Udacity Camera Based 2D Feature Tracking

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Task MP.1

In this task, we have to set up a new optimized loading procedure that is capable of processing a large image sequence. This was achieved by a ring buffer data structure, in which there was a fixed data buffer size and when it it's filled an image is popped out from the front.

Task MP.2

In this task, the existing implementation of key point detection included Shi-Tomasi algorithm only, and it was extended by implementing Harris detector in a separate function definition. And also, there was another function that included the modern key point detection algorithms like Brisk, FAST, ORB, AKAZE and SIFT detectors.

Task MP.3

In this task, the previous detectors functions were modified to calculate the times used by each detector to compare their performances. Also, all key points outside a predefined rectangle were removed to focus on the preceding vehicle which we want to track across the sequential frames.

Task MP.4

In this task, BRIEF, ORB, FREAK, AKAZE and SIFT descriptors were implemented in the key point descriptor function. Time calculation was added to compare the elapsed time for each descriptor.

Task MP.5

In this task, the existing implementation of matching key points function included brutal force matching, it was extended to include FLANN as well as k-nearest neighbor selector.

Task MP.6

In this task, the descriptor distance ratio test was implemented into the matching key points function, in addition to the cross check which was previously implemented. Both are used as filtering methods to remove bad key point matches.

Task MP.7

In this task, the number of key points on the preceding vehicle were counted for all 10 images. And this was done for all the previously implemented detectors.

Task MP.8

In this task, the matched key points were counted for all 10 images using all possible combinations of detectors and descriptors. In matching step, k-nn matcher was used with BF approach and descriptor distance ratio test.

It was noted from OpenCV documentation for AKAZE descriptor that it's used with AKAZE detector only. And from research in forums of OpenCV that ORB descriptor isn't used with SIFT detector.

Task MP.9

In this task, the time taken for all combinations of key points detectors and descriptors were recorded and compared to get the best 3 detector / descriptor combination. All the detailed results lies in the attached excel graphs.

The result we got that the top 3 combinations are:

1. FAST detector – ORB descriptor.
2. FAST detector – BREIF descriptor.
3. FAST detector – BRISK descriptor.

Shi-Tomasi Dtector			
Image Index	# of keypoints on Image	# of keypoints on vehicle	Elapsed Time for Dector per Image (ms)
0	1370	125	37.9695
1	1301	118	17.3899
2	1361	123	16.2274
3	1358	120	18.9961
4	1333	120	17.5507
5	1284	113	16.7101
6	1322	114	15.4865
7	1366	123	15.7671
8	1389	111	16.024
9	1339	112	16.8452
Mean	1342.3	117.9	18.89665
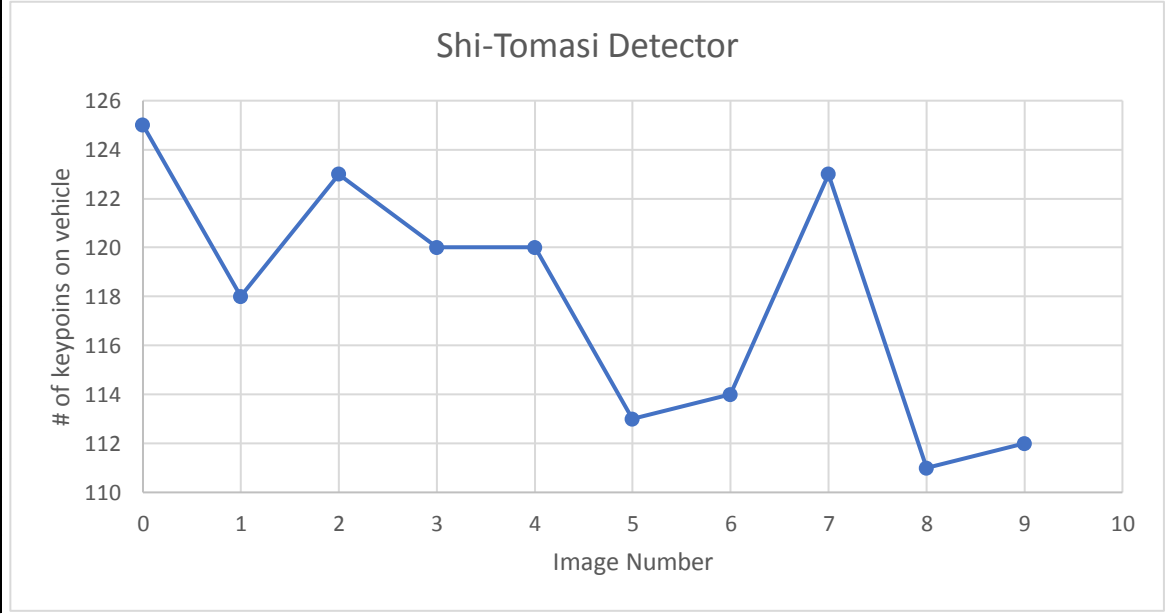
Shi-Tomasi Detector

Image Index	# of matches for BRISK	# of matches for BRIEF	# of matches for ORB	# of matches for FREAK
0				
1	125	125	125	125
2	118	118	118	118
3	123	123	123	123
4	120	120	120	120
5	120	120	120	120
6	113	113	113	113
7	114	114	114	114
8	123	123	123	123
9	111	111	111	111
SUM	1067	1067	1067	1067

# of Matches per Image

- # of matches for BRISK
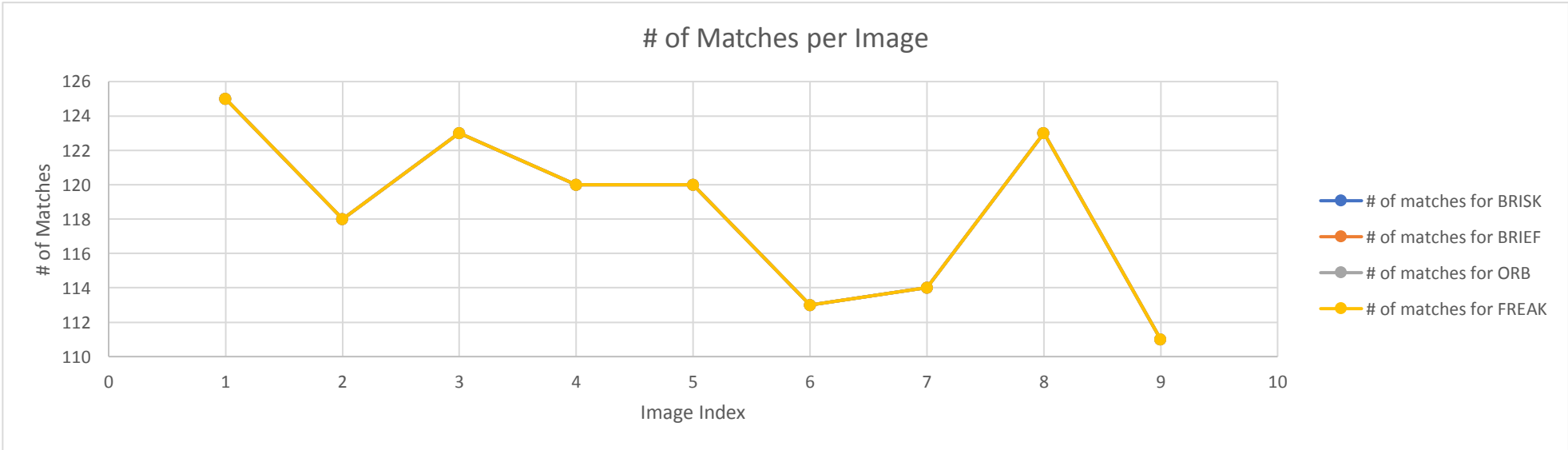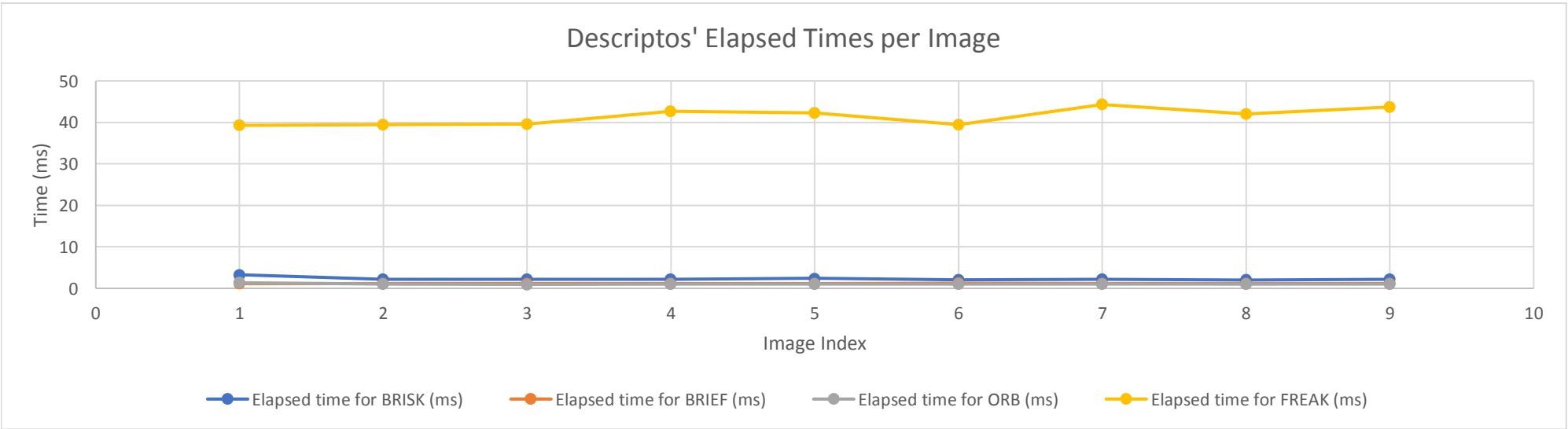- # of matches for BRIEF
- # of matches for ORB
- # of matches for FREAK

