Progress Review 3

Project Pegasus

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Team A - Avengers
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ILR #4

November 13, 2015

1. Individual Progress

Vision Algorithms

For the last two week, I worked on improving the quality and speed of marker detection. As seen in previous tests on my laptop (Intel i3), AprilTag detection worked at 14fps and Lucas Kanade (only tracking) gave 29fps. Intuitively, I tried to average out the algorithm runtime by trying to fuse the two algorithms.

I used the corner and center points as detected by the Apriltag detection algorithm to initiate Lucas Kanade Tracking. I observed that even when the marker was moving, the corner points robustly followed the marker but the tracking for the center point was not that robust. In case of higher jitter, the markers would snap to other points in the image and from then on, the wrong points were tracked. To mitigate that, AprilTag detection was done every few frames, currently once in 50 frames (can be tuned to obtain required average fps and correctness of the result). The new corners as obtained can exactly emulate the detections obtained using AprilTags. Results are shown after discussion of markers.

Markers – Sizes and Distances

AprilTag detection libraries provide appropriate transformations for obtaining the distance, x, y, z, roll, pitch and yaw from any detected marker. The same was extended to the virtual marker obtained by Lucas-Kanade Tracking. The camera parameters were calibrated using a known marker size at a known distance. The values were then tested and found to be accurate up to 5%, which is appropriate for our application.

Based on our application, we do not need have very hard limits on the distances for marker detection, but a maximum marker size of 1.5m diameter. Based on my initial tests, a marker of size 18cm is detected up to a distance of 4m from the marker. Checking a few similar sizes, the relationship is observed to be linear. A larger marker can be easily detected from further away but as the marker is brought closer, the full marker is not covered in the cameras view. For this, I tried a nested version of AprilTags. A small AprilTag (about a tenth of the size of the larger tag, for 36h11 family) is embedded at the center. I tried the same orientation for the inner tag as the outer one, but this increases the true negative detection. By rotating the inner marker by 45 degrees counter-clockwise (refer figure 1), robust detection of the outer marker is restored (refer figure 2-4 for test screenshots with a 72cm marker).

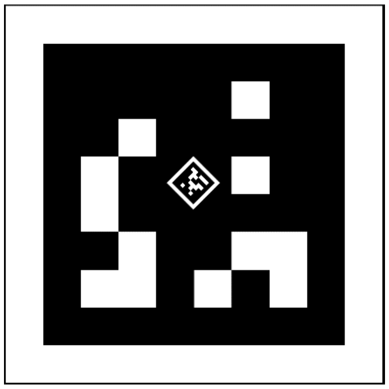
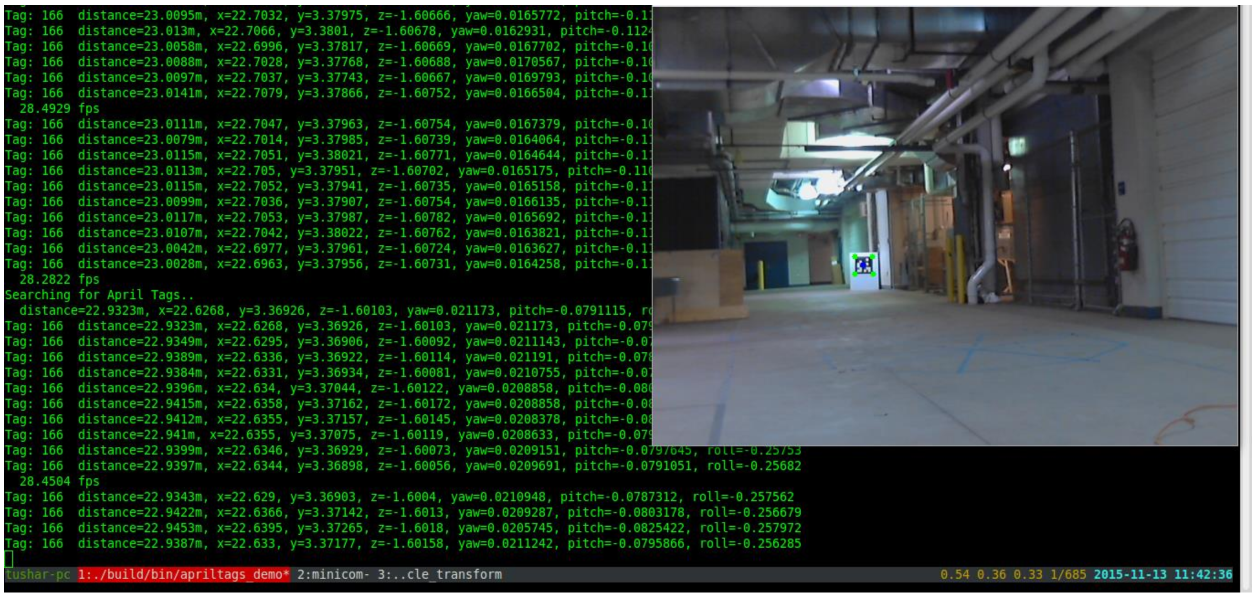


