MidTerm Project Camera-Based 2D Feature Tracking

Overview

The project template that was provided was re-structured to allow ease of running analyses from the command line in single or (compiled in batch) flows. Example:

```
dan@ros:~/SFND_2D_Feature_Tracking/build$ ./2D_feature_tracking
    incomplete arguments given.
    usage:
    ./2D_feature_tracking -d <DETECTOR_TYPE> -m <MATCHER_TYPE> -x <DESCRIPTOR_TYPE> -s <SELECTOR_TYPE> \
        [-v] [-f] [-l]
    -v: visualize results
    -f: focus on vehicle rectangle
    -l: limit keypts
    -b: run compiled-in batch tests (output stats.csv)
    DETECTOR_TYPE:  SHITOMASI, HARRIS, FAST, BRISK, ORB, AKAZE, SIFT
    MATCHER_TYPE:  MAT_BF, MAT_FLANN
    DESCRIPTOR_TYPE: BRISK, BRIEF, ORB, FREAK, AKAZE, SIFT
    SELECTOR_TYPE:  SEL_NN, SEL_KNN
    Example:
    ./2D_feature_tracking -d SHITOMASI -m MAT_BF -x BRISK -s SEL_NN
```

Task MP.1 - Data Buffer

The DataBuffer ('ring buffer') for this task is a templatized class located in dataStructures.h. Invocation via:

```
DataBuffer<DataFrame> dataBuffer(dataBufferSize)
```

The DataBuffer class conforms to the subset of the std::vector api and exposes begin() and end() iterators, as well as limiting storage to dataBufferSize objects.

Task MP.2 - Keypoint Detectors

Additional HARRIS, FAST, BRISK, ORB, AKAZE and SIFT keypoint detectors were added within the file 'matching2D_student.cpp', and each method is selectable via the '-d' argument to the program. The return value was agumented to include performance metrics.

Note: ORB was configured to return a maximum of 2000 points.

Task MP.3 - Keypoint Area Filter

A keypoints filter introduced using cv::Rect.contains() to filter keypoints within regions of interest (vehicle, license plate, etc.).

Task MP.4 - Keypoint Descriptors

Additional BRIEF, ORB, FREAK, AKAZE, and SIFT keypoint descriptors were added within 'matching2D_student.cpp' and each method is selectable via the '-x' argument to the program. The return value of the methods were augumented to include performance metrics.

Note: For each descriptor, cv::DescriptorExtractor.normType() is returned to the calling routine to be used in matcher configuration.

Task MP.5 - Keypoint Matchers

Added FLANN and KNN alternative matcher options. For FLANN, the matcher is parameterized by the type of the normalization parameter (either cv::flann::KDTreeIndexParams for cv::NORM_L2 descriptors or cv::flann::LshIndexParams(20, 15, 2) for cv::NORM_HAMMING descriptors)

Note: For brute-force matchers, we use crossCheck = true to improve the quality of the matches.

Task MP.6 - Distance Ratio Filtering

Distance ratio filtering was added to KNN selection with a min distance ratio of 0.8.

Task MP.7 - Keypoint Detection Analysis

The following analysis of points detected within the region of the vehicle using various detectors:

detector	img1	img2	img3	img4	img5	img6	img7	img8	img9	img10	avg_pts	stddev_pts
SHITOMASI	125	118	123	120	120	113	114	123	111	112	117.9	5.1
HARRIS	17	14	18	21	26	43	18	31	26	34	24.8	9.1
FAST	419	427	404	423	386	414	418	406	396	401	409.4	13.0
BRISK	264	282	282	277	297	279	289	272	266	254	276.2	12.6
ORB	291	314	317	330	326	346	342	338	327	312	324.3	16.4

detector	img1	img2	img3	img4	img5	img6	img7	img8	img9	img10	avg_pts	stddev_pts
AKAZE	166	157	161	155	163	164	173	175	177	179	167.0	8.5
SIFT	138	132	124	137	134	140	137	148	159	137	138.6	9.4

Of note is the HARRIS detector with a small number of detected keypoints, as well as a large variation in the detected keypoints within the vehicle region.

Visual Assessments of Detectors

Assessment of critical keypoints, including detection of taillights, license plate, roof line, upper brake light as tracking points as well as points outside of the vehicle of interest or on ephemeral points such as shadows.

