

Module Interface Specification for Image Feature Correspondences for Camera Calibration

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April 16, 2025

1 Revision History

| Date | Version | Notes |
|------------|---------|-----------------|
| 2025-03-21 | 1.0 | Initial Release |
| 2025-04-16 | 2.0 | Final Release |

2 Symbols, Abbreviations and Acronyms

See SRS Documentation at <https://github.com/KiranSingh15/CAS-741-Image-Correspondences/blob/main/docs/SRS/SRS.pdf>. Additional symbols and abbreviations are outlined in below.

| symbol | type | description |
|-----------------------------|---------------------------|--|
| b | \mathbb{N} | bin size |
| bf_matcher_object | - | Instance of a Brute Force Matcher object as BFMatcher Class |
| colour | \mathbb{N}^3 | 2D array of RGB values to assign red, green, and blue pixels |
| crosscheck flag | \mathbb{B} | flag used to assign how features are compared and matched |
| descriptors, fd1, fd2 | \mathbb{N} | Feature Descriptors as OpenCV Feature2D Class |
| head_dir | str | A str that indicates the local directory of the IFC program within the file path system |
| image_IDs | str | List of strings that contains all IDs of saved images |
| img, img_in, img_out | $\mathbb{N}^{h \times w}$ | Instance of an image object with height h and width w in pixels |
| img_obj_1, img_obj_2 | $\mathbb{N}^{h \times w}$ | Instances of image objects with height h and width w in pixels |
| <i>img_idx_1, img_idx_1</i> | \mathbb{N} | Indices of image names within the list image_IDs |
| img_kp | $\mathbb{N}^{h \times w}$ | Instance of an image with displayed keypoints |
| img_fd | $\mathbb{N}^{h \times w}$ | Instance of an image with size keypoints to account for feature descriptors |
| img_fm | $\mathbb{N}^{h \times w}$ | Instance of two combined images with corresponding matches between keypoints |
| k | \mathbb{N} | kernel size |
| keypoints, kp1, kp2 | - | Keypoints as OpenCV Keypoint Class |
| matches | - | instance of matched features as OpenCV DMatch Class |
| mthd_img_smoothing | \mathbb{N} | method employed to perform image smoothing, where values range from 1 to n methods. |
| mthd_kp_detection | \mathbb{N} | method employed to perform keypoint detection, where values range from 1 to n methods. |
| mthd_kp_description | \mathbb{N} | method employed to identify feature descriptors, where values range from 1 to n methods. |
| mthd_ft_match | \mathbb{N} | method employed to perform feature matching, where values range from 1 to n methods. |
| norm_method | \mathbb{N} | method used to determine the norm between two features per OpenCV NORM HAMMING |
| num_images | \mathbb{N} | number of images to be processed |
| orb_object | - | instance of an OpenCV ORB Class |

| | | |
|------------------|--------------|---|
| p | N | patch size |
| path_keypoints | str | Relative path to save keypoint data and imagery |
| path_descriptors | str | Relative path to save feature descriptor data and imagery |
| path_matches | str | Relative path to save feature match data and imagery |
| query_img_id | str | name of the query image |
| σ | \mathbb{R} | standard deviation of the Gaussian kernel |
| sel_read_path | str | user-defined read path to import imagery data |
| sel_save_path | str | user-defined read path to export imagery data |
| sorted_matches | - | instance of matched features as OpenCV DMatch Class |
| t | N | FAST Intensity Threshold |
| train_img_id | str | name of the training image |

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3 Introduction

The following document details the Module Interface Specifications for the Image Feature Correspondence Software. The software identifies regions with similar features and pixel intensities amongst images, and returns a set of correspondences between these images to support downstream perception for applications in robotics.

Complementary documents include the System Requirement Specifications and Module Guide. The full documentation and implementation can be found at <https://github.com/KiranSingh15/CAS-741-Image-Correspondences>.

4 Notation

The structure of the MIS for modules comes from [Hoffman and Strooper \(1995\)](#), with the addition that template modules have been adapted from [Ghezzi et al. \(2003\)](#). The mathematical notation comes from Chapter 3 of [Hoffman and Strooper \(1995\)](#). For instance, the symbol $:=$ is used for a multiple assignment statement and conditional rules follow the form $(c_1 \Rightarrow r_1 | c_2 \Rightarrow r_2 | \dots | c_n \Rightarrow r_n)$.

