Camera Based 2D Feature Tracking

MP.1 Data Buffer Optimization
Implemented circular buffer using boost::circular_buffer library.

MP.2 Keypoint Detection
Implemented detectors HARRIS, FAST, BRISK, ORB, AKAZE, and SIFT using OpenCV libraries and made them selectable by setting a string accordingly.

MP.3 Keypoint Removal
Used contains() function from cv::Rect class to find if keypoints are inside the specified rectangle bounding box.

MP.4 Keypoint Descriptors
Implemented descriptors BRIEF, ORB, FREAK, AKAZE and SIFT using OpenCV libraries and made them selectable by setting a string accordingly.

MP.5 Descriptor Matching
Implemented FLANN matching as well as k-nearest neighbor selection and made them selectable by setting a string accordingly.

MP.6 Descriptor Distance Ratio
Implemented descriptor distance ratio test for K-Nearest-Neighbor matching.

MP.7 Performance Evaluation 1
MP.8 Performance Evaluation 2
MP.9 Performance Evaluation 3

The results are summarized in the tables below.
Based on the results,
The top 3 detector/ descriptor combinations are:
    1)ORB-ORB
       Very fast execution and significant amount of keypoints are matched.
    2)FAST - BRIEF
       Faster than ORB-ORB but less number of keypoints on preceding vehicle.

3)SHITOMASI-ORB

Though keypoint detection takes a bit longer, more number of keypoints are detected and a greater fraction of them are matched.

Detector: AKAZE Descriptor: AKAZE

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	60.4865	166	46.2958	
1	46.8931	157	59.3022	138
2	61.3684	161	67.6707	138
3	62.5629	155	63.547	133
4	66.6823	163	60.799	127
5	83.585	164	111.824	129
6	56.7837	173	52.5322	146
7	51.1643	175	77.2053	147
8	67.9471	177	44.3145	151
9	58.0017	179	57.6569	150

Detector: AKAZE Descriptor: BRIEF

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	58.1949	166	1.02017	
1	62.2268	157	1.8874	141
2	69.1553	161	1.60201	134
3	51.1473	155	3.30675	131
4	73.5847	163	5.68024	130

5	51.744	164	1.94151	134
6	53.5356	173	3.94945	146
7	54.9597	175	3.98043	150
8	51.1745	177	2.03318	148
9	66.4535	179	4.91606	152

Detector: AKAZE Descriptor: FREAK

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	61.3227	166	65.3415	
1	51.5298	157	66.4411	126
2	53.7868	161	40.5448	129
3	51.0747	155	44.0023	127
4	63.7781	163	67.8373	121
5	55.1829	164	57.2068	122
6	59.5395	173	69.4757	133
7	61.9713	175	66.0785	144
8	70.5116	177	67.3683	147
9	58.9902	179	60.4962	138

Detector: AKAZE Descriptor: ORB

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	55.0903	166	6.34784	
1	56.1438	157	6.05726	131

2	50.5045	161	2.74857	129
3	50.5054	155	6.46444	127
4	50.5396	163	7.14064	117
5	63.1185	164	6.80871	130
6	55.3037	173	6.76244	131
7	50.9276	175	6.35794	137
8	50.0932	177	6.88176	135
9	51.5081	179	7.18823	145

Detector: AKAZE Descriptor: SIFT

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	57.1625	166	34.9751	
1	54.8062	157	41.8865	134
2	60.3147	161	40.8195	134
3	65.9016	155	39.368	130
4	67.9201	163	41.1555	136
5	72.972	164	37.4459	137
6	60.9143	173	43.0841	147
7	64.4511	175	43.8433	147
8	67.7467	177	39.2075	154
9	65.3845	179	39.251	151

Detector: BRISK Descriptor: BRIEF

Image	Keypoint_detection_	No_of_Kpts	Descriptor_extracti	No_of_matched_Kpts

	time		on_time	
0	11.206	67	0.853106	
1	10.0879	72	0.74845	47
2	10.0743	71	0.596589	50
3	10.4667	78	1.08797	47
4	10.658	83	0.608276	49
5	10.173	77	0.92906	53
6	11.1976	80	0.685073	51
7	10.7996	80	0.821266	63
8	10.6522	84	0.667162	54
9	10.6757	75	0.580024	66

Detector: BRISK Descriptor: FREAK

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	11.8393	67	62.5359	
1	11.3862	72	39.006	46
2	11.3211	71	38.5568	46
3	10.9826	78	37.4956	46
4	11.4502	83	36.6614	58
5	10.7339	77	37.7808	49
6	10.9354	80	37.2223	55
7	10.3607	80	41.5637	53
8	10.5708	84	38.5065	60