Figure 1. Nested AprilTag marker. Inner AprilTag is one tenth of the outer, and is rotated by 45 degrees counter-clockwise.



```
Tag: 166  distance=23.0095m, x=22.7032, y=3.37975, z=-1.60666, yaw=0.0165772, pitch=-0.1
Tag: 166  distance=23.013m, x=22.7066, y=3.3801, z=-1.60678, yaw=0.0162931, pitch=-0.112
Tag: 166  distance=23.0058m, x=22.6996, y=3.37817, z=-1.60669, yaw=0.0167702, pitch=-0.1
Tag: 166  distance=23.0088m, x=22.7028, y=3.37768, z=-1.60688, yaw=0.0170567, pitch=-0.1
Tag: 166  distance=23.0097m, x=22.7037, y=3.37743, z=-1.60667, yaw=0.0169793, pitch=-0.1
Tag: 166  distance=23.0141m, x=22.7079, y=3.37866, z=-1.60752, yaw=0.0166504, pitch=-0.1
  28.4929 fps
Tag: 166  distance=23.0111m, x=22.7047, y=3.37963, z=-1.60754, yaw=0.0167379, pitch=-0.1
Tag: 166  distance=23.0079m, x=22.7014, y=3.37985, z=-1.60739, yaw=0.0164064, pitch=-0.1
Tag: 166  distance=23.0115m, x=22.7051, y=3.38021, z=-1.60771, yaw=0.0164644, pitch=-0.1
Tag: 166  distance=23.0113m, x=22.705, y=3.37951, z=-1.60702, yaw=0.0165175, pitch=-0.11
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Tag: 166  distance=23.0099m, x=22.7036, y=3.37907, z=-1.60754, yaw=0.0166135, pitch=-0.1
Tag: 166  distance=23.0117m, x=22.7053, y=3.37987, z=-1.60782, yaw=0.0165692, pitch=-0.1
Tag: 166  distance=23.0107m, x=22.7042, y=3.38022, z=-1.60762, yaw=0.0163821, pitch=-0.1
Tag: 166  distance=23.0042m, x=22.6977, y=3.37961, z=-1.60724, yaw=0.0163627, pitch=-0.1
Tag: 166  distance=23.0028m, x=22.6963, y=3.37956, z=-1.60731, yaw=0.0164258, pitch=-0.1
  28.2822 fps
Searching for April Tags..
  distance=22.9323m, x=22.6268, y=3.36926, z=-1.60103, yaw=0.021173, pitch=-0.0791115, r
Tag: 166  distance=22.9323m, x=22.6268, y=3.36926, z=-1.60103, yaw=0.021173, pitch=-0.07
Tag: 166  distance=22.9349m, x=22.6295, y=3.36906, z=-1.60092, yaw=0.0211143, pitch=-0.0
Tag: 166  distance=22.9389m, x=22.6336, y=3.36922, z=-1.60114, yaw=0.021191, pitch=-0.07
Tag: 166  distance=22.9384m, x=22.6331, y=3.36934, z=-1.60081, yaw=0.0210755, pitch=-0.0
Tag: 166  distance=22.9396m, x=22.634, y=3.37044, z=-1.60122, yaw=0.0208858, pitch=-0.08
Tag: 166  distance=22.9415m, x=22.6358, y=3.37162, z=-1.60172, yaw=0.0208858, pitch=-0.0
