Camera Based 2D Feature Tracking

MP.1 – MP.6 were the steps to implement the project code. I implemented the image ring buffer, detector, keypoint removal, descriptor extraction, and descriptor matching by reviewing the previous lectures and assignments as well as reading through the OpenCV documentation online.

MP.7 – MP.9 were performance evaluations of the different detector and descriptor algorithms.

**MP.7**

To complete MP.7 I used a rectangle filter to remove all keypoints not on the preceding vehicle. I shrunk the rectangle filter coordinates down as small as possible while keeping all the keypoints on the preceding vehicle through all ten images. Below is the chart of my results. I also looked for which algorithms found keypoints on key parts of the car (like the license plate and tires).

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Detector \ Image** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **Average** | **License Plate** | **Tires** |
| SHITOMASI | 78 | 79 | 86 | 79 | 82 | 79 | 79 | 83 | 76 | 75 | 80 | Always Lots | Always Some |
| HARRIS | 29 | 31 | 33 | 36 | 34 | 38 | 34 | 39 | 40 | 36 | 35 | Never | Never |
| FAST | 87 | 84 | 83 | 94 | 84 | 88 | 96 | 98 | 88 | 94 | 90 | Sometimes | Sometimes |
| BRISK | 154 | 162 | 161 | 163 | 177 | 173 | 171 | 169 | 163 | 165 | 166 | Always Some | Sometimes |
| ORB | 545 | 521 | 523 | 556 | 530 | 556 | 549 | 550 | 537 | 532 | 540 | Always | Always |
| AKAZE | 103 | 93 | 99 | 95 | 104 | 107 | 111 | 109 | 110 | 101 | 103 | Never | Always |
| SIFT | 83 | 86 | 80 | 95 | 94 | 94 | 90 | 104 | 96 | 80 | 90 | Always Some | Always |

**MP.8**

To complete MP.8 I ran every combination of detector/descriptor algorithm that I have implemented. See the next page for a chart of my results.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Detector** | **Descriptor** | **Image 2** | **Image 3** | **Image 4** | **Image 5** | **Image 6** | **Image 7** | **Image 8** | **Image 9** | **Image 10** | **Average** |
| AKAZE | AKAZE | 1011 | 1025 | 1021 | 1027 | 1022 | 1039 | 1026 | 1043 | 999 | 1024 |
| SHITOMASI | BRISK | 752 | 731 | 708 | 697 | 703 | 685 | 715 | 753 | 715 | 718 |
| SHITOMASI | BRIEF | 1003 | 981 | 992 | 987 | 931 | 947 | 973 | 1003 | 971 | 976 |
| SHITOMASI | ORB | 898 | 876 | 915 | 900 | 891 | 879 | 870 | 909 | 878 | 891 |
| SHITOMASI | FREAK | 730 | 723 | 751 | 717 | 712 | 713 | 700 | 726 | 686 | 718 |
| SHITOMASI | SIFT | 1044 | 1050 | 1068 | 1045 | 1019 | 1032 | 1033 | 1078 | 1053 | 1047 |
| HARRIS | BRISK | 331 | 332 | 347 | 339 | 347 | 325 | 332 | 343 | 345 | 338 |
| HARRIS | BRIEF | 413 | 415 | 424 | 430 | 423 | 412 | 420 | 424 | 428 | 421 |
| HARRIS | ORB | 390 | 381 | 399 | 411 | 401 | 381 | 387 | 401 | 397 | 394 |
| HARRIS | FREAK | 310 | 313 | 331 | 333 | 327 | 314 | 317 | 332 | 317 | 322 |
| HARRIS | SIFT | 431 | 422 | 448 | 453 | 437 | 427 | 422 | 440 | 445 | 436 |
| FAST | BRISK | 999 | 988 | 989 | 953 | 1005 | 963 | 938 | 950 | 957 | 971 |
| FAST | BRIEF | 1284 | 1310 | 1293 | 1271 | 1219 | 1227 | 1223 | 1212 | 1222 | 1251 |
| FAST | ORB | 1197 | 1179 | 1200 | 1186 | 1174 | 1128 | 1126 | 1157 | 1144 | 1166 |
| FAST | FREAK | 934 | 939 | 938 | 922 | 934 | 909 | 889 | 897 | 912 | 919 |
| FAST | SIFT | 1409 | 1412 | 1391 | 1362 | 1357 | 1374 | 1379 | 1334 | 1341 | 1373 |
| BRISK | BRISK | 1494 | 1486 | 1477 | 1400 | 1451 | 1368 | 1400 | 1373 | 1385 | 1426 |
| BRISK | BRIEF | 1689 | 1739 | 1746 | 1674 | 1666 | 1622 | 1660 | 1646 | 1601 | 1671 |
| BRISK | ORB | 1435 | 1447 | 1411 | 1376 | 1425 | 1365 | 1350 | 1354 | 1362 | 1392 |
| BRISK | FREAK | 1333 | 1343 | 1358 | 1297 | 1369 | 1322 | 1296 | 1308 | 1285 | 1323 |
| BRISK | SIFT | 1677 | 1699 | 1648 | 1625 | 1688 | 1607 | 1645 | 1572 | 1580 | 1638 |
| ORB | BRISK | 4444 | 4421 | 4434 | 4453 | 4524 | 4438 | 4333 | 4342 | 4240 | 4403 |
| ORB | BRIEF | 3125 | 3069 | 3023 | 3062 | 3060 | 3105 | 2994 | 3165 | 3147 | 3083 |
| ORB | ORB | 4326 | 4340 | 4306 | 4369 | 4376 | 4367 | 4269 | 4303 | 4258 | 4324 |
| ORB | FREAK | 2112 | 2117 | 2108 | 2172 | 2137 | 2148 | 2105 | 2111 | 2195 | 2134 |
| ORB | SIFT | 4784 | 4756 | 4724 | 4780 | 4761 | 4741 | 4646 | 4663 | 4684 | 4727 |
| SIFT | BRISK | 566 | 559 | 566 | 534 | 544 | 542 | 552 | 530 | 560 | 550 |
| SIFT | BRIEF | 702 | 653 | 666 | 639 | 648 | 653 | 671 | 619 | 673 | 658 |
| SIFT | ORB | Insufficient memory (ORB tried to allocate 65 GB) | | | | | | | | |  |
| SIFT | FREAK | 539 | 522 | 537 | 510 | 519 | 511 | 545 | 518 | 536 | 526 |
| SIFT | SIFT | 803 | 781 | 759 | 754 | 756 | 738 | 743 | 815 | 815 | 774 |