9	10.3496	75	37.7328	61

Detector: BRISK Descriptor: ORB

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	11.4437	67	4.87686	
1	10.9041	72	3.61057	40
2	11.1165	71	3.90491	49
3	11.0332	78	4.03703	44
4	10.8859	83	10.5067	50
5	10.9708	77	3.67931	44
6	10.5399	80	4.12342	53
7	10.377	80	3.53351	50
8	10.6564	84	3.48116	56
9	10.924	75	4.08366	57

Detector: BRISK Descriptor: SIFT

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	12.3832	67	39.3064	
1	12.3186	72	22.364	50
2	10.9049	71	27.438	50
3	10.5899	78	24.2104	50

4	10.7547	83	34.0968	53
5	10.4713	77	28.8057	51
6	10.2214	80	25.185	57
7	10.6071	80	20.0613	54
8	10.774	84	22.3667	58
9	11.1406	75	18.7747	64

Detector: FAST Descriptor: BRIEF

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	0.355814	35	1.25304	
1	0.610332	38	1.2646	31
2	0.334564	38	0.530617	31
3	1.00065	40	0.91284	32
4	1.06	43	0.862699	35
5	0.310407	42	0.861866	36
6	1.10883	42	0.855285	33
7	1.21128	46	0.938538	37
8	1.22484	47	0.90251	39
9	1.08231	47	0.901178	45

Detector: FAST Descriptor: FREAK

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	0.637247	35	61.5443	

1	0.374394	38	59.6529	23
2	1.01111	38	68.9169	23
3	1.0274	40	65.1524	29
4	1.05958	43	63.9535	29
5	1.0533	42	70.2181	30
6	1.07583	42	65.8936	31
7	2.50156	46	63.8414	30
8	1.18651	47	66.1769	32
9	1.09055	47	66.816	39

Detector: FAST Descriptor: ORB

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	0.352998	35	2.97765	
1	0.354751	38	1.97019	28
2	0.314164	38	1.95465	30
3	1.17638	40	2.16056	32
4	0.313473	43	2.19931	35
5	1.05191	42	2.33055	34
6	1.059	42	2.2427	33
7	0.426514	46	0.783975	34
8	0.332375	47	1.8788	40
9	1.08745	47	0.97583	44

Detector: FAST Descriptor: SURF

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	0.526658	35	41.2912	
1	0.353458	38	24.6429	30
2	0.585404	38	25.2896	29
3	1.0757	40	36.5331	30
4	1.07106	43	38.8881	33
5	1.12104	42	36.563	35
6	0.622263	42	19.0141	34
7	1.09702	46	33.5772	33
8	1.12787	47	30.5831	36
9	1.08433	47	40.8023	35

Detector: HARRIS Descriptor: BRIEF

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	16.9563	41	0.837013	
1	14.7764	37	1.21009	35
2	11.8751	35	0.383426	33
3	13.5523	40	0.762332	32
4	14.2721	36	0.782114	34
5	10.848	36	0.490977	35
6	26.3091	38	0.772233	31
7	23.1503	37	2.38026	33

8	23.2215	33	0.514545	36
9	20.7419	35	2.71763	31

Detector: HARRIS Descriptor: FREAK

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	15.9701	41	41.7719	
1	11.3389	37	66.0788	31
2	12.2873	35	39.785	24
3	11.5069	40	39.2961	28
4	11.6559	36	37.4372	29
5	24.8172	36	70.6176	29
6	26.9301	38	70.1055	30
7	20.1714	37	52.8244	31
8	10.8716	33	37.841	28
9	15.7061	35	71.5222	25

Detector: HARRIS Descriptor: ORB

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	14.229	41	2.27581	
1	25.7688	37	2.05186	36
2	16.5395	35	2.03572	31

3	15.5566	40	1.85287	32
4	14.2263	36	2.2194	31
5	23.1386	36	1.89125	34
6	21.4881	38	2.13387	32
7	13.4016	37	2.33812	33
8	14.1056	33	2.26786	34
9	10.0834	35	2.00372	30

Detector: HARRIS Descriptor: SIFT

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	91.8386	41	21.0307	
1	14.5142	37	21.9768	38
2	10.8349	35	15.5466	33
3	21.4376	40	45.0536	34
4	27.2237	36	43.2448	36
5	17.4975	36	34.6714	34
6	26.5894	38	42.9227	32
7	28.534	37	43.0788	34
8	27.3198	33	45.2449	32
9	26.5019	35	47.428	31

Detector: ORB Descriptor: BRIEF

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts

0	7.17401	92	3.6001	
1	7.00779	102	1.43752	49
2	11.1171	106	1.2161	43
3	15.9951	113	1.4877	45
4	10.2881	109	1.49779	59
5	11.1987	125	1.35869	53
6	10.3124	130	1.58278	78
7	5.87735	129	1.7435	68
8	9.72248	127	1.95885	84
9	18.0093	128	2.00163	66