Tag: 166  distance=22.9412m, x=22.6355, y=3.37157, z=-1.60145, yaw=0.0208378, pitch=-0.0
Tag: 166  distance=22.941m, x=22.6355, y=3.37075, z=-1.60119, yaw=0.0208633, pitch=-0.07
Tag: 166  distance=22.9399m, x=22.6346, y=3.36929, z=-1.60073, yaw=0.0209151, pitch=-0.0797645, roll=-0.25753
Tag: 166  distance=22.9397m, x=22.6344, y=3.36898, z=-1.60056, yaw=0.0209691, pitch=-0.0791051, roll=-0.25682
  28.4504 fps
Tag: 166  distance=22.9343m, x=22.629, y=3.36903, z=-1.6004, yaw=0.0210948, pitch=-0.0787312, roll=-0.257562
Tag: 166  distance=22.9422m, x=22.6366, y=3.37142, z=-1.6013, yaw=0.0209287, pitch=-0.0803178, roll=-0.256679
Tag: 166  distance=22.9453m, x=22.6395, y=3.37265, z=-1.6018, yaw=0.0205745, pitch=-0.0825422, roll=-0.257972
Tag: 166  distance=22.9387m, x=22.633, y=3.37177, z=-1.60158, yaw=0.0211242, pitch=-0.0795866, roll=-0.256285

tushar-pc 1:./build/bin/apriltags_demo* 2:minicom- 3:..cle_transform                0.54 0.36 0.33 1/685 2015-11-13 11:42:36
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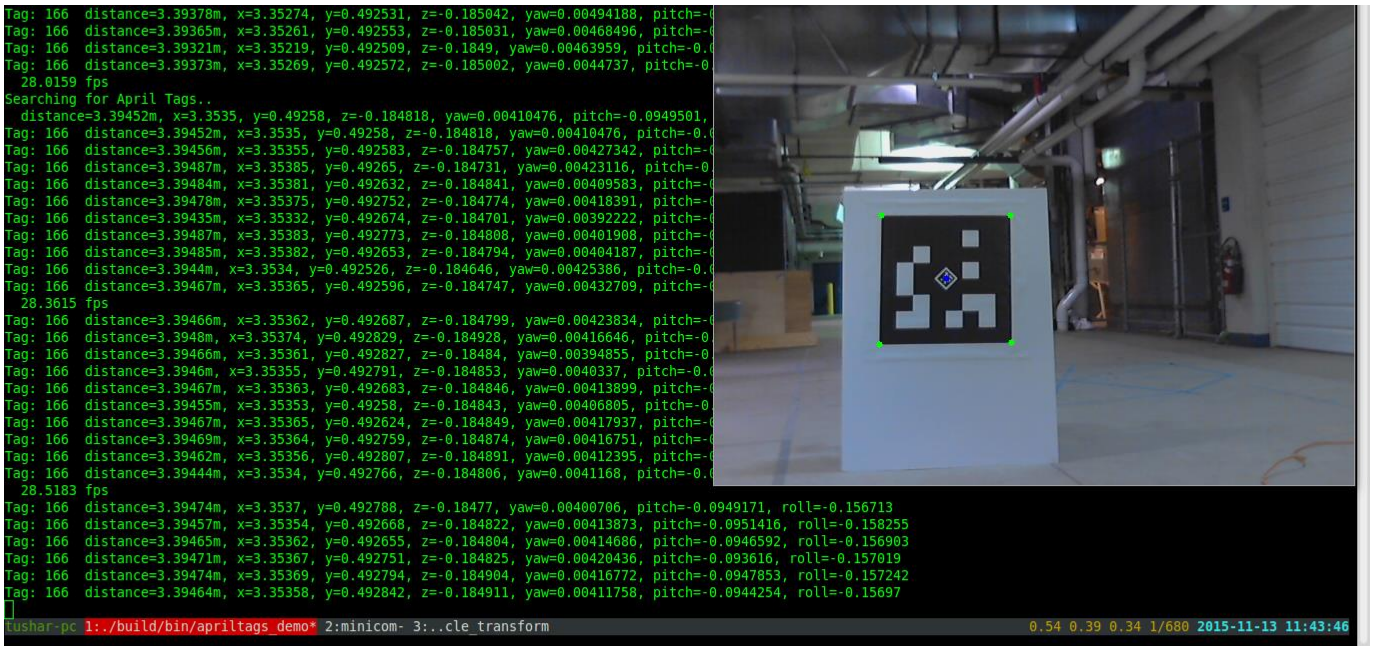
Figure 2. Nested AprilTag outer marker detection. Green Dots indicate corners of marker and blue marks the center. (Marker: Nested Apriltag, Distance: 22.938m, FPS: 28)



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Tag: 166  distance=3.39378m, x=3.35274, y=0.492531, z=-0.185042, yaw=0.00494188, pitch=-
Tag: 166  distance=3.39365m, x=3.35261, y=0.492553, z=-0.185031, yaw=0.00468496, pitch=-
Tag: 166  distance=3.39321m, x=3.35219, y=0.492509, z=-0.1849, yaw=0.00463959, pitch=-0.
Tag: 166  distance=3.39373m, x=3.35269, y=0.492572, z=-0.185002, yaw=0.0044737, pitch=-0
  28.0159 fps
Searching for April Tags..
  distance=3.39452m, x=3.3535, y=0.49258, z=-0.184818, yaw=0.00410476, pitch=-0.0949501,
Tag: 166  distance=3.39452m, x=3.3535, y=0.49258, z=-0.184818, yaw=0.00410476, pitch=-0.
Tag: 166  distance=3.39456m, x=3.35355, y=0.492583, z=-0.184757, yaw=0.00427342, pitch=-
Tag: 166  distance=3.39487m, x=3.35385, y=0.49265, z=-0.184731, yaw=0.00423116, pitch=-0
Tag: 166  distance=3.39484m, x=3.35381, y=0.492632, z=-0.184841, yaw=0.00409583, pitch=-
Tag: 166  distance=3.39478m, x=3.35375, y=0.492752, z=-0.184774, yaw=0.00418391, pitch=-