Image Index	Elapsed time for BRISK (ms)	Elapsed time for BRIEF (ms)	Elapsed time for ORB (ms)	Elapsed time for FREAK (ms)
0				
1	3.28107	1.19033	1.36258	39.2838
2	2.13899	1.19143	1.03264	39.399
3	2.23894	1.19361	0.94242	39.6157
4	2.21437	1.20197	1.00097	42.7316
5	2.3781	1.1604	0.970632	42.3201
6	2.05015	1.22436	0.981169	39.4515
7	2.18458	1.20156	0.995759	44.3081
8	1.99981	1.12714	0.984118	42.0627
9	2.20827	1.13994	1.03797	43.716
MEAN	2.299364444	1.181193333	1.034250889	41.43205556

Descriptos' Elapsed Times per Image

- Elapsed time for BRISK (ms)
- Elapsed time for BRIEF (ms)
- Elapsed time for ORB (ms)
- Elapsed time for FREAK (ms)

SUM of AVG Time	21.19601444	20.07784333	19.93090089	60.32870556

Harris Dtector			
Image Index	# of keypoints on Image	# of keypoints on vehicle	Elapsed Time for Dector per Image (ms)
0	115	17	51.327
1	98	14	29.1298
2	113	18	25.7072
3	121	21	24.474
4	160	26	25.7925
5	383	43	47.9735
6	85	18	23.7543
7	210	31	28.1114
8	171	26	26.2298
9	281	34	35.2825
Mean	173.7	24.8	31.7782
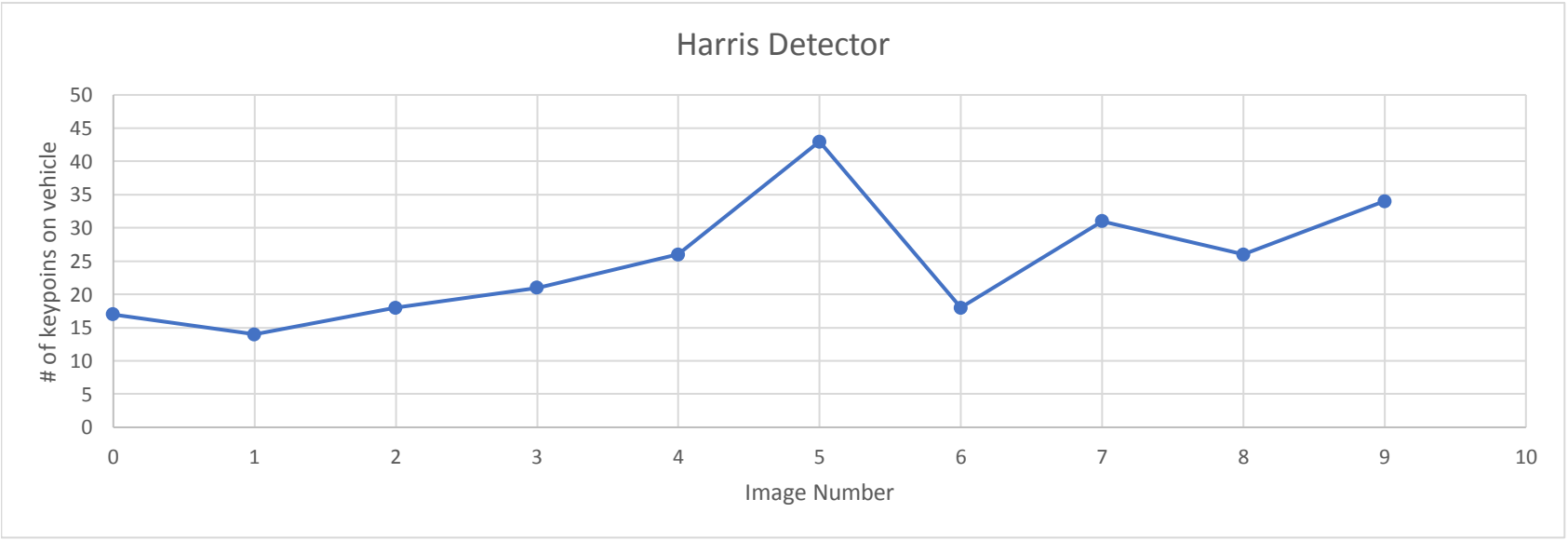
Harris Detector

Image Index	# of matches for BRISK	# of matches for BRIEF	# of matches for ORB	# of matches for FREAK
0				
1	17	17	17	17
2	14	14	14	14
3	18	18	18	18
4	21	21	21	21
5	26	26	26	26
6	43	43	43	43
7	18	18	18	18
8	31	31	31	31
9	26	26	26	26
SUM	214	214	214	214