- *SHITOMASI*: (+) points on edges, license plate, brake lights stable. (-) many points outside of vehicle, car cast shadow.
- *HARRIS*: (+) points on brake lights. (-) minimal keypoints, some critical keypoints intermittent.
- *FAST*: (+) large number of keypoints on vehicle. (-) lots of keypoints outside region of interst, car cast shadow, some mismatches.
- *BRISK*: (+) large number of keypoints on vehicle, esp license plate. (-) occasional mismatch.
- *ORB*: (+) large number of keypoints focused on upper half of vehicle (no vehicle cast shadow keypoints). (-) minmal keypoints on license plate.
- *AKAZE*: (+) mainly points on top of vehicle. (-) some car cast shadow keypoints, no license plate points.
- *SIFT*: (+) reasonable amount of keypoints, mostly on top of vehicle. (-) some errors, keypoints shifted.

Task MP.8 - Keypoint Matching Analysis

The following tabulates the combinations of detector and descriptor for matching using brute force (MAT_BF) and k nearest neighbor (SEL_KNN) with min descriptor distance ratio of 0.8.

detector	descriptor	img1-2	img2-3	img3-4	img4-5	img5-6	img6-7	img7-8	img8-9	img9-10
SHITOMASI	BRISK	752	731	708	697	703	685	715	753	715
SHITOMASI	BRIEF	1003	981	992	987	931	947	973	1003	971
SHITOMASI	ORB	897	885	909	908	890	870	873	905	882
SHITOMASI	FREAK	730	723	751	717	712	713	700	726	686
SHITOMASI	AKAZE	0	0	0	0	0	0	0	0	0
SHITOMASI	SIFT	1044	1050	1068	1045	1019	1032	1033	1078	1053
HARRIS	BRISK	65	52	67	75	106	88	62	119	121
HARRIS	BRIEF	82	77	85	93	134	133	67	150	143
HARRIS	ORB	73	67	79	89	126	112	66	144	132
HARRIS	FREAK	62	55	63	77	108	97	56	118	117
HARRIS	AKAZE	93	80	91	98	142	140	74	163	161
HARRIS	SIFT	90	77	90	95	141	120	72	154	160
FAST	BRISK	2241	2231	2194	2167	2218	2156	2066	2199	2182
FAST	BRIEF	3041	2994	3037	3014	2941	2930	2899	2992	2980
FAST	ORB	2723	2741	2777	2742	2758	2688	2690	2761	2744
FAST	FREAK	2160	2170	2140	2163	2205	2141	2071	2199	2153
FAST	AKAZE	0	0	0	0	0	0	0	0	0
FAST	SIFT	3354	3256	3260	3229	3208	3281	3256	3281	3337
BRISK	BRISK	1494	1486	1477	1400	1451	1368	1400	1373	1385
BRISK	BRIEF	1689	1739	1746	1674	1666	1622	1660	1646	1601
BRISK	ORB	1435	1440	1417	1392	1417	1371	1357	1364	1346
BRISK	FREAK	1333	1343	1358	1297	1369	1322	1296	1308	1285
BRISK	AKAZE	0	0	0	0	0	0	0	0	0
BRISK	SIFT	1677	1699	1648	1625	1688	1607	1645	1572	1580
ORB	BRISK	1209	1243	1265	1222	1251	1253	1239	1200	1176
ORB	BRIEF	967	923	872	907	903	907	935	880	919

detector	descriptor	img1-2	img2-3	img3-4	img4-5	img5-6	img6-7	img7-8	img8-9	img9-10
ORB	ORB	1273	1301	1321	1298	1301	1308	1280	1265	1262
ORB	FREAK	429	460	476	489	488	490	470	468	529
ORB	AKAZE	0	0	0	0	0	0	0	0	0
ORB	SIFT	1375	1357	1404	1412	1392	1365	1387	1355	1392
AKAZE	BRISK	894	881	898	908	906	943	933	945	931
AKAZE	BRIEF	949	968	985	988	979	1005	1011	1003	983
AKAZE	ORB	868	899	872	862	878	913	905	902	875
AKAZE	FREAK	832	855	848	847	872	873	873	934	902
AKAZE	AKAZE	1011	1025	1021	1027	1022	1039	1026	1043	999
AKAZE	SIFT	1033	1051	1025	1057	1055	1067	1057	1058	1046
SIFT	BRISK	567	561	564	539	542	544	551	531	561
SIFT	BRIEF	702	653	666	639	648	652	671	619	673
SIFT	FREAK	539	522	537	510	518	510	545	518	537
SIFT	AKAZE	0	0	0	0	0	0	0	0	0
SIFT	SIFT	803	781	759	754	755	738	743	814	815

Note: Akaze descriptors with non-Akaze detection resulted in exceptions.