Tag: 166  distance=3.39435m, x=3.35332, y=0.492674, z=-0.184701, yaw=0.00392222, pitch=-
Tag: 166  distance=3.39487m, x=3.35383, y=0.492773, z=-0.184808, yaw=0.00401908, pitch=-
Tag: 166  distance=3.39485m, x=3.35382, y=0.492653, z=-0.184794, yaw=0.00404187, pitch=-
Tag: 166  distance=3.3944m, x=3.3534, y=0.492526, z=-0.184646, yaw=0.00425386, pitch=-0.
Tag: 166  distance=3.39467m, x=3.35365, y=0.492596, z=-0.184747, yaw=0.00432709, pitch=-
  28.3615 fps
Tag: 166  distance=3.39466m, x=3.35362, y=0.492687, z=-0.184799, yaw=0.00423834, pitch=-
Tag: 166  distance=3.3948m, x=3.35374, y=0.492829, z=-0.184928, yaw=0.00416646, pitch=-0
Tag: 166  distance=3.39466m, x=3.35361, y=0.492827, z=-0.18484, yaw=0.00394855, pitch=-0
Tag: 166  distance=3.3946m, x=3.35355, y=0.492791, z=-0.184853, yaw=0.0040337, pitch=-0.
Tag: 166  distance=3.39467m, x=3.35363, y=0.492683, z=-0.184846, yaw=0.00413899, pitch=-
Tag: 166  distance=3.39455m, x=3.35353, y=0.49258, z=-0.184843, yaw=0.00406805, pitch=-0
Tag: 166  distance=3.39467m, x=3.35365, y=0.492624, z=-0.184849, yaw=0.00417937, pitch=-
Tag: 166  distance=3.39469m, x=3.35364, y=0.492759, z=-0.184874, yaw=0.00416751, pitch=-
Tag: 166  distance=3.39462m, x=3.35356, y=0.492807, z=-0.184891, yaw=0.00412395, pitch=-
Tag: 166  distance=3.39444m, x=3.3534, y=0.492766, z=-0.184806, yaw=0.0041168, pitch=-0.
  28.5183 fps
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Tag: 166  distance=3.39471m, x=3.35367, y=0.492751, z=-0.184825, yaw=0.00420436, pitch=-0.093616, roll=-0.157019
Tag: 166  distance=3.39474m, x=3.35369, y=0.492794, z=-0.184904, yaw=0.00416772, pitch=-0.0947853, roll=-0.157242
Tag: 166  distance=3.39464m, x=3.35358, y=0.492842, z=-0.184911, yaw=0.00411758, pitch=-0.0944254, roll=-0.15697

tushar-pc 1:./build/bin/apriltags_demo* 2:minicom- 3:..cle_transform                    0.54 0.39 0.34 1/680 2015-11-13 11:43:46
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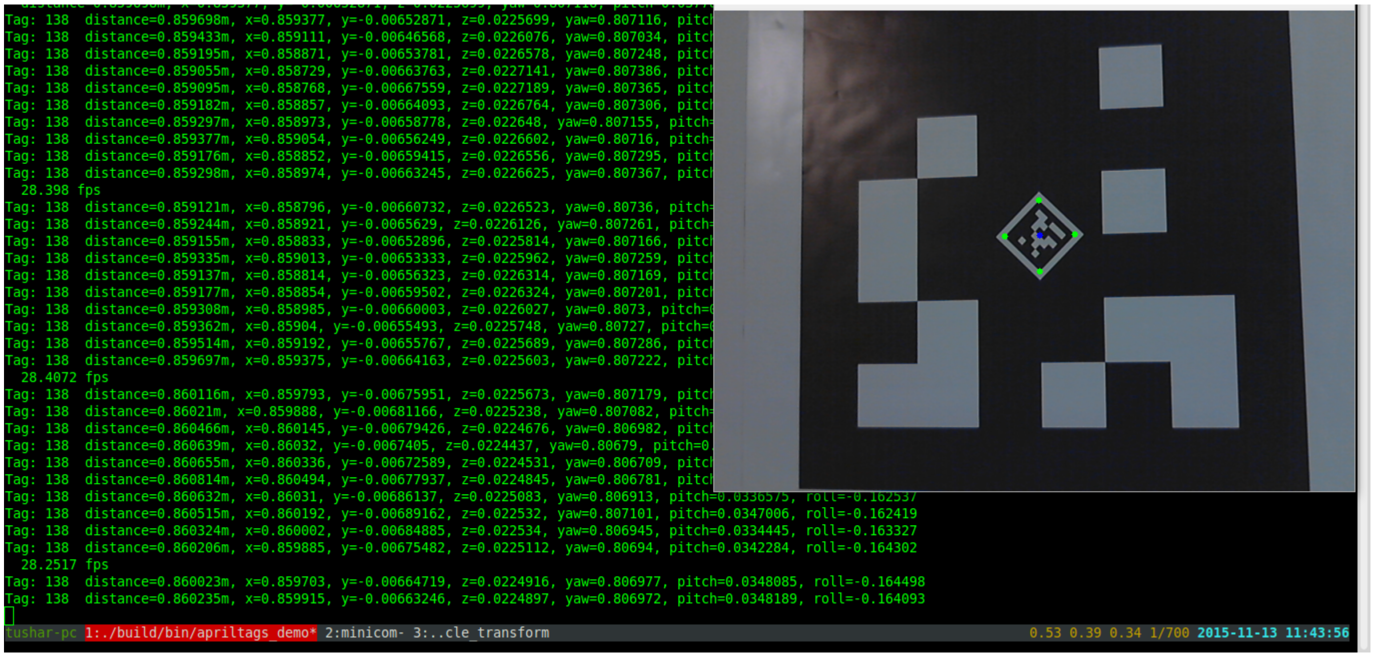
Figure 3. Nested AprilTag outer marker detection. Green Dots indicate corners of marker and blue marks the center. (Marker: Nested Apriltag, Distance: 3.39m, FPS: 28)