Detector: ORB Descriptor: FREAK

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	9.76366	92	68.0229	
1	6.66365	102	58.854	42
2	18.0137	106	67.3529	36
3	22.2427	113	67.8483	44
4	17.2058	109	61.1282	47
5	17.1118	125	61.5071	44
6	19.0505	130	68.2453	51
7	20.8997	129	67.6657	52
8	17.0413	127	67.1922	48
9	18.4869	128	65.1126	56

Detector: ORB Descriptor: ORB

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	13.3755	92	8.10123	
1	6.49233	102	8.88367	67
2	6.16125	106	7.40037	70
3	6.06943	113	8.46856	72
4	5.98879	109	8.09637	84
5	5.82754	125	8.07779	91
6	5.96947	130	7.70858	101
7	7.39321	129	7.84201	92
8	7.27723	127	8.76512	93
9	7.26162	128	8.51994	93

Detector: ORB Descriptor: SIFT

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	10.4388	92	34.4468	
1	5.87118	102	53.7777	67
2	13.6537	106	47.4924	79
3	6.69742	113	55.1034	78
4	17.773	109	52.9883	79
5	12.348	125	57.8984	82
6	18.4802	130	43.5745	95

7	15.8284	129	50.245	95
8	17.1125	127	59.7	94
9	18.698	128	54.0471	94

Detector: SHITOMASI Descriptor: SIFT

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	17.9531	125	42.1064	
1	12.7659	118	24.1647	112
2	16.8053	123	26.1345	109
3	28.7739	120	19.1451	104
4	17.6073	120	19.5161	103
5	27.5863	113	25.5416	99
6	31.5442	114	19.6471	101
7	28.1446	123	41.044	96
8	13.5153	111	19.2328	106
9	13.8379	112	32.5617	97

Detector: SHITOMASI Descriptor: BRIEF

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	16.255	125	2.42409	
1	25.652	118	1.79314	115

2	19.5695	123	1.08312	111
3	19.3568	120	3.66602	104
4	11.8226	120	3.9477	101
5	22.037	113	0.595923	102
6	12.5426	114	2.0119	102
7	20.6204	123	1.68346	100
8	22.8398	111	0.584235	109
9	28.4678	112	2.80642	100

Detector: SHITOMASI Descriptor: FREAK

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	13.521	125	42.792	
1	13.2254	118	39.715	86
2	26.5273	123	42.0242	90
3	11.4362	120	40.7335	86
4	11.8365	120	40.9865	88
5	16.2057	113	69.2122	86
6	14.64	114	42.7834	80
7	23.2437	123	66.3055	81
8	15.1158	111	67.175	86
9	13.9296	112	69.2529	85

Detector: SHITOMASI Descriptor: ORB

Image	Keypoint_detection_ti	No_of_Kp	Descriptor_extraction	No_of_matched_Kpts

	me	ts	_time	
0	19.1901	125	1.96185	
1	13.8088	118	2.44054	106
2	23.465	123	2.48244	102
3	15.9763	120	2.41509	99
4	28.725	120	3.02031	102
5	11.0771	113	2.53888	103
6	16.252	114	2.47829	97
7	27.5811	123	2.6193	98
8	25.6334	111	2.69538	104
9	12.5856	112	2.55923	97

Detector: SIFT Descriptor: BRIEF

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	102.626	138	0.902718	
1	86.457	132	0.729974	86
2	85.5796	124	1.5554	78
3	94.231	137	0.995495	76
4	88.8162	134	1.80392	85
5	92.3599	140	1.80723	69
6	95.4669	137	2.23025	74
7	93.3066	148	1.52468	76
8	92.5261	159	0.660251	70

9	89.4479	137	0.756034	88

Detector: SIFT Descriptor: FREAK

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	88.3693	138	64.7015	
1	77.873	132	38.5825	65
2	82.601	124	56.4846	72
3	78.1821	137	37.3037	64
4	89.7604	134	39.4036	66
5	86.3248	140	46.6889	59
6	85.77	137	48.4031	59
7	88.6532	148	51.9121	64
8	91.4593	159	38.0571	65
9	86.4073	137	45.7584	79

Detector: SIFT Descriptor: SIFT

Image	Keypoint_detection_time	No_of_Kpts	Descriptor_extraction_time	No_of_matched_Kpts
0	82.4321	138	72.697	
1	67.8572	132	56.2948	82
2	67.8035	124	55.4006	81
3	76.0738	137	54.3828	85
4	62.7916	134	60.6386	93
5	79.7524	140	57.971	90

6	65.0727	137	58.6422	81
7	73.2336	148	76.9628	82
8	70.3715	159	56.5937	102
9	77.4874	137	57.3935	104