The following table summarizes the primitive data types used by the Image Feature Correspondences for Camera Calibration software.

| Data Type | Notation | Description |
|----------------|--------------|---|
| character | char | a single symbol or digit |
| string | str | a sequence of characters |
| boolean | \mathbb{B} | a boolean in $\{0,1\}$ |
| integer | \mathbb{Z} | a number without a fractional component in $(-\infty, \infty)$ |
| natural number | \mathbb{N} | a number without a fractional component in $[0, \infty)$ |
| real | \mathbb{R} | any number in $(-\infty, \infty)$ |

The specification of Image Feature Correspondences for Camera Calibration uses some derived data types: sequences, strings, and tuples. Sequences are lists filled with elements of the same data type. Strings are sequences of characters. Tuples contain a list of values, potentially of different types. In addition, Image Feature Correspondences for Camera Calibration uses functions, which are defined by the data types of their inputs and outputs. Local functions are described by giving their type signature followed by their specification. Examples of common class definitions in OpenCV follow.

- brute force matcher objects as [BFMatcher Class](#)
- feature descriptor objects as [OpenCV DMatch Class](#)

- image keypoints objects as [OpenCV ORB Class](#)
- match objects as [OpenCV DMatch Class](#)
- ORB objects as [OpenCV ORB Class](#)
- OpenCV Norm objects as [OpenCV NORM HAMMING](#)

5 Module Decomposition

The following table is taken directly from the Module Guide document for this project.

| Level 1 | Level 2 |
|-------------------|---------------------------------|
| Hardware-Hiding | |
| | Control Module |
| | Input Format Module |
| | Specification Parameters Module |
| | Output Format Module |
| Behaviour-Hiding | Output Verification Module |
| | Image Smoothing Module |
| | Keypoint Detection Module |
| | Feature Descriptor Module |
| | Feature Matching Module |
| | Image Plot Module |
| Software Decision | OpenCV Library |

Table 2: Module Hierarchy

6 MIS of Control Module

6.1 Module

main

6.2 Uses

- config (Section 7)
- formatOutput (Section 9)
- verifyOutput (Section 10)
- detectKeypoints (Section 12)
- assignDescriptors (Section 13)
- matchFeatures (Section 14)
- plotImage (Section 15)

6.3 Syntax

6.3.1 Exported Constants

6.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|------|----|-----|------------|
| main | - | - | - |

6.4 Semantics

6.4.1 State Variables

- k : \mathbb{N}
- σ : \mathbb{R}
- t : \mathbb{N}
- b : \mathbb{N}
- p : \mathbb{N}
- $\text{mthd_img_smoothing}$: \mathbb{N}
- mthd_kp_detection : \mathbb{N}

- mthd_kp_description: \mathbb{N}
- mthd_ft_match: \mathbb{N}
- img_obj_1, img_obj_2: $\mathbb{N}^{h \times w}$
- img_kp, img_fd, img_fm: $\mathbb{N}^{h \times w}$
- orb_object: [OpenCV ORB Class](#)
- brute_force_obj: [BFMatcher Class](#)
- kp1, kp2: [OpenCV Keypoint Class](#)
- fd1, fd2: [OpenCV Feature2D Class](#)
- matches: [OpenCV DMatch Class](#)
- image_IDs: str^n
- head_dir as str
- path_input_img as str
- path_keypoints as str
- path_descriptors as str
- path_feature_matches as str

6.4.2 Environment Variables

none

6.4.3 Assumptions

none

6.4.4 Access Routine Semantics

main():

- transition: Modify the state of the Specification Parameters Module and the environment variables for the Image Plot Module and Output Format Module as follows:

```

[head_dir as str] = config.get_head_directory()
plotImage.set_parent_directory(head_dir)

[mthd_img_smoothing, mthd_kp_detection, mthd_kp_descriptors, mthd_ft_matching] = config.get_active_methods()

[k,  $\sigma$ , t, b, p] = config.get_chosen_parameters()

config.check_parameter_limits(k, b, p, t,  $\sigma$ )

[image_IDs, num_images] = config.get_img_IDs(head_dir)

## For images img1 and img2 in image_IDs, where img1  $\neq$  img2 and img1 < img2
# Smooth the image as a preprocessing step to keypoint detection
img_obj_1 = smoothImage.smooth_image(img_obj_1, k,  $\sigma$ )

# Identify the keypoints. Note that if the methods for keypoint detection and descriptors
are both == 1, then ORB is the selected method, and the keypoint and descriptor modules
should use the same ORB object, which likely will come from the OpenCV library

orb_object = detectKeypoints.initialize_orb(mthd_kp_detection, t, b, p)
brute_force_object = matchFeatures.create_BF_matcher(mthd_ft_match, 6, TRUE) where 6
is the enumerated value of the Hamming Norm
kp1 = detectKeypoints.detect_keypoints(orb_object, img_1)
kp2 = detectKeypoints.detect_keypoints(orb_object, img_2)

# export keypoints to csv
formatOutput.output_keypoints(img_IDs(img_idx_1), head_dir, kp1), where the image index
corresponds to the selected keypoints
formatOutput.output_keypoints(img_IDs(img_idx_2), head_dir, kp2)

# Assign descriptors to keypoints
fd1 = assignDescriptors.compute_descriptors(img_1, kp1)
fd2 = assignDescriptors.compute_descriptors(img_2, kp2)

# export descriptors to csv
formatOutput.output_features(img_IDs(img_idx_1), head_dir, fd1), where the image index
corresponds to the selected descriptors
formatOutput.output_features(img_IDs(img_idx_2), head_dir, fd1)

# generate and save image with keypoints
img_kp = plotImage.gen_kp_img(img_IDs(img_idx_1), kp1, 0)