Task MP.9 - Feature Detecting Analysis

Below are the top three recommendations for keypoint detection for vehicle tracking (full table follows).

rank	detect	descript	matcher	select	det[ms]	#kpts	desc[ms]	match[ms]	#mat_kpts	avg_total_time[ms]	#mat_vehkpts
1	ORB	BRISK	MAT_BF	SEL_KNN	128.626	2000	52.2	20.8	1228	201.7	226
2	FAST	ORB	MAT_BF	SEL_KNN	40.7212	4904	65.4	145.4	2736	251.4	306
3	SHITOMASI	ORB	MAT_BF	SEL_KNN	77.7339	1339	32.1	14.9	891	124.8	100

Selection Rationale

The criteria for selection included:

1. Accuracy and repeatability (generally excluded HARRIS detectors) - verified visually match quality
2. Number of features detected within region of interested (negatively affected SHITOMASI detector flows)
3. Performance - minimal average total processing time and maximal features per second.

All selected detectors used brute-force matching with K-nearest neighbor selection. The ORB/2000 - BRISK flow was top choice due to a combination of being reasonably performant, with a larger number of keypoints detected within the region of interest. The FAST - ORB combination came in second, primarily due to the slower processing time. The third option was chosen because produced what was considered a sufficient number of tracking points on the region of interest, and did so in a performant manner - approximately twice the speed of first two choices.

Additional Notes: The ORB and FAST detectors allow selection of the number of detected keypoints. Both could potentially be optimized to better suit throughput targets. ORB descriptors seemed to perform well overall (based on number of keypoints processed and with brute-force/knn matching) for any keypoint method employed.

Full Table of Detector/Descriptor Results:

detect	descript	matcher	select	det[ms]	#kpts	desc[ms]	match[ms]	#mat_kpts	avg_total_time[ms]	pts_sec
HARRIS	BRISK	MAT_BF	SEL_KNN	76.8733	180	5.93221	0.704258	83	83.51	994
HARRIS	BRISK	MAT_BF	SEL_NN	77.6858	180	5.83177	0.968041	90	84.49	1065
HARRIS	BRIEF	MAT_BF	SEL_KNN	78.4427	180	7.18155	0.809005	107	86.43	1238
HARRIS	BRIEF	MAT_BF	SEL_NN	78.7623	180	7.0369	1.05365	101	86.85	1163
HARRIS	ORB	MAT_BF	SEL_NN	79.6146	180	21.1884	1.27585	94	102.08	921
HARRIS	BRIEF	MAT_FLANN	SEL_NN	78.0075	180	6.71901	19.9148	154	104.64	1472
HARRIS	ORB	MAT_BF	SEL_KNN	82.4238	180	22.6496	0.795571	98	105.87	926
HARRIS	BRISK	MAT_FLANN	SEL_NN	77.496	180	5.7936	25.0564	157	108.35	1449