# of Matches per Images

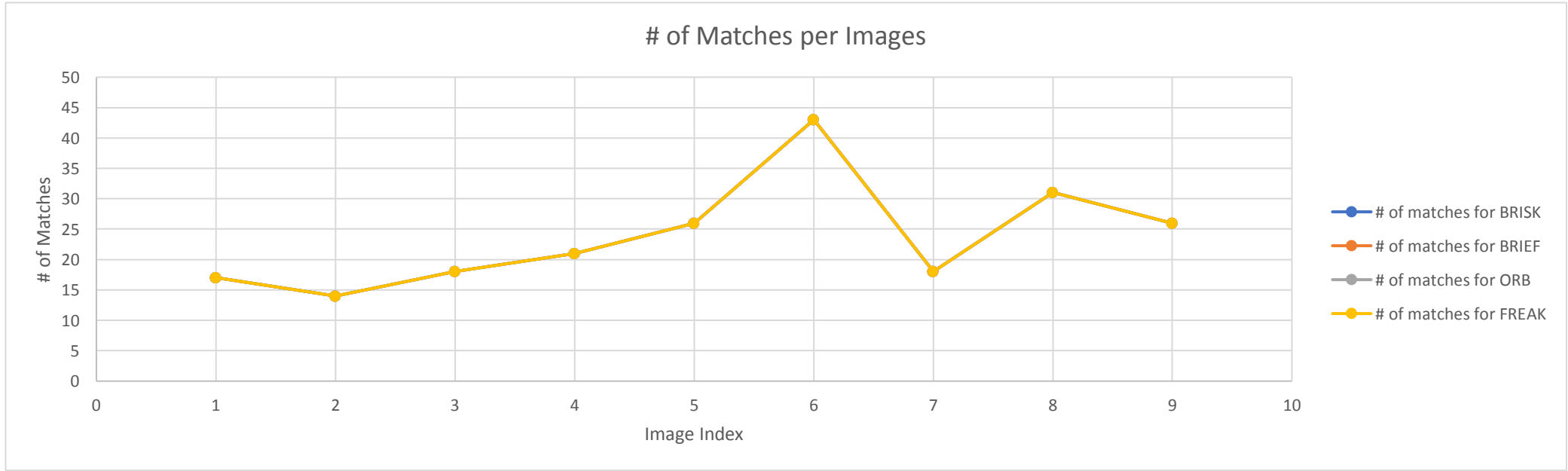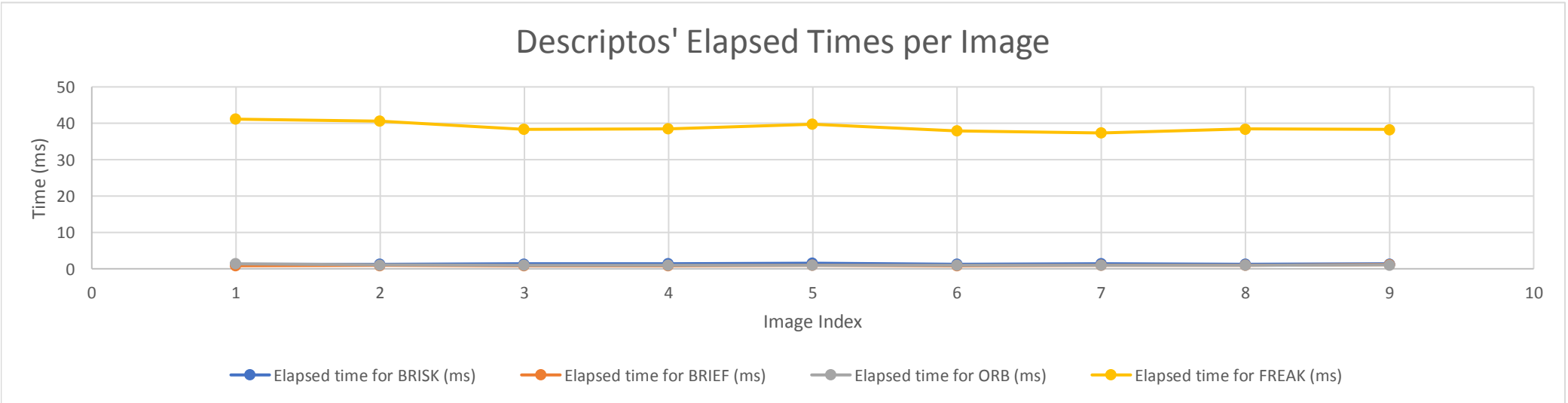| Image Index	Elapsed time for BRISK (ms)	Elapsed time for BRIEF (ms)	Elapsed time for ORB (ms)	Elapsed time for FREAK (ms)
0				
1	1.27392	0.82633	1.36258	41.1343
2	1.22858	0.889363	1.03264	40.5603
3	1.31849	0.853068	0.94242	38.306
4	1.42741	0.847829	1.00097	38.5369
5	1.52883	0.998824	0.970632	39.726
6	1.24221	0.847583	0.981169	37.9194
7	1.37399	0.93302	0.995759	37.337
8	1.2335	0.934522	0.984118	38.4031
9	1.33276	1.15552	1.03797	38.279
MEAN	1.328854444	0.920673222	1.034250889	38.91133333

Descriptos' Elapsed Times per Image

SUM of AVG Time	33.10705444	32.69887322	32.81245089	70.68953333

FAST Dtector			
Image Index	# of keypoints on Image	# of keypoints on vehicle	Elapsed Time for Dector per Image (ms)
0	1824	149	1.05047
1	1832	152	0.979416
2	1810	150	1.19246
3	1817	155	1.17089
4	1793	149	1.05252
5	1796	149	1.36714
6	1788	156	1.37199
7	1695	150	1.11795
8	1749	138	1.39656
9	1770	143	0.971066
Mean	1787.4	149.1	1.1670462
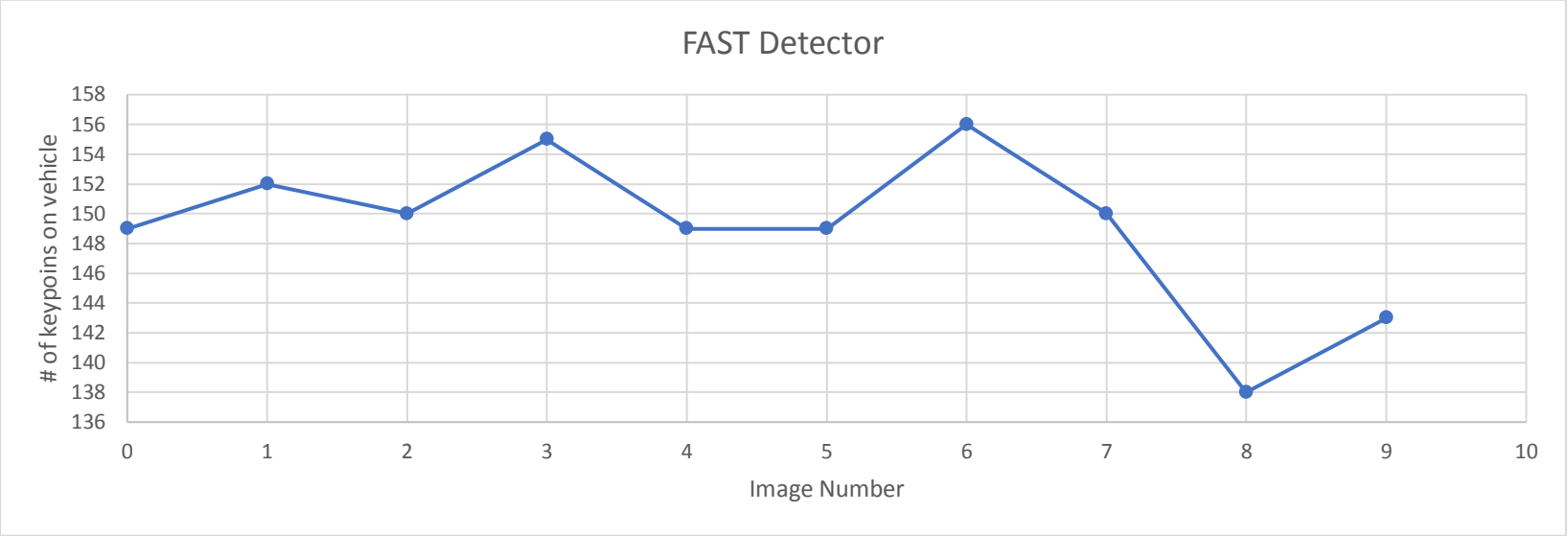
FAST Detector

Image Index	# of matches for BRISK	# of matches for BRIEF	# of matches for ORB	# of matches for FREAK
0				
1	149	149	149	149
2	152	152	152	152
3	150	150	150	150
4	155	155	155	155
5	149	149	149	149
6	149	149	149	149
7	156	156	156	156
8	150	150	150	150
9	138	138	138	138
SUM	1348	1348	1348	1348