```

```

plotImage.save_image(img_kp, ""kpDetection", img_IDs(img_idx_1))

# generate and save image with scaled keypoints
img_kp = plotImage.gen_kp_img(img_IDs(img_idx_2), kp2, 0)
plotImage.save_image(img_kp, ""kpDetection", img_IDs(img_idx_2))

# generate and save image with scaled keypoints
img_fd = plotImage.gen_kp_img(img_IDs(img_idx_1), kp1, 4), where flag = 4 represents a
flag to draw rich keypoints
plotImage.save_image(img_kp, "fDescriptors", img_IDs(img_idx_1))

img_fd = plotImage.gen_kp_img(img_IDs(img_idx_2), kp2, 4)
plotImage.save_image(img_kp, "fDescriptors", img_IDs(img_idx_2))

##

# Compare features between differing images
matches = matchFeatures.match_features(brute_force_obj, fd1, fd2)
matches = matchFeatures.sort_matches(brute_force_obj, matches)

# verify that the match structure conforms to the conditions in the Output Verification
Module
verifyOutput.check_match_uniqueness(img_IDs(img_idx_1), img_IDs(img_idx_2), matches)

# export matches to csv
formatOutput.output_matches(img_IDs(img_idx_1), img_IDs(img_idx_2), head_dir, matches)

# generate and save images with corresponding matches
img_fm = plotImage.gen_matched_features(img_obj_1, kp1, img_obj_2, kp2, matches, 200,
2), where 200 of the best matches are shown, and the flag of 2 indicates that unmatched
keypoints will not be displayed.
plotImage.save_image(img_fm, "fMatches", img_IDs(img_idx_1) + img_IDs(img_idx_2))

```

7 MIS of Input Format Module

This module addresses the functional requirements as follows.

- R1
- R2
- R3
- R4

7.1 Module

config

7.2 Uses

- specParams (Section [8](#))

7.3 Syntax

7.3.1 Exported Constants

7.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|------------------------|---|---|-------------------------|
| get_head_directory | - | head_dir as string | noHeadFound |
| get_active_methods | - | mthd_img_smoothing: \mathbb{N} , mthd_kp_detection: \mathbb{N} , mthd_kp_description: \mathbb{N} , mthd_ft_match: \mathbb{N} | - |
| get_chosen_parameters | - | k: \mathbb{N} , b: \mathbb{N} , p: \mathbb{N} , t: \mathbb{N} , σ : \mathbb{R} | - |
| set_input_img_path | head_dir as str | img_dir as str, local_folder as str | - |
| get_img_IDs | head_dir as str | img_IDs as str^n | - |
| check_parameter_limits | k: \mathbb{N} , b: \mathbb{N} , p: \mathbb{N} , t: \mathbb{N} , σ \mathbb{R} | - | invalid_parameters |
| check_method_limits | mthd_img_smoothing: \mathbb{N} , mthd_kp_detection: \mathbb{N} , mthd_kp_description: \mathbb{N} , mthd_ft_match: \mathbb{N} , method_count: \mathbb{N}^4 | - | invalid_method_selected |
| verify_imported_image | img $\in \mathbb{N}^{h \times w}$, img_path as str, img_id as str | - | ReadImageError |

7.4 Semantics

7.4.1 State Variables

- head_dir as str
- local_folder as str
- img_dir as str

- $k: \mathbb{N}$
- $\sigma: \mathbb{R}$
- $t: \mathbb{N}$
- $b: \mathbb{N}$
- $p: \mathbb{N}$
- `mthd_img_smoothing`: \mathbb{N}
- `mthd_kp_detection`: \mathbb{N}
- `mthd_kp_description`: \mathbb{N}
- `mthd_ft_match`: \mathbb{N}
- `method_count`: \mathbb{N}^4

7.4.2 Environment Variables

7.4.3 Assumptions

none

7.4.4 Access Routine Semantics

`get_head_directory()`:

- output: `head_dir = Path(os.getcwd())` where `head_dir` defined as a member of the [Python Path Class](#), and `os.getcwd()` is defined as a method of the [Python OS class](#).
- exception `exc:= noHeadFound` if path is not returned