detect	descript	matcher	select	det[ms]	#kpts	desc[ms]	match[ms]	#mat_kpts	avg_total_time[ms]	pts_sec
HARRIS	BRIEF	MAT_FLANN	SEL_KNN	80.1704	180	7.01908	21.3348	107	108.52	986
HARRIS	BRISK	MAT_FLANN	SEL_KNN	77.8165	180	5.90232	25.8408	84	109.56	767
SHITOMASI	ORB	MAT_BF	SEL_KNN	77.7339	1339	32.1486	14.9347	891	124.82	7138
HARRIS	ORB	MAT_FLANN	SEL_KNN	80.3332	180	22.414	22.527	98	125.27	782
SHITOMASI	BRISK	MAT_BF	SEL_KNN	75.962	1339	36.263	15.2748	717	127.50	5624
HARRIS	ORB	MAT_FLANN	SEL_NN	86.2295	180	22.4899	24.1831	152	132.90	1144
SHITOMASI	BRIEF	MAT_BF	SEL_KNN	77.1979	1339	44.3382	14.2477	976	135.78	7188
SHITOMASI	ORB	MAT_BF	SEL_NN	78.7122	1339	32.828	27.1805	913	138.72	6582
SHITOMASI	BRISK	MAT_BF	SEL_NN	76.0711	1339	36.4203	30.1073	826	142.60	5792
SHITOMASI	BRIEF	MAT_BF	SEL_NN	77.0629	1339	44.9044	29.0785	977	151.05	6468
HARRIS	FREAK	MAT_BF	SEL_KNN	74.5762	180	76.174	0.657558	83	151.41	548
HARRIS	FREAK	MAT_BF	SEL_NN	75.7374	180	76.2663	1.51271	86	153.52	560
HARRIS	FREAK	MAT_FLANN	SEL_NN	74.6096	180	75.3391	27.696	155	177.64	873
HARRIS	FREAK	MAT_FLANN	SEL_KNN	74.7266	180	76.4241	27.9743	83	179.13	463
SHITOMASI	FREAK	MAT_BF	SEL_KNN	73.6171	1339	100.939	20.3776	717	194.93	3678
ORB	BRISK	MAT_BF	SEL_KNN	128.626	2000	52.2385	20.7843	1228	201.65	6090
SHITOMASI	FREAK	MAT_BF	SEL_NN	75.8697	1339	102.219	39.0772	810	217.17	3730
ORB	FREAK	MAT_BF	SEL_KNN	130.073	2000	90.1174	6.39304	477	226.58	2105
ORB	FREAK	MAT_BF	SEL_NN	130.033	2000	89.6327	10.7991	448	230.46	1944
ORB	BRIEF	MAT_BF	SEL_KNN	131.413	2000	68.656	33.7623	912	233.83	3900
ORB	BRISK	MAT_BF	SEL_NN	141.363	2000	52.7468	45.2776	1171	239.39	4892
BRISK	BRIEF	MAT_BF	SEL_KNN	116.084	2706	88.7405	46.0053	1671	250.83	6662
FAST	ORB	MAT_BF	SEL_KNN	40.7212	4904	65.3633	145.352	2736	251.44	10881
BRISK	ORB	MAT_BF	SEL_KNN	114.809	2706	99.7926	41.7155	1393	256.32	5435
BRISK	BRISK	MAT_BF	SEL_KNN	115.852	2706	78.7087	69.7997	1426	264.36	5394
ORB	BRIEF	MAT_BF	SEL_NN	134.099	2000	68.9626	70.9353	956	274.00	3489
ORB	ORB	MAT_BF	SEL_KNN	128.387	2000	103.876	44.9519	1289	277.21	4650
BRISK	FREAK	MAT_BF	SEL_KNN	119.368	2706	131.057	44.5711	1323	295.00	4485
BRISK	BRIEF	MAT_BF	SEL_NN	120.505	2706	88.0788	88.871	1590	297.45	5345
BRISK	ORB	MAT_BF	SEL_NN	115.624	2706	99.0743	89.5611	1539	304.26	5058
ORB	ORB	MAT_BF	SEL_NN	129.075	2000	104.469	71.9234	1369	305.47	4482
FAST	BRIEF	MAT_BF	SEL_KNN	40.3575	4904	139.543	138.62	2980	318.52	9356
BRISK	BRISK	MAT_BF	SEL_NN	115.339	2706	78.0211	146.148	1558	339.51	4589
BRISK	FREAK	MAT_BF	SEL_NN	116.063	2706	130.225	96.0375	1391	342.33	4063
FAST	BRISK	MAT_BF	SEL_KNN	39.7102	4904	136.317	192.891	2183	368.92	5917
ORB	FREAK	MAT_FLANN	SEL_NN	128.912	2000	90.2631	160.122	628	379.30	1656
ORB	FREAK	MAT_FLANN	SEL_KNN	130.017	2000	89.1457	161.753	477	380.92	1252
FAST	ORB	MAT_BF	SEL_NN	39.7561	4904	65.1978	296.687	2754	401.64	6857
FAST	FREAK	MAT_BF	SEL_KNN	39.7234	4904	190.098	191.366	2155	421.19	5116
FAST	BRIEF	MAT_BF	SEL_NN	39.6728	4904	140.143	267.634	2910	447.45	6504
HARRIS	SIFT	MAT_BF	SEL_KNN	73.851	180	419.073	3.89345	111	496.82	223
HARRIS	SIFT	MAT_BF	SEL_NN	76.0981	180	417.222	8.0705	108	501.39	215
HARRIS	SIFT	MAT_FLANN	SEL_NN	74.5758	180	418.426	17.3812	161	510.38	315
HARRIS	SIFT	MAT_FLANN	SEL_KNN	74.3209	180	419.711	18.0985	111	512.13	217