# of Matches per Image

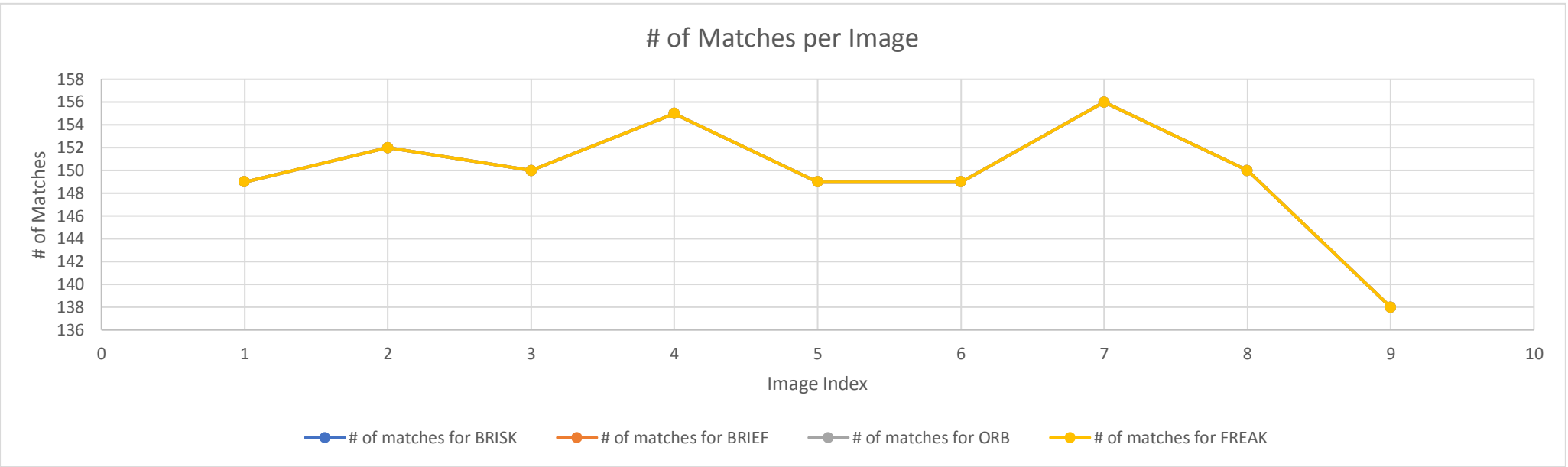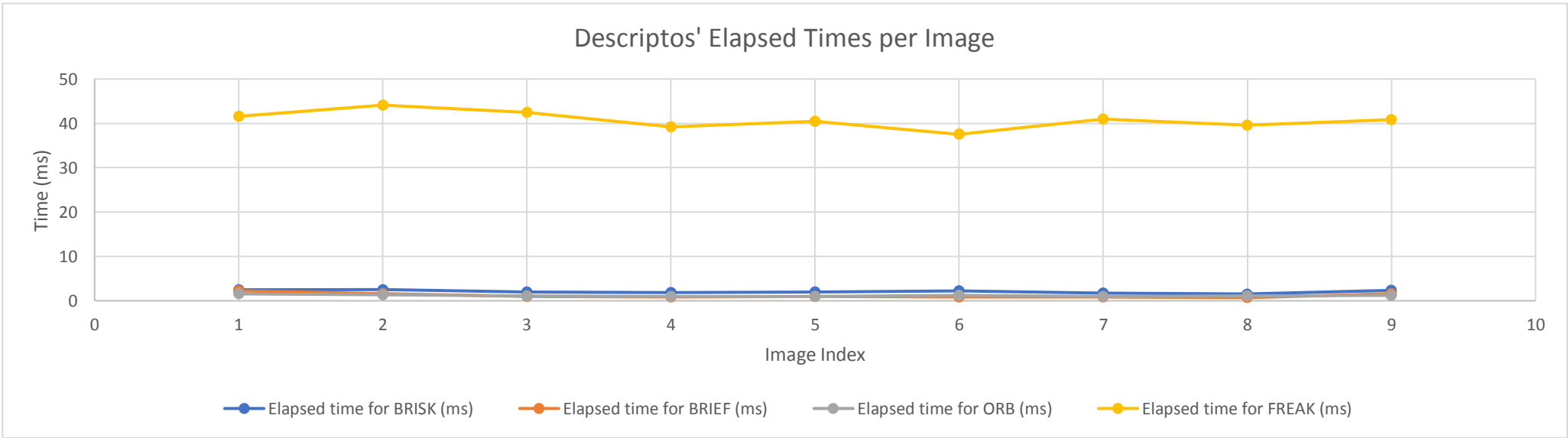| Image Index	Elapsed time for BRISK (ms)	Elapsed time for BRIEF (ms)	Elapsed time for ORB (ms)	Elapsed time for FREAK (ms)
0				
1	2.47156	2.25496	1.55587	41.5878
2	2.5294	1.56428	1.30849	44.115
3	1.97899	0.989502	1.06965	42.5209
4	1.87305	0.827229	0.96978	39.2108
5	2.02625	1.00674	0.985359	40.4161
6	2.1949	0.8677	1.21539	37.5235
7	1.75564	0.864526	0.976874	40.9968
8	1.54204	0.696562	1.14501	39.5779
9	2.30055	1.62431	1.21668	40.8955
MEAN	2.074708889	1.188423222	1.160344778	40.76047778

Descriptos' Elapsed Times per Image

SUM of AVG Time	3.241755089	2.355469422	2.327390978	41.92752398

BRISK Dtector			
Image Index	# of keypoints on Image	# of keypoints on vehicle	Elapsed Time for Dector per Image (ms)
0	2757	264	52.7642
1	2777	282	42.3601
2	2741	282	42.0089
3	2735	277	41.6495
4	2757	297	40.7387
5	2695	279	39.9898
6	2715	289	38.7836
7	2628	272	39.8095
8	2639	266	39.3914
9	2672	254	41.0838
Mean	2711.6	276.2	41.85795
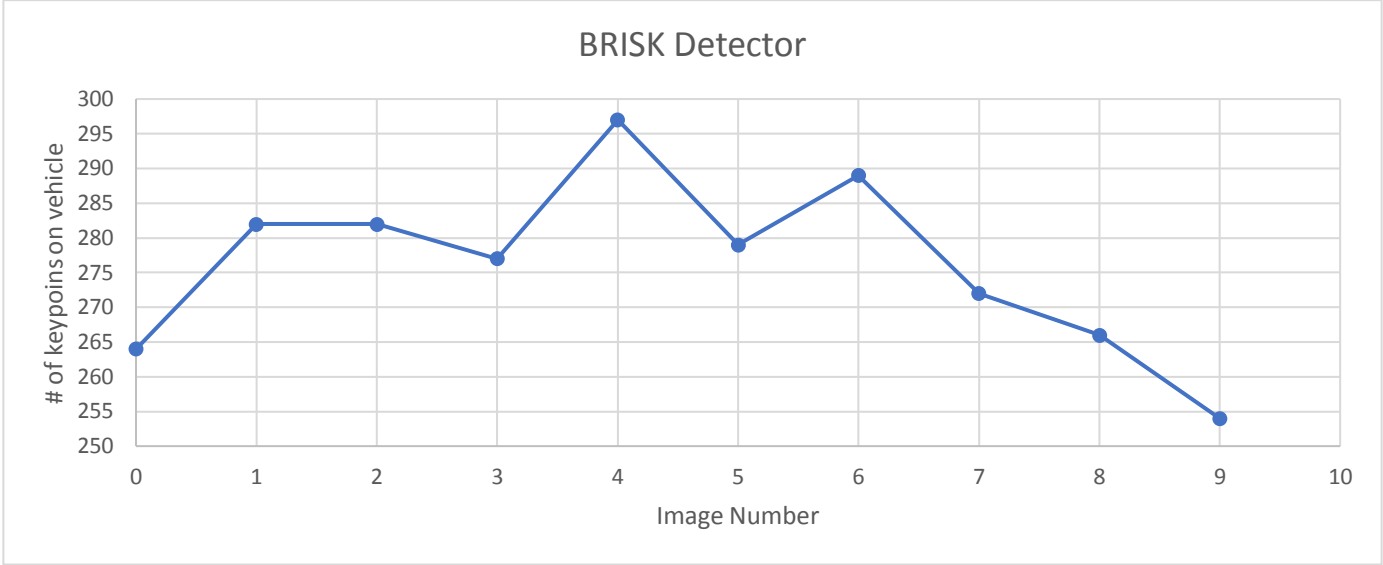
BRISK Detector