`get_active_methods()`:

`[mthd_img_smoothing, mthd_kp_detection, mthd_kp_description, mthd_ft_match]`
`= specParams.get_assigned_methods()`

- output: `out := [mthd_img_smoothing, mthd_kp_detection, mthd_kp_description, mthd_ft_match]`
- exception `exc:= none`

`get_chosen_parameters()`:

`[k, σ , t, b, p] = specParams.get_assigned_parameters()`

- output: `out:= [k, b, p, t, σ]`
- exception `exc:= none`

set_input_img_path(head_dir):

- transition: tran:= local_folder = “Raw_Images”
- transition: tran:= img_dir = head_dir + local_folder
- output: out:= none
- exception exc:= none

get_img_IDs(head_dir):

```
img_path = Path(head_dir + "Raw_Images")
img_dir = Path(img_path)
image_IDs = [(file.stem, file.suffix, file.name) for file in img_dir.iterdir() if file.is_file()]
num_images = len(input_img)
```

- output: out:= image_IDs $\in str^n$, num_images $\in \mathbb{N}$
- exception: none

check_parameter_limits(k, b, p, t, σ):

- output: out:= none
- exception: exc:=invalid_parameters

| | |
|----------------------------|----------------------------------|
| $\neg(k < 1)$ | \Rightarrow “badKernelSize” |
| $\neg(k > 15)$ | \Rightarrow “badKernelSize” |
| $\neg(k \% 2 \neq 0)$ | \Rightarrow “badKernelSize” |
| $\neg(0 < \sigma < 10)$ | \Rightarrow “badStdDeviation” |
| $\neg(2 \leq t \leq 255)$ | \Rightarrow “badFASTThreshold” |
| $\neg(1 \leq b \leq 2048)$ | \Rightarrow “badBinSize” |
| $\neg(5 \leq p \leq 100)$ | \Rightarrow “badPatchSize” |

check_method_limits(mthd_img_smoothing, mthd_kp_detection, mthd_kp_description, mthd_ft_match, method_count):

- output: out:= none
- exception: exc:=invalid_method_selected

| | |
|---|--|
| $\neg(\text{mthd_img_smoothing} < 0)$ | \Rightarrow “invalidSmoothingMethod” |
| $\neg(\text{mthd_img_smoothing} > \text{method_count}[0])$ | \Rightarrow “invalidSmoothingMethod” |

| | |
|--|--|
| $\neg (\text{mthd_img_smoothing} < 0)$ | \Rightarrow “invalidKPDetectionMethod” |
| $\neg (\text{mthd_img_smoothing} > \text{method_count}[1])$ | \Rightarrow “invalidKPDetectionMethod” |
| $\neg (\text{mthd_img_smoothing} < 0)$ | \Rightarrow “invalidDescriptionMethod” |
| $\neg (\text{mthd_img_smoothing} > \text{method_count}[2])$ | \Rightarrow “invalidDescriptionMethod” |
| $\neg (\text{mthd_img_smoothing} < 0)$ | \Rightarrow “invalidMatchingMethod” |
| $\neg (\text{mthd_img_smoothing} > \text{method_count}[3])$ | \Rightarrow “invalidMatchingMethod” |

`verify_imported_image((img, img_path, img_id)):`

- output: none
- exception: `exc:= “ReadImageError”` if `img` is of type ‘None’

8 MIS of Specification Parameters Module

This module addresses the functional requirements as follows.

- R1

8.1 Module

specParams (Section 7)

8.2 Uses

None.

8.3 Syntax

8.3.1 Exported Constants

none

8.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|-------------------------|----|---|------------|
| get_available_methods | - | method_count: \mathbb{N}^4 | - |
| get_assigned_parameters | - | k: \mathbb{N} σ : \mathbb{R} t: \mathbb{Z} b: \mathbb{Z} p: \mathbb{Z} | - |
| get_assigned_methods | - | mthd_img_smoothing: \mathbb{N} mthd_kp_detection: \mathbb{N} mthd_kp_description: \mathbb{N} mthd_ft_match: \mathbb{N} | - |

8.4 Semantics

8.4.1 State Variables

- head_dir as str
- k: \mathbb{N}
- σ : \mathbb{R}

- $t: \mathbb{N}$
- $b: \mathbb{N}$
- $p: \mathbb{N}$
- $\text{mthd_img_smoothing}: \mathbb{N}$
- $\text{mthd_kp_detection}: \mathbb{N}$
- $\text{mthd_kp_description}: \mathbb{N}$
- $\text{mthd_ft_match}: \mathbb{N}$
- $\text{method_count}: \mathbb{N}^4$
- $\text{mthds_avail_is}: \text{str}^{(n1)}$, as a list of strings where $n1$ is defined at runtime
- $\text{mthds_avail_kpd}: \text{str}^{(n2)}$, as a list of strings where $n2$ is defined at runtime
- $\text{mthds_avail_fd}: \text{str}^{(n3)}$, as a list of strings where $n3$ is defined at runtime
- $\text{mthds_avail_ftm}: \text{str}^{(n4)}$, where $n4$ is defined at runtime