detect	descript	matcher	select	det[ms]	#kpts	desc[ms]	match[ms]	#mat_kpts	avg_total_time[ms]	pts_sec
SHITOMASI	BRIEF	MAT_FLANN	SEL_NN	75.6779	1339	43.7592	413.9	1231	533.34	2308
SHITOMASI	BRIEF	MAT_FLANN	SEL_KNN	75.6099	1339	43.9996	418.437	976	538.05	1814
FAST	BRISK	MAT_BF	SEL_NN	39.8745	4904	132.943	371.72	2602	544.54	4778
AKAZE	BRISK	MAT_BF	SEL_KNN	522.84	1342	37.6834	15.8988	915	576.42	1587
FAST	FREAK	MAT_BF	SEL_NN	40.3176	4904	188.69	351.467	2517	580.47	4336
HARRIS	AKAZE	MAT_BF	SEL_KNN	75.4243	180	505.428	0.5748	115	581.43	198
HARRIS	AKAZE	MAT_BF	SEL_NN	77.4923	180	508.893	0.940852	109	587.33	186
SHITOMASI	ORB	MAT_FLANN	SEL_KNN	75.7156	1339	31.8506	494.214	891	601.78	1481
SHITOMASI	ORB	MAT_FLANN	SEL_NN	75.7295	1339	32.3055	494.924	1219	602.96	2022
AKAZE	BRISK	MAT_BF	SEL_NN	533.915	1342	38.2981	33.0823	985	605.30	1627
AKAZE	BRIEF	MAT_BF	SEL_KNN	543.156	1342	45.4834	20.7666	985	609.41	1616
HARRIS	AKAZE	MAT_FLANN	SEL_NN	77.0869	180	519.932	19.9439	161	616.96	261
HARRIS	AKAZE	MAT_FLANN	SEL_KNN	79.524	180	517.872	20.5523	116	617.95	188
AKAZE	ORB	MAT_BF	SEL_KNN	542.971	1342	63.2824	23.7657	886	630.02	1406
AKAZE	ORB	MAT_BF	SEL_NN	532.612	1342	61.9908	44.0962	944	638.70	1478
AKAZE	BRIEF	MAT_BF	SEL_NN	544.234	1342	45.9169	55.1235	1002	645.27	1553
AKAZE	FREAK	MAT_BF	SEL_KNN	530.491	1342	102.043	14.5601	870	647.09	1344
SHITOMASI	SIFT	MAT_FLANN	SEL_NN	72.0445	1339	433.803	142.569	1342	648.42	2070
SHITOMASI	SIFT	MAT_FLANN	SEL_KNN	72.5531	1339	433.798	153.077	1049	659.43	1591
AKAZE	FREAK	MAT_BF	SEL_NN	536.991	1342	102.653	28.9299	946	668.57	1415
SHITOMASI	SIFT	MAT_BF	SEL_KNN	71.7202	1339	434.113	258.183	1046	764.02	1369
SHITOMASI	BRISK	MAT_FLANN	SEL_KNN	75.8815	1339	36.481	682.363	718	794.73	903
SHITOMASI	BRISK	MAT_FLANN	SEL_NN	77.1337	1339	36.4849	693.459	1290	807.08	1598
ORB	BRISK	MAT_FLANN	SEL_KNN	126.959	2000	53.0792	666.55	1228	846.59	1451
ORB	ORB	MAT_FLANN	SEL_NN	127.427	2000	102.068	619.415	2000	848.91	2356
ORB	ORB	MAT_FLANN	SEL_KNN	126.539	2000	102.571	624.056	1290	853.17	1512
ORB	BRISK	MAT_FLANN	SEL_NN	128.987	2000	53.0369	690.701	1581	872.72	1812
AKAZE	ORB	MAT_FLANN	SEL_KNN	529.496	1342	62.0855	341.504	886	933.09	950
AKAZE	ORB	MAT_FLANN	SEL_NN	532.492	1342	63.5804	347.694	1341	943.77	1421
SHITOMASI	FREAK	MAT_FLANN	SEL_KNN	71.1551	1339	100.712	772.042	717	943.91	760
SHITOMASI	FREAK	MAT_FLANN	SEL_NN	71.1222	1339	99.5704	806.537	1247	977.23	1276
SHITOMASI	SIFT	MAT_BF	SEL_NN	73.1721	1339	433.121	484.841	1079	991.13	1089
AKAZE	AKAZE	MAT_BF	SEL_KNN	529.105	1342	522.471	17.1824	1023	1068.76	957
AKAZE	AKAZE	MAT_BF	SEL_NN	527.694	1342	520.532	34.0865	1047	1082.31	967
AKAZE	BRIEF	MAT_FLANN	SEL_NN	528.989	1342	44.4986	510.564	1344	1084.05	1240
AKAZE	BRIEF	MAT_FLANN	SEL_KNN	534.996	1342	45.3245	506.014	985	1086.33	907
ORB	BRIEF	MAT_FLANN	SEL_NN	126.267	2000	65.523	1004.1	2000	1195.89	1672
ORB	BRIEF	MAT_FLANN	SEL_KNN	125.74	2000	67.1069	1005.37	912	1198.22	761
AKAZE	SIFT	MAT_FLANN	SEL_NN	533.277	1342	591.994	145.41	1344	1270.68	1058
AKAZE	SIFT	MAT_FLANN	SEL_KNN	534.927	1342	596.27	155.934	1055	1287.13	820
BRISK	ORB	MAT_FLANN	SEL_NN	115.54	2706	99.4362	1081.77	2674	1296.75	2062
BRISK	ORB	MAT_FLANN	SEL_KNN	117.15	2706	99.097	1110.77	1393	1327.02	1050
FAST	SIFT	MAT_FLANN	SEL_NN	39.3191	4904	738.249	563.167	4911	1340.74	3663
BRISK	SIFT	MAT_FLANN	SEL_NN	114.952	2706	909.937	316.705	2716	1341.59	2024