Image Index	# of matches for BRISK	# of matches for BRIEF	# of matches for ORB	# of matches for FREAK
0				
1	264	264	264	264
2	282	282	282	282
3	282	282	282	282
4	277	277	277	277
5	297	297	297	297
6	279	279	279	279
7	289	289	289	289
8	272	272	272	272
9	266	266	266	266
SUM	2508	2508	2508	2508

# of matches per Image

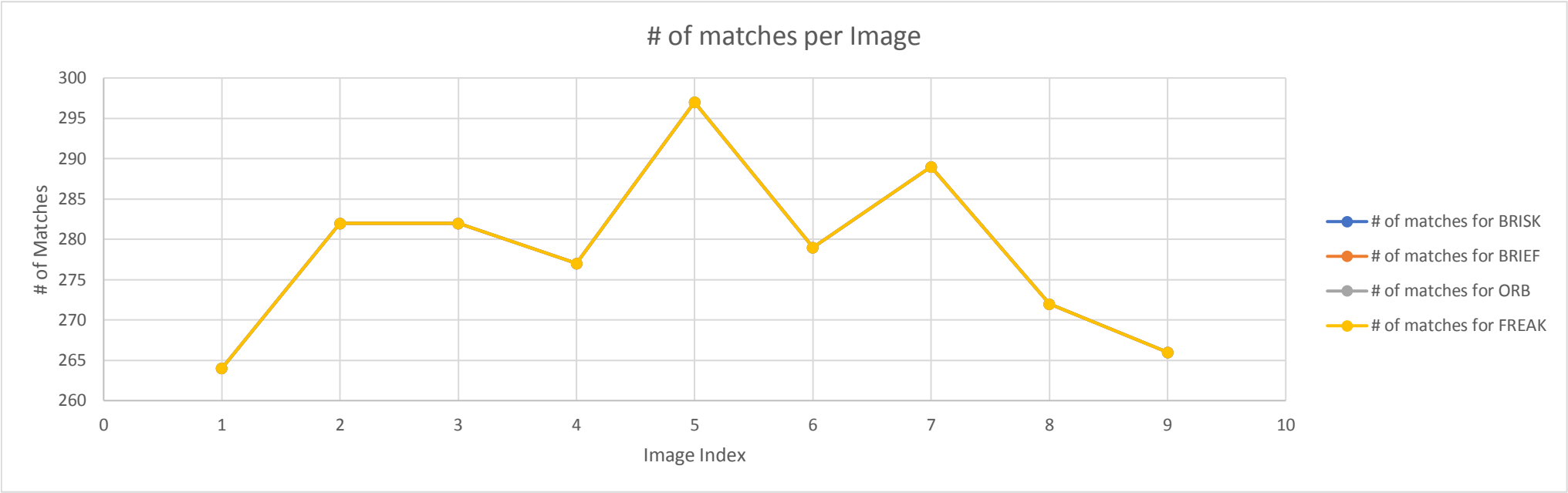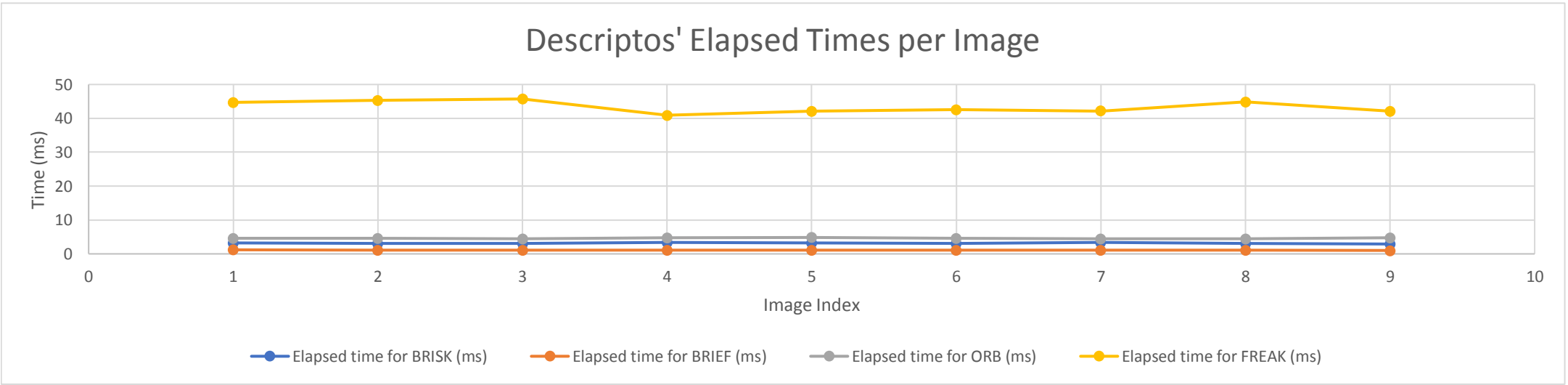| Image Index	Elapsed time for BRISK (ms)	Elapsed time for BRIEF (ms)	Elapsed time for ORB (ms)	Elapsed time for FREAK (ms)
0				
1	3.21746	1.19998	4.55586	44.7023
2	3.098	1.05425	4.53957	45.3295
3	3.13258	1.077	4.45834	45.7246
4	3.38358	1.08476	4.71926	40.9301
5	3.23052	1.10191	4.84708	42.0751
6	3.14321	1.05275	4.60777	42.6073
7	3.35481	1.10707	4.49382	42.1956
8	3.15031	1.13238	4.50023	44.9015
9	2.90685	1.01467	4.7335	42.1599
MEAN	3.179702222	1.091641111	4.606158889	43.40287778

Descriptos' Elapsed Times per Image

SUM of AVG Time	45.03765222	42.94959111	46.46410889	85.26082778

ORB Dtector			
Image Index	# of keypoints on Image	# of keypoints on vehicle	Elapsed Time for Dector per Image (ms)
0	500	92	17.9672
1	500	102	8.0247
2	500	106	7.62688
3	500	113	7.39937
4	500	109	7.82889
5	500	125	7.56767
6	500	130	8.22909
7	500	129	7.89605
8	500	127	7.89133
9	500	128	8.01667
Mean	500	116.1	8.844785
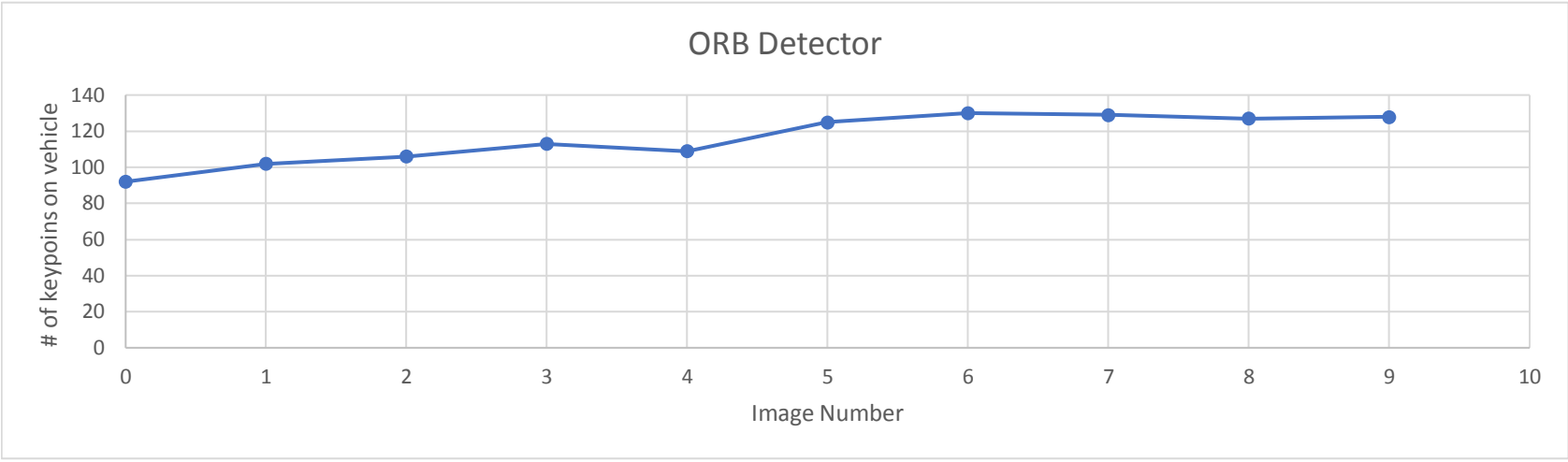
ORB Detector