8.4.2 Environment Variables

none

8.4.3 Assumptions

none

8.4.4 Access Routine Semantics

`get_available_methods():`

```
# image manipulation
mthds_is = ["Gaussian Kernel"] # methods of image smoothing
mthds_kpd = ["FAST", "Harris"] # methods of keypoint detection
mthds_fd = ["Binary Descriptors"] # methods of assigning feature descriptors

# image comparison
mthds_ftm = [ "Hamming Distance - Brute Force", "Hamming Distance - FLANN", ]

method_count = [len(mthds_is), len(mthds_kpd), len(mthds_fd), len(mthds_ftm)]

• output: out:= method_count
```

- exception: none

get_assigned_parameters():

Note that these parameters may be updated by the user with the Specification Parameters Module itself.

$k := 5$

$\sigma := 1$

$t := 15$

$b := 2000$

$p := 31$

- output: out:= [k, σ t, b, p]

- exception: none

get_assigned_methods():

Note that these methods may be updated by the user with the Specification Parameters Module itself.

mthd_img_smoothing:= 1

mthd_kp_detection:= 1

mthd_kp_description:= 1

mthd_ft_match:= 1

- output: out:= [mthd_img_smoothing, mthd_kp_detection, mthd_kp_description, mthd_ft_match]

- exception: none

9 MIS of Output Format Module

- R14
- R15

9.1 Module

formatOutput

9.2 Uses

- OpenCVLib (Section [16](#))

9.3 Syntax

9.3.1 Exported Constants

Not applicable.

9.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|-----------------------|--|--|------------|
| define_output_folders | - | greyscale_folder_nm: str, smoothed_imagery_folder_nm: str, keypoint_folder_nm: str, descriptor_folder_nm: str, matches_folder_nm: str | - |
| make_directory | folder_name: str | output_folder as directory folder | |
| output_keypoints | img_id: str, parent_dir: str, keypoints: OpenCV Keypoint Class | - | - |
| output_features | img_id: str, parent_dir: str, descriptors: OpenCV DMatch Class | - | - |
| output_matches | query_img_id: str, train_img_id: str, parent_dir: str, matches: BFMatcher Class | - | - |

9.4 Semantics

9.4.1 State Variables

- greyscale_fldr as str
- smoothed_imagery_fldr as str
- keypoint_fldr as str
- feature_fldr as str
- match_fldr as str
- keypoint_path as str
- feature_path as str
- match_path as str

9.4.2 Environment Variables

- output_folder: path

9.4.3 Assumptions

none

9.4.4 Access Routine Semantics

define_output_folders():

```
greyscale_fldr = "gsImagery"  
smoothed_imagery_fldr = "gkImagery"  
keypoint_fldr = "kpDetection"  
descriptor_fldr = "fDescriptors"  
matches_fldr = "fMatches"
```

- output: out:= [greyscale_fldr, smoothed_imagery_fldr, keypoint_folder_nm, descriptor_fldr, matches_fldr]
- exception: none

make_directory(folder_name):

- transition:= output_folder = os.makedirs(folder_name, exist_ok=True) per [Python OS Class](#)
- output: out:= none
- exception: none

output_keypoints(img_id, parent_id, keypoints):

- transition: tran:= keypoint_path = parent_dir + keypoint_fldr + img_id + "kp" + ".csv", where keypoint_path specifies the path to the output CSV file for the identified keypoints. This file will output the keypoint properties as follows per the [OpenCV Keypoint Class](#).
 - horizontal pixel position
 - vertical pixel position
 - size
 - angle
 - response
- output: none

- exception: none

output_features(img_id, parent_dir, features):

- transition: tran:= feature_path = parent_dir + img_id + feature_fldr + “fd” + “.csv”, where descriptor_path specifies the path to the output CSV file for the identified feature descriptors. This file will output the descriptor properties as follows per the [OpenCV Feature2D Class](#).
 - horizontal pixel position: \mathbb{N}
 - vertical pixel position: \mathbb{N}
 - size: \mathbb{N}
 - angle: \mathbb{R}^+
 - response: \mathbb{N}
 - descriptor: \mathbb{N}_{256}^{32} , where each bit is a 32-byte vector, and \mathbb{N}_{256} represents unsigned 8-bit numbers $[0, 255]$
- output: none
- exception: none

output_matches(query_img_id, train_img_id, parent_dir, matches):