```
Tag: 138  distance=0.859698m, x=0.859377, y=-0.00652871, z=0.0225699, yaw=0.807116, pitc
Tag: 138  distance=0.859433m, x=0.859111, y=-0.00646568, z=0.0226076, yaw=0.807034, pitc
Tag: 138  distance=0.859195m, x=0.858871, y=-0.00653781, z=0.0226578, yaw=0.807248, pitc
Tag: 138  distance=0.859055m, x=0.858729, y=-0.00663763, z=0.0227141, yaw=0.807386, pitc
Tag: 138  distance=0.859095m, x=0.858768, y=-0.00667559, z=0.0227189, yaw=0.807365, pitc
Tag: 138  distance=0.859182m, x=0.858857, y=-0.00664093, z=0.0226764, yaw=0.807306, pitc
Tag: 138  distance=0.859297m, x=0.858973, y=-0.00658778, z=0.022648, yaw=0.807155, pitch=
Tag: 138  distance=0.859377m, x=0.859054, y=-0.00656249, z=0.0226602, yaw=0.80716, pitch=
Tag: 138  distance=0.859176m, x=0.858852, y=-0.00659415, z=0.0226556, yaw=0.807295, pitc
Tag: 138  distance=0.859298m, x=0.858974, y=-0.00663245, z=0.0226625, yaw=0.807367, pitc
  28.398 fps
Tag: 138  distance=0.859121m, x=0.858796, y=-0.00660732, z=0.0226523, yaw=0.80736, pitch=
Tag: 138  distance=0.859244m, x=0.858921, y=-0.0065629, z=0.0226126, yaw=0.807261, pitch=
Tag: 138  distance=0.859155m, x=0.858833, y=-0.00652896, z=0.0225814, yaw=0.807166, pitc
Tag: 138  distance=0.859335m, x=0.859013, y=-0.00653333, z=0.0225962, yaw=0.807259, pitc
Tag: 138  distance=0.859137m, x=0.858814, y=-0.00656323, z=0.0226314, yaw=0.807169, pitc
Tag: 138  distance=0.859177m, x=0.858854, y=-0.00659502, z=0.0226324, yaw=0.807201, pitc
Tag: 138  distance=0.859308m, x=0.858985, y=-0.00660003, z=0.0226027, yaw=0.8073, pitch=
Tag: 138  distance=0.859362m, x=0.85904, y=-0.00655493, z=0.0225748, yaw=0.80727, pitch=
Tag: 138  distance=0.859514m, x=0.859192, y=-0.00655767, z=0.0225689, yaw=0.807286, pitc
Tag: 138  distance=0.859697m, x=0.859375, y=-0.00664163, z=0.0225603, yaw=0.807222, pitc
  28.4072 fps
Tag: 138  distance=0.860116m, x=0.859793, y=-0.00675951, z=0.0225673, yaw=0.807179, pitc
Tag: 138  distance=0.86021m, x=0.859888, y=-0.00681166, z=0.0225238, yaw=0.807082, pitch=
Tag: 138  distance=0.860466m, x=0.860145, y=-0.00679426, z=0.0224676, yaw=0.806982, pitc
Tag: 138  distance=0.860639m, x=0.86032, y=-0.0067405, z=0.0224437, yaw=0.80679, pitch=0.
Tag: 138  distance=0.860655m, x=0.860336, y=-0.00672589, z=0.0224531, yaw=0.806709, pitc
Tag: 138  distance=0.860814m, x=0.860494, y=-0.00677937, z=0.0224845, yaw=0.806781, pitc
Tag: 138  distance=0.860632m, x=0.86031, y=-0.00686137, z=0.0225083, yaw=0.806913, pitch=0.0336575, roll=-0.162537
Tag: 138  distance=0.860515m, x=0.860192, y=-0.00689162, z=0.022532, yaw=0.807101, pitch=0.0347006, roll=-0.162419
Tag: 138  distance=0.860324m, x=0.860002, y=-0.00684885, z=0.022534, yaw=0.806945, pitch=0.0334445, roll=-0.163327
Tag: 138  distance=0.860206m, x=0.859885, y=-0.00675482, z=0.0225112, yaw=0.80694, pitch=0.0342284, roll=-0.164302
  28.2517 fps
Tag: 138  distance=0.860023m, x=0.859703, y=-0.00664719, z=0.0224916, yaw=0.806977, pitch=0.0348085, roll=-0.164498
Tag: 138  distance=0.860235m, x=0.859915, y=-0.00663246, z=0.0224897, yaw=0.806972, pitch=0.0348189, roll=-0.164093

