Sensor Fusion Nanodegree

Camera-Based 2D Tracking: Midterm Project Report

MP.0 Mid-Term Report

This report briefly describes the implementation of each task.

MP.1 Data Buffer Optimization

```
58
59      //// STUDENT ASSIGNMENT
60      //// TASK MP.1 -> replace the following code with ring buffer of size dataBufferSize
61
62      // push image into data frame buffer
63      DataFrame frame;
64      frame.cameraImg = imgGray;
65      if (dataBuffer.size() < dataBufferSize)
66      {
67          dataBuffer.push_back(frame);
68      }
69      else
70      {
71          dataBuffer.push_back(frame);
72          dataBuffer.erase(dataBuffer.begin());
73      }
74
75      //// EOF STUDENT ASSIGNMENT
```

Using the *std::vector* functions *push_back* and *erase*, new images are added to the end of the buffer and old ones are removed from the top, if the size of the data buffer had reached the predefined size.

MP.2 Keypoint Detection

The Harris detector was implemented in the function *detKeypointsHarris* along with Non Maximum Supression. The rest of the detectors are implemented in the function *detKeypointsModern*, where each detector type uses the default parameters.

MP.3 Keypoint Removal

Keypoints that do not belong to the predefined region of interest (the preceding vehicle) are removed using the *cv::rect::contains* function.

MP.4 Keypoint Descriptors

The different descriptor types are implemented in *descKeypoints* and can be selected based on the string *descriptorType*. The descriptors are created with the default parameters and assigned to the *extractor* variable.

MP.5 Descriptor Matching

The FLANN-based matching was implemented in *matchDescriptors* and is selectable based on *matcherType*. Also, a workaround for the opencv bug is implemented to convert binary descriptors to float for FLANN-based matching.

MP.6 Descriptor Distance Ration

For the KNN matching, the best two matches for each descriptor in the source are detected and saved to the array *knnmatches*. Afterwards, looping over *knnmatches*, only unambiguous matches are saved to the output array *matches* based on a distance ratio of 0.8.

MP.7 Performance Evaluation 1

Detector Type	Img#	No. Of keypoints	Mean neighborhood size	Standard deviation of neighborhood	Computation Time	Example	Notes
Shi-Tomasi	Img1	125	4	0	~19 ms		- Constant neighborhood size - No overlap - Keypoint clusters around number plate
	Img2	118	4	0			
	Img3	123	4	0			
	Img4	120	4	0			
	Img5	120	4	0			
	Img6	113	4	0			
	Img7	114	4	0			
	Img8	123	4	0			
	Img9	111	4	0			
	Img10	112	4	0			
Harris	Img1	17	6	0	~20 ms		- Constant neighborhood size - No overlap - No distinctive clusters - Keypoints only detected at very high changes in intensity
	Img2	15	6	0			
	Img3	19	6	0			
	Img4	19	6	0			
	Img5	25	6	0			
	Img6	46	6	0			
	Img7	17	6	0			
	Img8	31	6	0			
	Img9	25	6	0			
	Img10	34	6	0			
FAST	Img1	149	7	0	~1 ms		- Constant neighborhood size - The majority of keypoints are overlapping - Clusters around large changes in intensity
	Img2	152	7	0			
	Img3	150	7	0			
	Img4	155	7	0			
	Img5	149	7	0			
	Img6	149	7	0			
	Img7	156	7	0			
	Img8	150	7	0			
	Img9	138	7	0			
	Img10	143	7	0			
BRISK	Img1	264	22.5	212.5	~50 ms		- Relatively large keypoints - The majority of keypoints are overlapping
	Img2	282	21.78	212.13			
	Img3	282	21.65	191.0			
	Img4	277	20.35	159.23			
	Img5	297	22.59	220.7			
	Img6	279	22.94	249.96			
	Img7	289	21.80	215.38			
	Img8	272	22.15	226.02			
	Img9	266	22.56	230.7			
	Img10	254	22.04	215.12			
ORB	Img1	92	57	661.1	~8 ms		- Very large keypoints - The majority of keypoints are overlapping - A lot of concentric keypoints
	Img2	102	57.22	680.59			
	Img3	106	56.5	672.11			
	Img4	113	55.14	629.78			
	Img5	109	56.74	625.65			
	Img6	125	56.64	596.8			
	Img7	130	56.77	646.4			
	Img8	129	55.43	611.9			
	Img9	127	54.67	638.1			
	Img10	128	54.39	560.29			
AKAZE	Img1	166	7.73	15.3	~120 ms		- Relatively small keypoints - Few overlapping keypoints - Evenly distributed
	Img2	157	7.49	12.42			
	Img3	161	7.45	12.62			
	Img4	155	7.57	11.96			
	Img5	163	7.73	11.8			
	Img6	164	7.68	11.4			
	Img7	173	7.73	11.78			
	Img8	175	7.82	12.32			
	Img9	177	7.82	12.2			
	Img10	179	7.89	12.97			
SIFT	Img1	138	4.98	35.0	~170 ms		- Mostly small keypoints - A few overlapping keypoints
	Img2	132	5.09	38.1			
	Img3	124	4.94	36.24			
	Img4	137	4.73	27.46			
	Img5	134	4.7	30.37			
	Img6	140	4.68	31.1			
	Img7	137	5.4	42.42			
	Img8	148	4.62	26.45			
	Img9	159	5.52	44.49			
	Img10	137	5.62	44.64			