**MP.9**

I completed MP.9 at the same time as MP.8. See the next page for the chart of my results. I do not have results for the SIFT detector with the ORB descriptor because it tries to allocate more RAM than my machine has and crashes.

My first pick for top three pairs is the FAST detector with the ORB descriptor. It is the fasted pair (much faster than almost everything else) which is important in a real time application. Additionally, the FAST detector results in a good number of keypoints on the preceding vehicle, including some on interesting features like the license plate and tires.

My second pick is the FAST detector with the BRIEF descriptor. It is almost as fast as FAST/ORB and has the same benefits of the FAST keypoints.

My third pick is the SHITOMASI detector with the ORB descriptor. It is much slower than the previous two, but still probably suitable for most real time applications. Additionally, SHITOMASI creates a good number of keypoints on the preceding vehicle, including lots on the license plate and tires.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Detector** | **Descriptor** | **Detector (ms)** | **Descriptor (ms)** | **Sum (ms)** |
| AKAZE | AKAZE | 90.3 | 84.4 | 174.7 |
| SHITOMASI | BRISK | 21.6 | 13.6 | 35.2 |
| SHITOMASI | BRIEF | 21.4 | 5.3 | 26.7 |
| SHITOMASI | ORB | 17.6 | 3.1 | 20.7 |
| SHITOMASI | FREAK | 13.8 | 55.5 | 69.3 |
| SHITOMASI | SIFT | 15.9 | 34.4 | 50.3 |
| HARRIS | BRISK | 17.5 | 6.9 | 24.4 |
| HARRIS | BRIEF | 17.6 | 2.9 | 20.5 |
| HARRIS | ORB | 15.6 | 1.8 | 17.4 |
| HARRIS | FREAK | 11 | 44.5 | 55.5 |
| HARRIS | SIFT | 16.5 | 26.4 | 42.9 |
| FAST | BRISK | 1 | 17.8 | 18.8 |
| FAST | BRIEF | 0.9 | 6.3 | 7.2 |
| FAST | ORB | 1 | 3.8 | 4.8 |
| FAST | FREAK | 0.9 | 54.9 | 55.8 |
| FAST | SIFT | 1.1 | 92.3 | 93.4 |
| BRISK | BRISK | 42.5 | 27.6 | 70.1 |
| BRISK | BRIEF | 41.7 | 9.9 | 51.6 |
| BRISK | ORB | 43 | 9.1 | 52.1 |
| BRISK | FREAK | 40.7 | 65 | 105.7 |
| BRISK | SIFT | 42 | 255.8 | 297.8 |
| ORB | BRISK | 13.6 | 73.4 | 87 |
| ORB | BRIEF | 15.8 | 26.9 | 42.7 |
| ORB | ORB | 14.6 | 24.4 | 39 |
| ORB | FREAK | 13.7 | 73.9 | 87.6 |
| ORB | SIFT | 13.6 | 2208 | 2221.6 |
| SIFT | BRISK | 137.1 | 13.5 | 150.6 |
| SIFT | BRIEF | 136.9 | 4.9 | 141.8 |
| SIFT | ORB |  |  |  |
| SIFT | FREAK | 143.6 | 54.6 | 198.2 |
| SIFT | SIFT | 108.9 | 116.5 | 225.4 |