tushar-pc 1:./build/bin/apriltags_demo* 2:minicom- 3:..cle_transform                    0.53 0.39 0.34 1/700 2015-11-13 11:43:56
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Figure 4. Nested AprilTag inner marker detection. Green Dots indicate corners of marker and blue marks the center. (Marker: Nested Apriltag, Distance: 0.86m, FPS: 28)

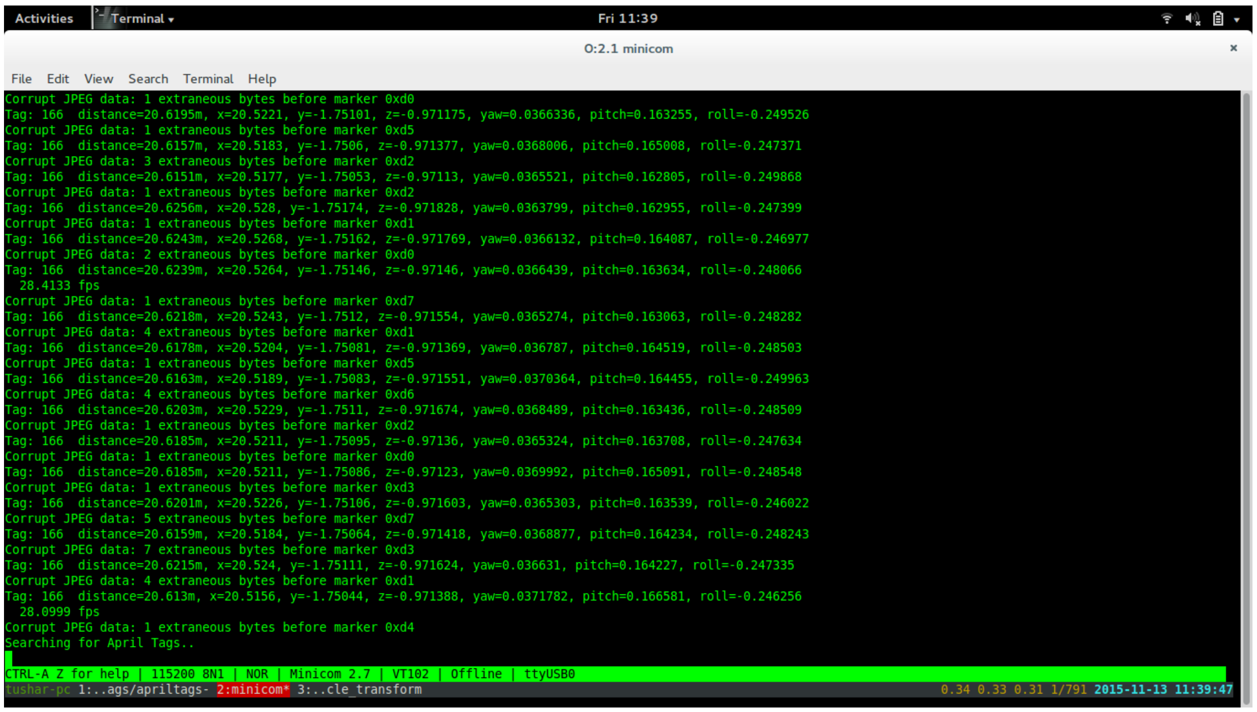
Based on few estimates of the required flying altitude a few markers were printed and tested (refer table 1).