Image Index	# of matches for BRISK	# of matches for BRIEF	# of matches for ORB	# of matches for FREAK
0				
1	83	92	92	46
2	93	102	102	53
3	95	106	106	56
4	103	113	113	65
5	101	109	109	55
6	116	125	125	64
7	120	130	130	66
8	120	129	129	71
9	119	127	127	73
SUM	950	1033	1033	549

# of Matches per Image

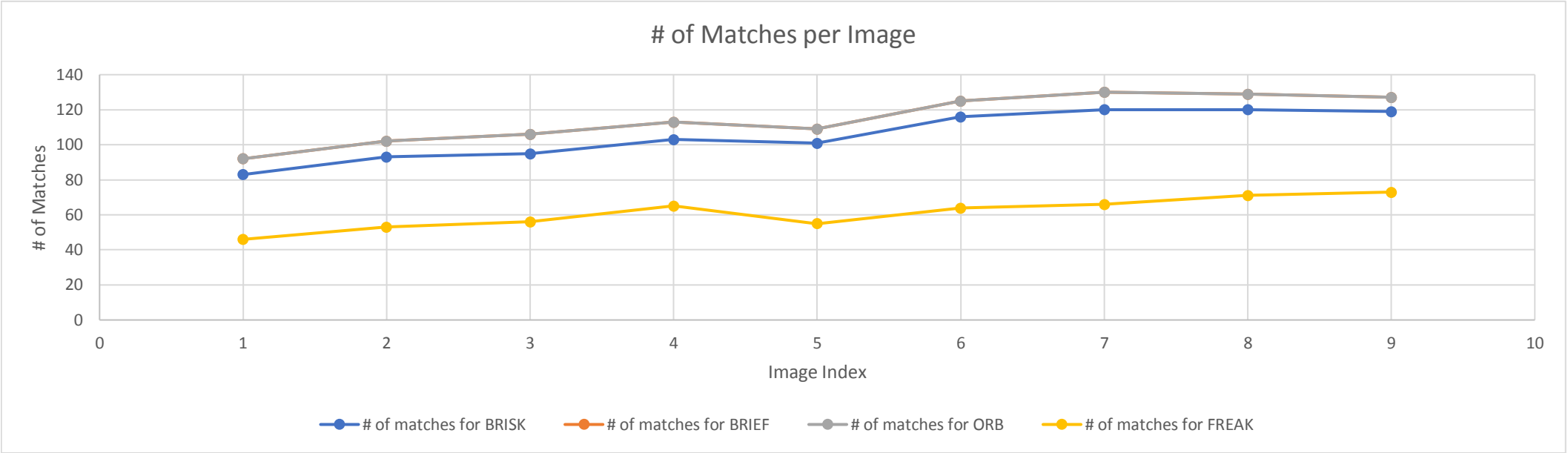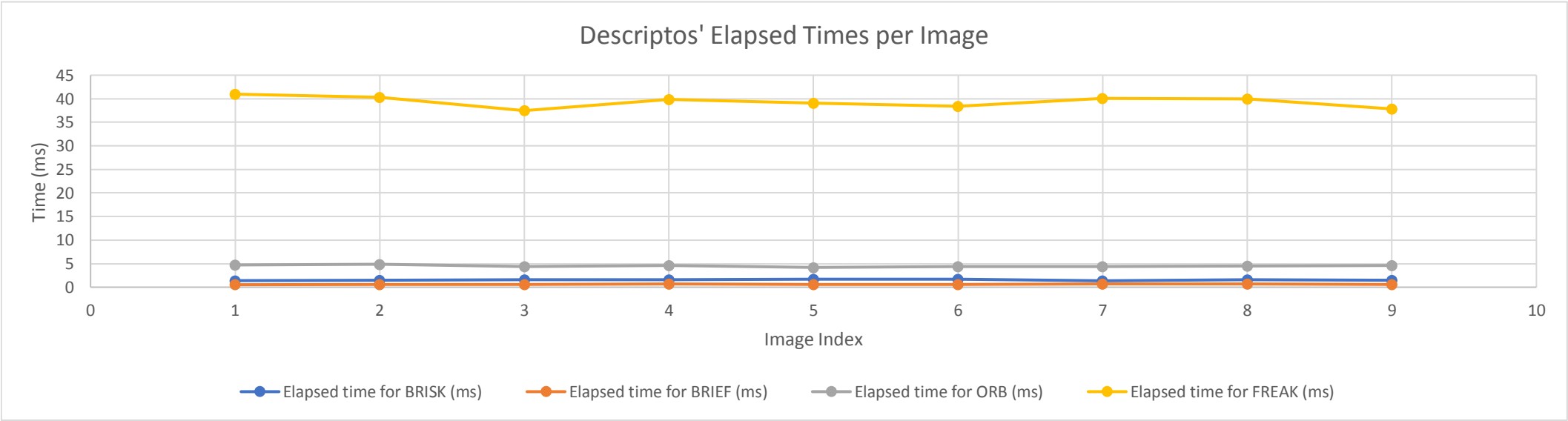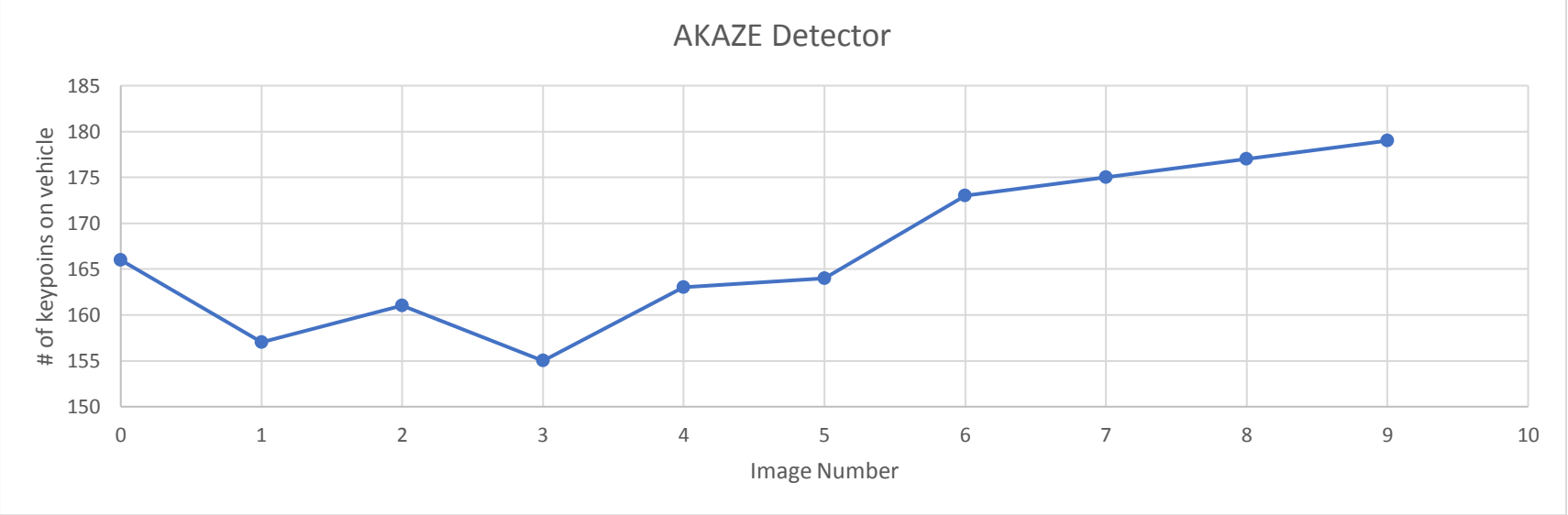| Image Index	Elapsed time for BRISK (ms)	Elapsed time for BRIEF (ms)	Elapsed time for ORB (ms)	Elapsed time for FREAK (ms)
0				
1	1.39917	0.529602	4.67537	40.976
2	1.423	0.565598	4.8742	40.353
3	1.59642	0.537727	4.37605	37.4768
4	1.64204	0.667713	4.5776	39.8486
5	1.67468	0.608478	4.20171	39.0734
6	1.69821	0.613843	4.36106	38.425
7	1.39939	0.696743	4.33904	40.0348
8	1.53776	0.69541	4.46232	39.9273
9	1.46976	0.605237	4.56357	37.8216
MEAN	1.537825556	0.613372333	4.492324444	39.32627778