MP.8 Performance Evaluation II

Descriptor Type / Detector Type		BRISK				BRIEF				ORB				FREAK				AKAZE				SIFT			
	Img#	No of matches	Detector time	Descriptor time	Total time	No of matches	Detector time	Descriptor time	Total time	No of matches	Detector time	Descriptor time	Total time	No of matches	Detector time	Descriptor time	Total time	No of matches	Detector time	Descriptor time	Total time	No of matches	Detector time	Descriptor time	Total time
Shi-Tomasi	1,2	95.00	29.5	5.04	34.54	115	20.12	2.24	22.36	106	20.62	1.45	22.07	86	18.32	50.34	68.66					112	12.08	19.91	31.99
	2,3	88	20.33	3.62	23.95	111	21.9	1.87	23.77	102	23.68	1.09	24.77	90	18.05	49.12	67.17					109	17.26	20.45	37.71
	3,4	80	19.65	3.43	23.08	104	19.03	1.7	20.73	99	19.76	1.23	20.99	86	12.9	48.5	61.40					104	12.79	17.69	30.48
	4,5	90	20.1	2.59	22.69	101	19.45	1.77	21.22	102	18.3	1.02	19.32	88	14.2	61.62	75.82					103	12.74	17.47	30.21
	5,6	82	18.76	2.51	21.27	102	18.43	1.7	20.13	103	19.24	1.05	20.29	86	12.5	50.95	63.45					99	12.23	16.5	28.73
	6,7	79	18.3	2.59	20.89	102	18	1.75	19.75	97	22	1.833	23.83	80	13.77	58.84	72.61					101	15.43	27.64	43.07
	7,8	85	19.39	2.64	22.03	100	22.58	1.73	24.31	98	18.3	1.09	19.39	81	13.48	50.58	64.06					96	12.26	17.32	29.58
	8,9	86	18.63	3.79	22.42	109	19.49	1.67	21.16	104	18.64	1.03	19.67	86	12.9	58.28	71.18					106	20.68	23.66	44.34
	9,10	82	18.85	2.53	21.38	100.00	16.96	1.8	18.76	97	19.9	1.47	21.37	85	15.3	65.2	80.50					97	14.79	17.67	32.46
Harris	1,2	9.00	19.53	1.43	20.96	12	19.06	1.36	20.42	11	18.35	1.11	19.46	12	19.2	48.3	67.50					12.00	18.18	25.07	43.25
	2,3	11	18.9	1.45	20.35	13	19.57	1.3	20.87	13	19.57	0.93	20.50	10	17.9	50	67.90					13	20.25	26.26	46.51
	3,4	14	23.15	1.54	24.69	15	1.16	18.08	19.24	16	19.78	0.9	20.68	14	16.5	55.9	72.40					16	21.069	27.723	48.79
	4,5	13	21.02	1.56	22.58	17	20.4	1.32	21.72	17	20.04	0.92	20.96	14	14	47.78	61.78					17	18.89	25.98	44.87
	5,6	16	41.42	1.83	43.25	24	39.16	1.97	41.13	23	44.3	1.09	45.39	18	32.89	48.5	81.39					23	43.58	27.9	71.48
	6,7	13	17.86	1.56	19.42	24	21.6	1.3	22.90	17	16.7	0.84	17.54	14	12.37	49	61.37					23	21.24	33.5	54.74
	7,8	12	20.8	1.62	22.42	15	20.1	1.6	21.70	13	21.12	1.24	22.36	10	17.9	61.2	79.10					13	25.56	23.53	49.09
	8,9	17	23.2	1.54	24.74	25	19.09	1.28	20.37	27	19.522	0.9	20.42	19	15	57.7	72.70					24	20.3	25.7	46.00
	9,10	17	28.66	1.62	30.28	24	24.76	1.82	26.58	25	27.3	0.89	28.19	18	21.8	49.7	71.50					24	25.44	18	43.44
FAST	1,2	97	1.29	2.94	4.23	119	2.11	1.87	3.98	118	1.29	1.38	2.67	98	0.97	55.3	56.27					118	0.925	40.23	41.16
	2,3	104	0.9	3.2	4.10	130	0.97	1.93	2.90	123	0.85	1.3	2.15	99	2.27	66.8	69.07					123	1.06	47.67	48.73
	3,4	101	0.89	2.0	2.89	118	0.89	1.14	2.03	112	0.86	1.9	2.76	91	0.9	56.53	57.43					110	0.89	40.7	41.59
	4,5	98	0.9	2.2	3.10	126	0.8	1.1	1.90	126	0.96	1.1	2.06	98	0.93	54.7	55.63					119	0.99	38.4	39.39
	5,6	85	0.9	2.0	2.90	108	0.8	1.33	2.13	106	1.47	1.11	2.58	85	1.19	56.06	57.25					114	0.79	30.3	31.09
	6,7	107	0.8	2.0	2.80	123	0.87	0.84	1.71	122	1.35	1.14	2.49	99	1.11	53.0	54.11					119	0.8	34.95	35.75
	7,8	107	1.37	1.9	3.27	131	0.9	0.82	1.72	122	0.84	1.2	2.04	102	0.911	65.83	66.74					123	1.35	36.09	37.44
	8,9	100	1.78	1.39	3.17	125	1.0	1.98	2.98	123	0.94	1.1	2.04	101	0.86	47.76	48.62					117	0.8	40.47	41.27