detect	descript	matcher	select	det[ms]	#kpts	desc[ms]	match[ms]	#mat_kpts	avg_total_time[ms]	pts_sec
BRISK	SIFT	MAT_FLANN	SEL_KNN	114.576	2706	912.139	329.189	1693	1355.90	1249
AKAZE	BRISK	MAT_FLANN	SEL_NN	525.648	1342	37.3679	802.075	1344	1365.09	985
AKAZE	BRISK	MAT_FLANN	SEL_KNN	528.714	1342	38.0884	808.693	915	1375.50	665
FAST	SIFT	MAT_FLANN	SEL_KNN	39.3442	4904	739.993	598.397	3345	1377.73	2428
AKAZE	SIFT	MAT_BF	SEL_KNN	531.536	1342	592.745	263.378	1049	1387.66	756
AKAZE	AKAZE	MAT_FLANN	SEL_NN	524.723	1342	523.755	554.567	1344	1603.05	838
AKAZE	AKAZE	MAT_FLANN	SEL_KNN	525.544	1342	520.405	558.736	1023	1604.69	638
AKAZE	SIFT	MAT_BF	SEL_NN	528.796	1342	597.904	492.797	1076	1619.50	664
ORB	SIFT	MAT_FLANN	SEL_KNN	127.677	2000	1307.5	232.566	1394	1667.74	836
ORB	SIFT	MAT_FLANN	SEL_NN	129.276	2000	1330.84	222.498	2000	1682.61	1189
BRISK	BRIEF	MAT_FLANN	SEL_NN	116.854	2706	89.0781	1625.51	2687	1831.44	1467
BRISK	BRIEF	MAT_FLANN	SEL_KNN	114.659	2706	89.7281	1630.66	1671	1835.05	911
BRISK	SIFT	MAT_BF	SEL_KNN	115.856	2706	910.079	946.34	1637	1972.28	830
ORB	SIFT	MAT_BF	SEL_KNN	126.403	2000	1318.2	544.871	1382	1989.47	695
AKAZE	FREAK	MAT_FLANN	SEL_KNN	528.741	1342	101.841	1362.03	870	1992.61	437
AKAZE	FREAK	MAT_FLANN	SEL_NN	529.353	1342	103.225	1360.86	1344	1993.44	674
SIFT	BRISK	MAT_BF	SEL_KNN	2050.96	1380	36.7253	16.4052	551	2104.09	262
SIFT	BRIEF	MAT_BF	SEL_KNN	2081.95	1380	39.2859	13.4605	658	2134.70	308
SIFT	BRIEF	MAT_BF	SEL_NN	2058.73	1380	40.2136	43.9449	714	2142.89	333
SIFT	BRISK	MAT_BF	SEL_NN	2091.58	1380	37.2984	33.1752	671	2162.05	310
SIFT	FREAK	MAT_BF	SEL_KNN	2091.75	1380	102.486	13.4367	526	2207.67	238
SIFT	FREAK	MAT_BF	SEL_NN	2089.89	1380	101.826	25.276	639	2216.99	288
BRISK	FREAK	MAT_FLANN	SEL_KNN	119.036	2706	131.991	1976.95	1323	2227.98	594
BRISK	FREAK	MAT_FLANN	SEL_NN	119.392	2706	132.477	2047.06	2302	2298.93	1001