- transition: tran:= match_path = parent_dir + query_img_id + train_img_id + match_fldr + “fm” + “.csv”, where match_path specifies the path to the output CSV file for the identified matches. This file will output the properties for each keypoint as follows per the [BFMatcher Class](#).
 - query index: \mathbb{N}
 - query horizontal position: \mathbb{N}
 - query vertical position: \mathbb{N}
 - train index: \mathbb{N}
 - train horizontal position: \mathbb{N}
 - train vertical position: \mathbb{N}
 - Distance: \mathbb{N}
- output: none
- exception: none

9.4.5 Local Functions

none

10 MIS of Output Verification Module

- R13

10.1 Module

verifyOutput

10.2 Uses

None.

10.3 Syntax

10.3.1 Exported Constants

10.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|------------------------|---|-------------------------------|--------------------------------|
| check_match_uniqueness | query_img_id: str, train_img_id: str, matches: BFMatcher Class | flag_uniqueness: \mathbb{B} | same_image, same_descriptor |

10.4 Semantics

10.4.1 State Variables

none

10.4.2 Environment Variables

none

10.4.3 Assumptions

none

10.4.4 Access Routine Semantics

check_match_uniqueness (query_img_id, train_img_id, matches):

- output: out: = flag_uniqueness = query_img_id != train_img_id
- exception:

- `exc := “same_image” | (query_img_id == train_img_id)`, where the query and training images share the same name.
- `exc := “same_descriptor” | (matches.query_x == matches.train_x && matches.query_y == matches.train_y)`, where the coordinates of the matched features match between both query and training images.

10.4.5 Local Functions

none

11 MIS of Image Smoothing Module

- R9

11.1 Module

smoothImage

11.2 Uses

- config (Section 6)

11.3 Syntax

11.3.1 Exported Constants

None.

11.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|--------------|---|------------------------------------|------------|
| smooth_image | mthd_img_smoothing: \mathbb{N} img_in: $\mathbb{N}^{h \times w}$ k: \mathbb{N} σ : \mathbb{R} | img_out: $\mathbb{N}^{h \times w}$ | - |

11.3.3 Environment Variables

none

11.3.4 Assumptions

- Exceptions on input limits are handled in specParams module.

11.3.5 Access Routine Semantics

smooth_image(mthd_img_smoothing, img_in, k, σ | mthd_img_smoothing == 1):

- output: out:= img_out = gaussianBlur(img_in, k, σ)
- exception: None

12 MIS of Keypoint Detection Module

- R6
- R10

12.1 Module

detectKeypoints

12.2 Uses

- config (Section 7)
- smoothImage (Section 11)
- OpenCVLib (Section 16)

12.3 Syntax

12.3.1 Exported Constants

12.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|------------------|--|--|------------|
| initialize_orb | mthd_kp_detection: \mathbb{N} , t: \mathbb{N} , b: \mathbb{N} , p: \mathbb{N} | orb_object: OpenCV ORB Class | - |
| get_orb_object | - | orb_object: OpenCV ORB Class | - |
| detect_keypoints | orb_object: OpenCV ORB Class , img: $\mathbb{N}^{h \times w}$ | keypoints: OpenCV Keypoint Class | - |

12.4 Semantics

12.4.1 State Variables

- orb_object as [OpenCV ORB Class](#)

12.4.2 Environment Variables

none

12.4.3 Assumptions

none

12.4.4 Access Routine Semantics

`initialize_orb(mthd_kp_detection, t, b, p | mthd_kp_detection == 1, mthd_kp_description == 1):`

- transition: `tran:= orb_object = ORB.create(t, b, p)`
- output: none
- exception: none

`get_orb_object():`

- output: `out:= orb_object`
- exception: none

`detect_keypoints(orb_object, img):`

`keypoints = orb_object.detect(img)`

- output: `out:= keypoints`
- exception: none

13 MIS of Feature Descriptor Module

- R7
- R11

13.1 Module

assignDescriptors

13.2 Uses

- config (Section 6)
- detectKeypoints (Section 12)
- OpenCVLib (Section 16)

13.3 Syntax

13.3.1 Exported Constants

13.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|---------------------|---|---|------------|
| compute_descriptors | img: $\mathbb{Z}^{h \times w}$, keypoints: OpenCV Key-point Class | descriptors: OpenCV Feature2D Class | - |

13.4 Semantics

13.4.1 State Variables

- orb_object: [OpenCV ORB Class](#)

13.4.2 Environment Variables

None.

13.4.3 Assumptions

- ORB object is instantiated in the Keypoint Detector Module.