	9,10	100	0.95	2.0	2.95	119	0.87	0.79	1.66	119	0.94	1.1	2.04	105	0.8	64.29	65.09					103	0.86	33.26	34.12
BRISK	1,2	171	52	3.5	55.50	176	48.9	1.29	50.19	162	49.7	5.6	55.30	160	49.88	53.74	103.62					182	50.08	68.74	118.82
	2,3	176	49.53	3.5	53.03	205	49.45	1.2	50.65	175	49.7	5.0	54.70	177	53.00	52.2	105.20					193	65.55	77.07	142.62
	3,4	157	48.65	3.4	52.05	185	47.46	1.78	49.24	158	48.34	5.0	53.34	155	54.04	52.02	106.06					169	51.83	86.64	138.47
	4,5	176	47.47	3.67	51.14	179	49.74	1.31	51.05	167	48	5.2	53.20	173	58.65	49.58	108.23					183	53.55	103.73	157.28
	5,6	174	48.06	3.55	51.61	183	47.55	1.23	48.78	160	53.34	4.82	58.16	161	55.8	52.52	108.32					171	64.54	72.7	137.24
	6,7	188	47.94	3.62	51.56	195	51.32	1.28	52.60	182	52.0	5.0	57.00	183	47.36	54.33	101.69					195	50.08	74.04	124.12
	7,8	173	47.1	3.42	50.52	207	46.96	1.18	48.14	167	47.77	5.02	52.79	169	46.96	52.3	99.26					194	49.5	68.2	117.70
	8,9	171	47.44	3.41	50.85	189	50.62	1.15	51.77	171	47.56	5.02	52.58	178	48.45	53.8	102.25					176	52.09	73.6	125.69
	9,10	184	48.2	3.2	51.40	183	47.3	1.2	48.50	172	47.0	4.85	51.85	168	47.2	48.58	95.78					183	51.86	65.5	117.36
ORB	1,2	73	9.87	1.57	11.44	49	10.25	0.6	10.85	67	8.82	5.1	13.92	42	9.72	53.68	63.40								
	2,3	74	9.72	2.14	11.86	43	10.42	0.62	11.04	70	12.05	5.93	17.98	36	10.3	62.3	72.60								
	3,4	79	9.32	1.66	10.98	45	9.2	0.75	9.95	72	11.54	8.43	19.97	44	8.1	51.57	59.67								
	4,5	85	8.6	1.7	10.30	59	8.1	0.77	8.87	84	9.82	6.99	16.81	47	8.8	50.8	59.60								
	5,6	79	9.86	1.8	11.66	53	8.36	0.99	9.35	91	13.67	7.26	20.93	44	9.0	59.0	68.00								
	6,7	92	8.42	1.87	10.29	78	7.63	1.14	8.77	101	13.29	5.93	19.22	51	8.25	50.59	58.84								
	7,8	90	8.59	1.87	10.46	68	10.49	0.73	11.22	92	10.0	6.28	16.28	52	8.11	48.6	56.71								
	8,9	88	8.92	1.98	10.90	84	7.8	1.12	8.92	93	8.33	5.4	13.73	48	9.15	50.7	59.85								
	9,10	91	16.94	2.14	19.08	66	9.93	0.74	10.67	93	8.36	6.43	14.79	48	9.15	50.7	59.85								
AKAZE	1,2																	138	113.86	101.8	215.66				
	2,3																	138	126.83	114.84	241.67				
	3,4																	133	123.88	104.26	228.14				
	4,5																	127	109.9	114.15	224.05				
	5,6																	129	110.7	112.15	222.85				
	6,7																	146	127	135	262.00				
	7,8																	147	156.05	132.34	288.39				
	8,9																	151	183.02	141.56	324.58				
	9,10																	150	174.4	117.6	292.00				
SIFT	1,2	64	238.22	1.75	239.97	86	174.8	1.19	175.99					65	160.65	48.82	209.47					82	142.44	94.94	237.38
	2,3	66	218.32	1.8	220.12	78	197.14	0.78	197.92					72	175.0	50.6	225.60					81	159.9	99.58	259.48
	3,4	62	225.37	2.17	227.54	76	164	1.33	165.33					64	203.8	56.0	259.80					85	159.86	97.2	257.06
	4,5	66	259.66	2.03	261.69	85	171.8	1.32	173.12					66	206.2	55.09	261.29					93	180	144.2	324.20
	5,6	59	187.07	1.97	189.04	69	182.0	2.57	184.57					59	167.4	53.6	221.00					90	183.3	194.67	377.97
	6,7	64	181.77	2.07	183.84	74	254.1	0.95	255.05					59	217.02	57.5	274.52					81	155.72	168.35	324.07
	7,8	64	232.3	2.04	234.34	76	207.14	1.33	208.47					64	169.1	54.4	223.50					82	174.1	101.3	275.40
	8,9	67	172.1	2.27	174.37	70	178.66	0.91	179.57					65	177.3	53.3	230.60					102	220.73	182.63	403.36
	9,10	80	254.46	1.79	256.25	88	228.44	0.86	229.30					79	292.97	51.3	344.27					104	188.35	113.2	301.55

