Integer) The number of stars (= number of rows) in the Guide Star Catalogue
4. **st_M** : (Float) The slope of the Z-vector line
5. **st_Q** : (Float) The y-intercept of the Z-vector line
6. **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

Output:

1. **SIM** : ((n_rw_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 = (n_rw_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: –/–/—-
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. **str_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** : ((n_rw_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. **CSPA** : ((X,1) - Matrix) - The possible SSP-ID matches for given angular distance
2. **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: –/–/—-
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)
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** : ((n_rw_GC, 6) - Matrix) - The Star Identification Matrix (SIM)
2. **n_rw_GC** : (Integer) The number of stars (= number of rows) in the Guide Star Catalogue
3. **c_fe_IDs** : ((4,1) - Matrix) - Has the Feature Extraction IDs of stars that are used to generate c_img_AngDst, in the following order: $[S_1; S_2; S_3; S_4]$

Output:

1. **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. **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

st_gnrt_op_4_str_mtch.m

Code Type: MATLAB - Function
Code author: KT Prajwal Prathiksh
Created on: 26/04/2020
Last modified: –/–/—-
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_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. **st_bi** : ((N, 4) - Matrix) - The body-frame vector of each corresponding star. It is 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 first column corresponds to the index of the star as denoted in fe_output
3. **st_GD_SC** : ((n_rw_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** : ((N, 3) - Matrix) - The body-frame vectors - (X, Y, Z), of the matched stars
2. **st_op_ri** : ((N, 3) - Matrix) - The inertial-frame vectors - (X, Y, Z), of the corresponding matched stars
3. **n_st_strs** : (Integer) - The number of stars matched by Star Matching

st_pseudo_input.m

Code Type: MATLAB - Script
Code author: KT Prajwal Prathiksh
Created on: 26/04/2020
Last modified: –/–/—-
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. **n_fe_strs** : (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. **n_fe_strs** : (Integer) - The number of stars identified by feature extraction