Descriptos' Elapsed Times per Image

SUM of AVG Time	10.38261056	9.458157333	13.33710944	48.17106278

AKAZE Dtector			
Image Index	# of keypoints on Image	# of keypoints on vehicle	Elapsed Time for Dector per Image (ms)
0	1351	166	98.6954
1	1327	157	79.3089
2	1311	161	81.495
3	1351	155	80.5942
4	1360	163	76.32
5	1347	164	79.341
6	1363	173	81.9346
7	1331	175	83.1111
8	1357	177	81.948
9	1331	179	80.8712
Mean	1342.9	167	82.36194

AKAZE Detector

Note : AKAZE descriptor can only be used with KAZE or AKAZE keypoints

Image Index	# of matches for AKAZE
0	
1	166
2	157
3	161
4	155
5	163
6	164
7	173
8	175
9	177
SUM	1491

# of Matches per Image
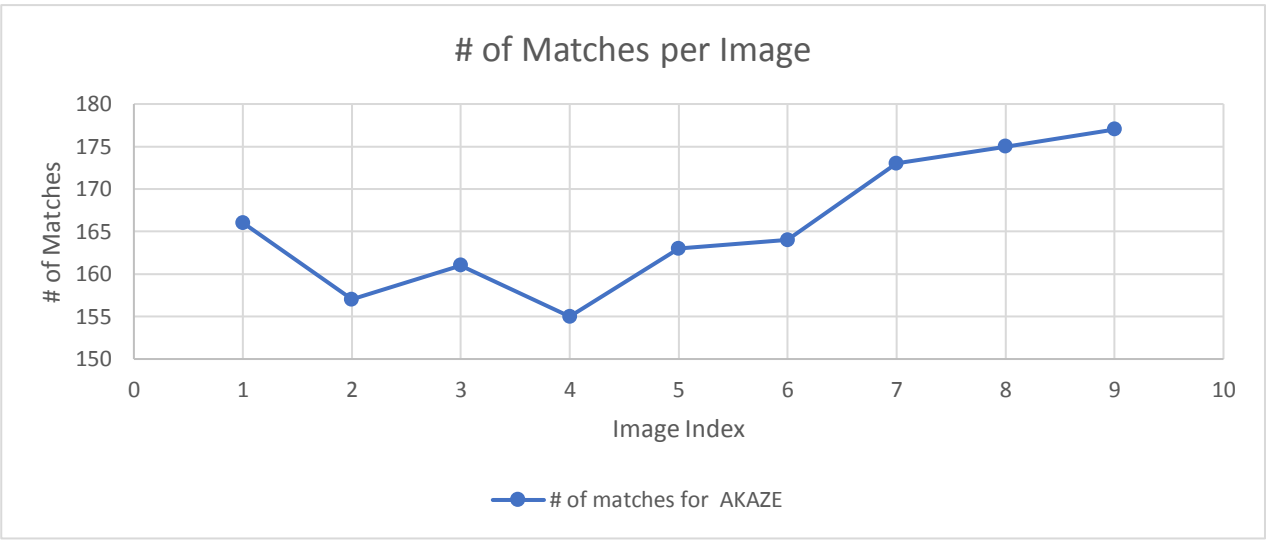
Image Index	Elapsed time for AKAZE (ms)
0	
1	69.8382
2	68.7352
3	74.1472
4	69.5598
5	71.8534
6	74.5233
7	68.5908
8	75.8074
9	70.988
MEAN	71.56036667

ELAPSED TIME FOR AKAZE PER IMAGE
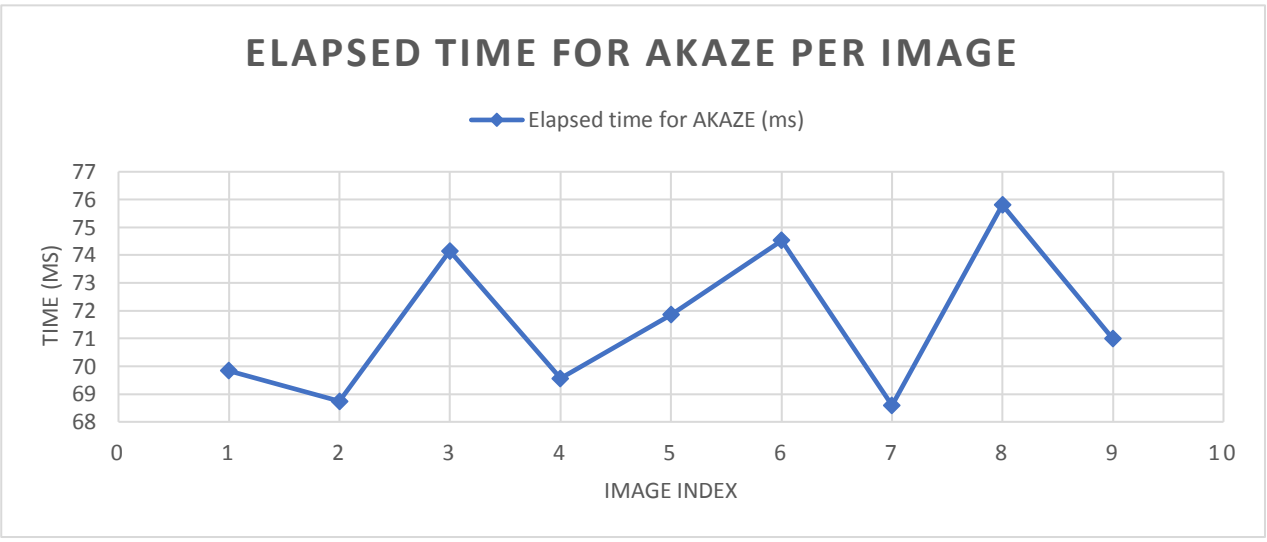
SUM of AVG Time	153.9223067

SIFT Dtector			
Image Index	# of keypoints on Image	# of keypoints on vehicle	Elapsed Time for Dector per Image (ms)
0	1438	138	136.531
1	1371	132	118.755
2	1380	124	123.528
3	1335	137	118.032
4	1305	134	120.8
5	1370	140	121.378
6	1396	137	123.53
7	1382	148	124.806
8	1463	159	133.156
9	1422	137	140.256
Mean	1386.2	138.6	126.0772