13.4.4 Access Routine Semantics

```
compute_descriptors(orb_obj, img, keypoints):  
orb_object = get_orb_object()
```

- output: desc := orb_object.compute(img, keypoints)
- exception: None

14 MIS of Feature Matching Module

- R8
- R12

14.1 Module

matchFeatures

14.2 Uses

- config (Section 6)
- detectKeypoints (Section 12)
- assignDescriptors (Section 13)
- OpenCVLib (Section 16)

14.3 Syntax

14.3.1 Exported Constants

14.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|-------------------|--|--|------------|
| create_BF_matcher | mthd_fm_match: \mathbb{N} , norm_method: \mathbb{N} , crosscheck_flag: \mathbb{B} | bf_matcher_object: BFMatcher Class | - |
| get_bfm_object | - | bf_matcher_object: BFMatcher Class | - |
| match_features | bf_matcher_object: BFMatcher Class , desc1, desc2: OpenCV Feature2D Class | matches: OpenCV DMatch Class | - |
| sort_matches | bf_matcher_object: BFMatcher Class , matches: OpenCV DMatch Class , | sorted_matches: OpenCV DMatch Class | - |

14.4 Semantics

14.4.1 State Variables

- `bf_matcher_object`: [BFMatcher Class](#)

14.4.2 Environment Variables

None.

14.4.3 Assumptions

Exception handling on user-selected methods and parameters are handled in the Parameter Specification Module.

14.4.4 Access Routine Semantics

`create_BF_matcher(mthd_fm_match, norm_method, crosscheck_flag | mthd_fm_match == 1):`

- output: `out:= bf_matcher_object = BFMatcher(norm_method, crosscheck_flag)`
- exception: None

`matches = match_features(bf_matcher_object, desc1, desc2)`

- output: `out:= matches = bf_matcher_object.match(desc1, desc2)`
- exception: None

`sort_matches(bf_matcher_object, matches):`

- output: `out:= sorted_matches = bf_matcher_object.sorted(matches)`, where , such that the entries are organized in ascending order of the distance attribute
- exception: None

15 MIS of Image Plot Module

15.1 Module

plotImage

15.2 Uses

- OpenCVLib (Section 16)

15.3 Syntax

15.3.1 Exported Constants

none

15.3.2 Exported Access Programs

| Name | In | Out | Exceptions |
|----------------------|---|--|------------|
| set_parent_directory | dir: str | - | - |
| gen_kp_img | img_in: $\mathbb{N}^{h \times w}$, keypoints: OpenCV Key-point Class , flags: \mathbb{N} | img_kp $\in \mathbb{N}^{h \times w}$ | - |
| gen_matched_features | img_1, img_2: $\mathbb{N}^{h \times w}$, kp1, kp2: OpenCV Key-point Class , matches: OpenCV DMatch Class max_matches: \mathbb{N} , flags: \mathbb{N} | img_matches: $\mathbb{N}^{h \times w}$ | - |
| save_image | img_in: $\mathbb{N}^{h \times w}$, target_folder: str, img_name: str | png_out: png image | - |

15.4 Semantics

15.4.1 State Variables

- DrawMatchesFlag: \mathbb{N}
- colour: $= \mathbb{N}^3$

15.4.2 Environment Variables

- `parent_dir:= str`
- `img_output_path:= str`

15.4.3 Assumptions

- `gen_kp_img` has been initialized with keypoints

15.4.4 Access Routine Semantics

`set_parent_directory(dir)`

- transition: `tran:= parent_dir = dir`
- output: none
- exception: none

`gen_kp_img(img_in, keypoints, flags):`

`img_keypoints = drawKeypoints(img_in, keypoints, colour, flags)`

- output: `img_keypoints` $\in \mathbb{N}^{h \times w}$
- exception: none

`gen_matched_features(img_1, img_2, kp1, kp2, matches, max_matches):`

`img_matches = cv.drawMatches(img_1, kp1, img_2, kp2, matches[:max_matches], flags)`

- output: `img_matches` $\in \mathbb{N}^{h \times w}$, where the displayed matches range from 1:max_matches have the smallest distance attribute
- exception: none

`save_image(img_in, target_folder, img_name):`

- transition: `img_output_path = join(parent_dir, target_folder, img_name)`
- output: `out:= png_out = imwrite(img_in, img_output_path)`
- exception: none

16 MIS of OpenCV Module

16.1 Module

OpenCVLib

16.2 Uses

- config (Section [7](#))

16.3 Syntax

16.3.1 Exported Constants

None.