S.No.	Detection distances for different nested apriltag markers			
	Outer AprilTag		Inner AprilTag	
1	4.5cm Outer		0.45cm Inner	
	Max: 1.8m	Min: 8 cm	Not detected	
2	18cm Outer		1.8cm Inner	
	Max: 7.2m	Min: 40cm	Max: 50cm	Min: 4cm
3	72cm Outer		7.2cm Inner	
	Max: 30m	Min: 1.6m	Max: 2m	Min: 16cm

Table 1. Relation of marker sizes to detection ranges

Odroid Setup

As discussed in the earlier ILRs, seeing poor performance for vision on BeagleBoard xM, we had decided to use the Odroid XU4 for vision processing. The odroid alongwith a few necessary accessories was ordered. When received, I setup a microSD card with an ARM Ubuntu server 14.04 image. After setting up basic networking, I installed OpenCV on the odroid to test the aforementioned algorithm. As expected, the apriltag detection was much slower on the odroid, but Lucas Kanade was still sufficiently fast (refer table 2).



```
Corrupt JPEG data: 1 extraneous bytes before marker 0xd0
Tag: 166  distance=20.6195m, x=20.5221, y=-1.75101, z=-0.971175, yaw=0.0366336, pitch=0.163255, roll=-0.249526
Corrupt JPEG data: 1 extraneous bytes before marker 0xd5
Tag: 166  distance=20.6157m, x=20.5183, y=-1.7506, z=-0.971377, yaw=0.0368006, pitch=0.165008, roll=-0.247371
Corrupt JPEG data: 3 extraneous bytes before marker 0xd2
Tag: 166  distance=20.6151m, x=20.5177, y=-1.75053, z=-0.97113, yaw=0.0365521, pitch=0.162805, roll=-0.249868
Corrupt JPEG data: 1 extraneous bytes before marker 0xd2
Tag: 166  distance=20.6256m, x=20.528, y=-1.75174, z=-0.971828, yaw=0.0363799, pitch=0.162955, roll=-0.247399
Corrupt JPEG data: 1 extraneous bytes before marker 0xd1
Tag: 166  distance=20.6243m, x=20.5268, y=-1.75162, z=-0.971769, yaw=0.0366132, pitch=0.164087, roll=-0.246977
Corrupt JPEG data: 2 extraneous bytes before marker 0xd0
Tag: 166  distance=20.6239m, x=20.5264, y=-1.75146, z=-0.97146, yaw=0.0366439, pitch=0.163634, roll=-0.248066
  28.4133 fps
Corrupt JPEG data: 1 extraneous bytes before marker 0xd7
Tag: 166  distance=20.6218m, x=20.5243, y=-1.7512, z=-0.971554, yaw=0.0365274, pitch=0.163063, roll=-0.248282
Corrupt JPEG data: 4 extraneous bytes before marker 0xd1
Tag: 166  distance=20.6178m, x=20.5204, y=-1.75081, z=-0.971369, yaw=0.036787, pitch=0.164519, roll=-0.248503
Corrupt JPEG data: 1 extraneous bytes before marker 0xd5
Tag: 166  distance=20.6163m, x=20.5189, y=-1.75083, z=-0.971551, yaw=0.0370364, pitch=0.164455, roll=-0.249963
Corrupt JPEG data: 4 extraneous bytes before marker 0xd6
Tag: 166  distance=20.6203m, x=20.5229, y=-1.7511, z=-0.971674, yaw=0.0368489, pitch=0.163436, roll=-0.248509
Corrupt JPEG data: 1 extraneous bytes before marker 0xd2
Tag: 166  distance=20.6185m, x=20.5211, y=-1.75095, z=-0.97136, yaw=0.0365324, pitch=0.163708, roll=-0.247634
Corrupt JPEG data: 1 extraneous bytes before marker 0xd0
Tag: 166  distance=20.6185m, x=20.5211, y=-1.75086, z=-0.97123, yaw=0.0369992, pitch=0.165091, roll=-0.248548
Corrupt JPEG data: 1 extraneous bytes before marker 0xd3
Tag: 166  distance=20.6201m, x=20.5226, y=-1.75106, z=-0.971603, yaw=0.0365303, pitch=0.163539, roll=-0.246022
Corrupt JPEG data: 5 extraneous bytes before marker 0xd7
Tag: 166  distance=20.6159m, x=20.5184, y=-1.75064, z=-0.971418, yaw=0.0368877, pitch=0.164234, roll=-0.248243
Corrupt JPEG data: 7 extraneous bytes before marker 0xd3
Tag: 166  distance=20.6215m, x=20.524, y=-1.75111, z=-0.971624, yaw=0.036631, pitch=0.164227, roll=-0.247335
Corrupt JPEG data: 4 extraneous bytes before marker 0xd1
Tag: 166  distance=20.613m, x=20.5156, y=-1.75044, z=-0.971388, yaw=0.0371782, pitch=0.166581, roll=-0.246256
  28.0999 fps
Corrupt JPEG data: 1 extraneous bytes before marker 0xd4
Searching for April Tags..

CTRL-A Z for help | 115200 8N1 | NOR | Minicom 2.7 | VT102 | Offline | ttyUSB0
tushar-pc 1:..ags/apriltags- 2:minicom* 3:..cle_transform                    0.34 0.33 0.31 1/791 2015-11-13 11:39:47
```