SIFT Detector
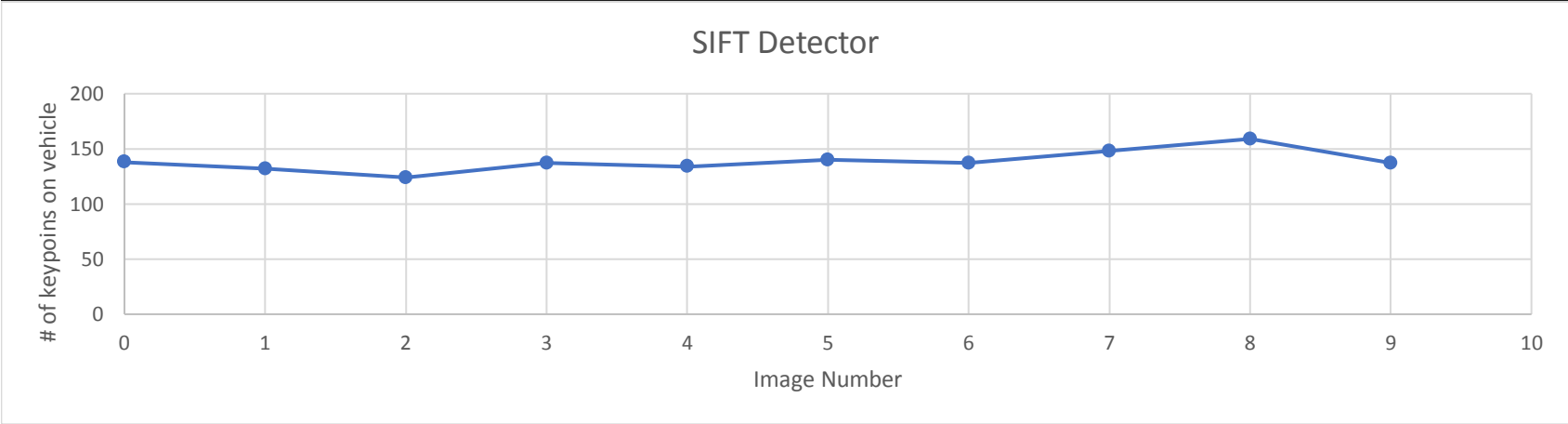
Image Index	# of matches for BRISK	# of matches for BRIEF	# of matches for FREAK	# of matches for SIFT
0				
1	137	132	137	138
2	132	124	131	132
3	124	137	123	124
4	137	134	136	137
5	134	140	133	134
6	137	140	139	140
7	137	137	135	137
8	148	148	147	148
9	159	159	158	159
SUM	1245	1251	1239	1249

# of Matches per Image

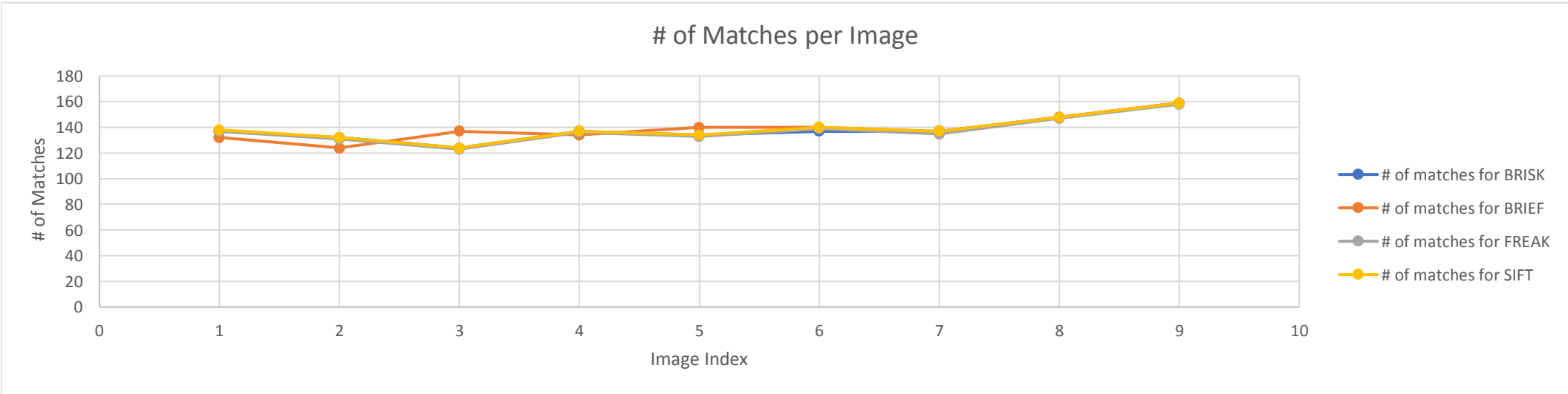| Image Index	Elapsed time for BRISK (ms)	Elapsed time for BRIEF (ms)	Elapsed time for FREAK (ms)	Elapsed time for SIFT (ms)
0				
1	1.6768	0.777349	40.3885	79.2136
2	1.64411	0.759691	42.6813	74.528
3	1.84806	0.815263	41.2392	77.812
4	1.62583	0.799117	39.5215	78.3423
5	1.68593	0.830829	42.3891	78.4994
6	1.87657	0.7993	43.1499	76.0344
7	1.98509	0.753277	39.209	87.0206
8	1.90826	0.91335	41.0367	81.1545
9	1.56911	0.783742	40.2762	83.7402
MEAN	1.757751111	0.803546444	41.09904444	79.59388889

Descriptos' Elapsed Times per Image
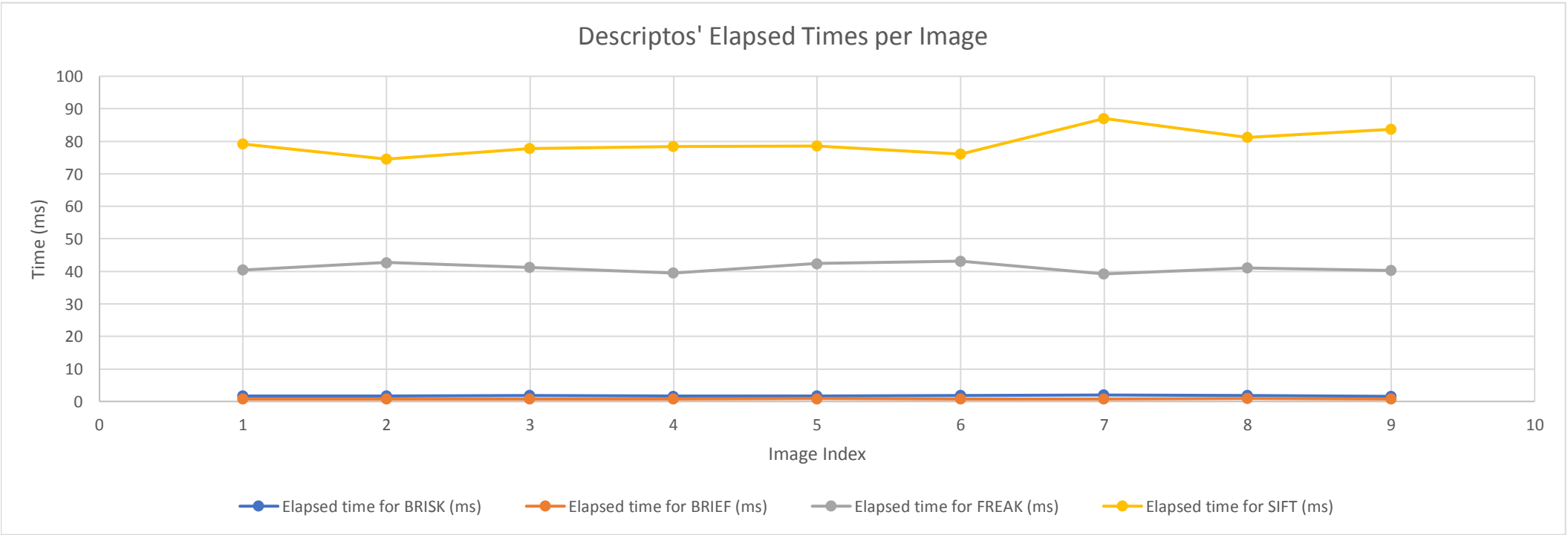
SUM of AVG Time	127.8349511	126.8807464	167.1762444	205.6710889