MP.9 Performance Evaluation II

		Descriptor					
		BRISK	BRIEF	ORB	FREAK	AKAZE	SIFT
Detector	Shi-Tomasi						
	Harris						
	FAST						
	BRISK						
	ORB						
	AKAZE						
	SIFT						

The performance evaluation was carried out as follows:

1. All detector/descriptor combination that yield significantly low amounts of matches or significantly high computation times were directly excluded and are indicated in red in the table above. Some of these combinations required a computation time of several hundreds of milliseconds, which might be critical in real-time applications, depending on the computation time of the rest of the processing pipeline. The rest of the eliminated combinations only found fewer than a hundred matches, which is comparatively low.
2. The remaining combinations from step 1 are combinations of the Shi-Tomasi, FAST and BRISK detectors with multiple descriptors. So the next step was to determine the best combination for each detector type, which yields the Shi-Tomasi/BRIEF, FAST/BRIEF and BRISK/BRIEF combinations, as indicated in green in the table above.
3. Since the results of all three combinations are similar in terms of computation power and number of matches (2-50 ms and over 100 matches), another metric for the comparison could be the relation between the number of matches to the number keypoints detected. This metric shows how many keypoints could not be matched or were too ambiguous and were filtered out by the distance ratio. The results are shown in the table below.

   With the highest matches-to-keypoints percentage and the fastest computation time, the **FAST/BRIEF** can be considered the best combination. Since it has the highest absolute number of matches and a larger neighborhood size, the **BRISK/BRIEF** combination can be considered second best. With a relatively high computation time and a relatively low amounts of keypoints and matches, the **Shi-Tomasi/BRIEF** combination comes last.

Combination	Average no. of keypoints	Average no. of matches	Percentage of matches
Shi-Tomasi/BRIEF	118.00	105.00	88.98
FAST/BRIEF	134.00	122.00	91.04
BRISK/BRIEF	267.00	189.00	70.79