ORB	SIFT	MAT_BF	SEL_NN	125.942	2000	1306.31	1033.69	1268	2465.94	514
BRISK	BRISK	MAT_FLANN	SEL_NN	114.896	2706	78.6215	2308.99	2716	2502.51	1085
SIFT	BRIEF	MAT_FLANN	SEL_NN	2076.63	1380	39.8708	394.44	1260	2510.94	502
BRISK	BRISK	MAT_FLANN	SEL_KNN	116.483	2706	79.4687	2321.55	1426	2517.50	566
SIFT	BRIEF	MAT_FLANN	SEL_KNN	2085.28	1380	40.1983	404.6	658	2530.08	260
SIFT	BRISK	MAT_FLANN	SEL_NN	2045.14	1380	36.8024	644.996	1320	2726.94	484
SIFT	BRISK	MAT_FLANN	SEL_KNN	2052.07	1380	36.7373	653.538	551	2742.35	201
BRISK	SIFT	MAT_BF	SEL_NN	115.826	2706	913.298	1858.03	1581	2887.15	548
SIFT	FREAK	MAT_FLANN	SEL_NN	2093.36	1380	103.193	852.499	1256	3049.05	412
SIFT	FREAK	MAT_FLANN	SEL_KNN	2090.63	1380	102.574	874.673	526	3067.88	171
FAST	SIFT	MAT_BF	SEL_KNN	39.558	4904	740.879	2987.78	3273	3768.22	869
FAST	BRIEF	MAT_FLANN	SEL_KNN	39.3724	4904	140.617	3738.09	2980	3918.08	761
FAST	BRIEF	MAT_FLANN	SEL_NN	39.4713	4904	144.233	3752.26	4378	3935.96	1112
SIFT	SIFT	MAT_FLANN	SEL_NN	2046.61	1380	2065.3	152.507	1381	4264.42	324
SIFT	SIFT	MAT_FLANN	SEL_KNN	2046.88	1380	2065.34	159.268	782	4271.49	183
SIFT	SIFT	MAT_BF	SEL_KNN	2057.86	1380	2065.49	271.451	773	4394.80	176
SIFT	SIFT	MAT_BF	SEL_NN	2051.54	1380	2086.49	515.555	834	4653.59	179
FAST	ORB	MAT_FLANN	SEL_KNN	39.2628	4904	65.4424	4574.86	2736	4679.57	585
FAST	ORB	MAT_FLANN	SEL_NN	39.5808	4904	66.1047	4585.49	4320	4691.18	921
FAST	SIFT	MAT_BF	SEL_NN	40.0014	4904	754.366	5987.4	3357	6781.77	495

detect	descript	matcher	select	det[ms]	#kpts	desc[ms]	match[ms]	#mat_kpts	avg_total_time[ms]	pts_sec
FAST	BRISK	MAT_FLANN	SEL_KNN	39.3163	4904	134.962	6987.82	2184	7162.10	305
FAST	BRISK	MAT_FLANN	SEL_NN	39.6312	4904	136.366	7080.64	4672	7256.64	644
FAST	FREAK	MAT_FLANN	SEL_KNN	39.1044	4904	188.219	8216.46	2156	8443.78	255
FAST	FREAK	MAT_FLANN	SEL_NN	39.9213	4904	191.7	8670.51	4464	8902.13	501