16.3.2 Exported Access Programs

General OpenCV Access Programs

| Name | Input | Output | Exceptions |
|---------------|--|--|----------------|
| imread | sel_read_path: str | $\text{img} \in \mathbb{N}^{h \times w}$ | invalidImgPath |
| imwrite | sel_save_path: str , out_img: $\mathbb{N}^{h \times w}$ | img_png as .png | invalidImgPath |
| gaussianBlur | img: $\mathbb{N}^{h \times w}$, k: \mathbb{N} , σ : \mathbb{R} | smooth_img: $\mathbb{N}^{m \times n}$ | - |
| drawKeypoints | img_in: $\mathbb{N}^{h \times w}$, keypoints: OpenCV Keypoint Class , colour: \mathbb{N}^3 , flags: \mathbb{N} | img_kp: $\mathbb{N}^{h \times w}$ | - |
| drawMatches | img1_in: $\mathbb{N}^{h_1 \times w_1}$, img2_in: $\mathbb{N}^{h_2 \times w_2}$ kp1, kp2: OpenCV Keypoint Class , flags: \mathbb{N} | img_matches: $\mathbb{N}^{(h_1+h_2) \times (w_1+w_2)}$ | - |
| ORB.create | b: \mathbb{N} , p: \mathbb{N} , t: \mathbb{N} | orb_object: OpenCV ORB Class | - |
| BFMatcher | match_method: \mathbb{N} , cross_check_flag: \mathbb{B} | brute_force_object: OpenCV Brute Force Matcher Class | - |

ORB Object Member Functions

| Name | In | Out | Exceptions |
|---------|---|---|---------------------------------|
| detect | img: $\mathbb{Z}^{h \times w}$ | keypoints: OpenCV Keypoint Class | invalidImg |
| compute | img $\in \mathbb{Z}^{h \times w}$, keypoints: OpenCV Keypoint Class | descriptors: OpenCV Feature2D Class | invalidImg, invalidKeypoints |

Brute Force Matcher Object Functions

| Name | In | Out | Exceptions |
|--------|---|---|--|
| match | fd1, fd2: OpenCV Feature2D Class | matches: OpenCV DMatch Class | Raises an error if descriptors are invalid or empty. |
| sorted | unsorted_matches: OpenCV DMatch Class | sorted_matches: OpenCV DMatch Class | - |

16.4 Semantics

16.4.1 State Variables

- orb_object: [OpenCV ORB Class](#)
- bf_matcher_object: [BFMatcher Class](#)

16.4.2 Environment Variables

None.

16.4.3 Assumptions

- The input image is a valid grayscale or color image.
- Keypoints are detected before computing descriptors.
- ORB objects are initialized prior to use.
- BFMatcher objects are initialized prior to use.

16.4.4 Access Routine Semantics

imread(sel_read_path:str):

- output: out:= img $\in \mathbb{N}^{h \times w}$
- exception: if no image identified, flag as `InvalidImgPath`

imwrite(sel_save_path, out_img):

- output: out:= img_png as .png file
- exception: exc:= `invalidImage`

gaussianBlur(img, k, σ):

- output: out:= img_out

- exception: none

`drawKeypoints(img_in, keypoints, colour, flags):`

- output: `out:= img_kp`
- exception: none

`drawMatches(img1_in, img2_in, kp1, kp2, matches, flags):`

- output: `img_matches` $\in \mathbb{N}^{(h_1+h_2) \times (w_1+w_2)}$

`ORB.create(b, p, t):`

- output: `out:= orb_object` as [OpenCV ORB Class](#)
- exception: None.

`detect(img):`

- output: `out:= keypoints` as [OpenCV Keypoint Class](#)
- exception: `invalidImage`

`compute(img, keypoints):`

- output: `out:= descriptors` as [OpenCV Feature2D Class](#)
- exception: `exc:=`
 - image not found \Rightarrow `invalidImg`
 - keypoints not found \Rightarrow `invalidKeypoints`

`match(fd1, fd2):`

- output: `out:= matches` M as [OpenCV DMatch Class](#).
- exception: `exc:=` Raises an error if the descriptors are invalid or empty.
 - descriptors are invalid

`sorted(unsorted_matches):`

- output: `out:= sorted_matches`, where matches are sorted from `unsorted_matches` in ascending order of the distance attribute of the [OpenCV DMatch Class](#)
- exception: Raises an error if the match set is empty.

References

- Carlo Ghezzi, Mehdi Jazayeri, and Dino Mandrioli. *Fundamentals of Software Engineering*. Prentice Hall, Upper Saddle River, NJ, USA, 2nd edition, 2003.
- Daniel M. Hoffman and Paul A. Strooper. *Software Design, Automated Testing, and Maintenance: A Practical Approach*. International Thomson Computer Press, New York, NY, USA, 1995. URL <http://citeseer.ist.psu.edu/428727.html>.

17 Appendix

[Extra information if required —SS]