Figure 4. Nested AprilTag outer marker detection on the Odroid XU4. Green Dots indicate corners of marker and blue marks the center. (Marker: Nested Apriltag, Distance: 20.6m, FPS: 28)

Algorithm	FPS on Laptop (i3 4th gen)	FPS on Odroid (Quad core ARM)
AprilTag detection	14	7
Lucas Kanade	30	29
Merged (LK + AprilTag detection)	29	28

Table 2. Relation of marker sizes to detection ranges

Miscellaneous

I worked with Pratik to do trigonometric calculations for estimating number of sensors to cover a sphere around the vehicle.

I helped Sean and Adam assemble the UAV when it arrived.

2. Challenges

Vision Algorithms

A few issues were faced when trying to include LK tracking into AprilTag detection. The AprilTag library is built without dependence on OpenCV (except for the demo), and hence the build architecture had to be tweaked to add the OpenCV LK tracking code.

Markers – Distance and Size

US letter paper sized markers were printed and tested iteratively. To confirm that the camera focus allowed larger markers to be detected at higher distances, with Sean's help, I requested Prof Dolan to get a few poster size markers printed. I faced a few issue to generate a pdf with the correct size and resolution of the marker to be printed.

Odroid setup

Networking setup was not possible in the lab due to the managed Ethernet network, hence, I had to shift the apparatus to my home where I was able to setup the network, check DHCP leases and SSH into the system. Further, I bought the Odroid USB to UART cable for accessing the Odroid console in the Lab.

Issues

1. JPEG compression errors are seen when the code is run on the Odroid, even though the results are fine.
2. Intermittently, the code does not start due to an opencv error on the Odroid (probably because the camera is not opening correctly)

3. Teamwork

In these two weeks, Pratik worked on final tests on individual proximity sensors (IR, Ultrasonics, Lidar, Lidar lite) and build basic configuration with IRs to test obstacle detection on a dummy UAV. Furthermore, a specific version of the Ultrasonic sensor seemed appropriate for our application as it could detect oblique surfaces, grass and trees robustly and had a larger field of view compared to the IR sensor.

Adam worked on finalizing the PCB for the obstacle detection sensors.

The frame for the UAV was delayed, due to which Sean worked temporarily on the Pioneer UGV with Adams help to get its mechanical and electronic system set up. Sean also assisted Pratik with testing obstacle detection combination system. On arrival of the UAV frame, we had a small build party where all of us started assembling the mechanical and electronic system of the UAV. The basic assembly was done, but we required more inventory (connectors and crimps) for assembling further, which was taken up by Adam.

4. Future Plans

In the following weeks, Pratik is aiming to finalize the sensors to use for obstacle detection along with their configuration around the vehicle and the algorithm to sample data from them.

Adam shall get the electronics and basic flight controller up and running on the UAV for testing a hover remote controlled flight.

Sean shall design the mounting for obstacle detection sensors after getting the configuration from Pratik. He shall also start working on the basic design of the underbelly of the UAV.

I will be reducing the amount of time I spend on vision system, as it seems to be up to a state where further improvements can be made only after testing with the UAV. Although, I will still try to resolve the issues listed earlier or develop workarounds. I shall be helping Pratik with a visualization system for testing obstacle detection systems. Finally, I will dive deep into the flight control code to see how to integrate the data from the vision system into the UAV controller.