This report contains information based on the new idea of implementing CCA in the hardware to perform the edge analysis and segmentation of the image. This will theoretically leave the CPU to calculate the quads and decoding and if found, also determining pose estimation.

# Accuracy:

## Matlab:

Below is a table with each algorithm’s accuracy reports. All the images except input17.bmp, the April Tag can be found. Input17.bmp, the April Tag is off the edge of the image.

Key: Algorithm/Threshold Size/Shortcut

Algorithms

* B: Baseline (Ravven Detect 2, Quad Ravven 2)
* M: MagTheta (Ravven Detect 2, Quad Ravven 3)
* F: FPGA (Ravven Detect 4, Quad Ravven 4)

Threshold Size

* L: Large (7 and 3)
* S: Small (1.89 and 1.56)

Shortcut

* F: Fast (Loaded grayscale and/or mag theta)
* A: Accurate (Computed grayscale and mag theta)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Images (.bmps) | Algorithms | | | | | | | |
| B/L/F | B/L/A | B/S/F | B/S/A | M/S | M/L | F/S | F/L |
| Input1 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Input2 | Yes | Yes | Yes | Yes | Yes | Yes | No | Yes |
| Input3 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Input4 | Yes | Yes | No | No | No | Yes | No | No |
| Input5 | Yes | Yes | Yes | No | No | Yes | No | Yes |
| Input6 | Yes | Yes | No | Yes | No | Yes | No | Yes |
| Input7 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Input8 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Input9 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Input10 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Input11 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Input12 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Input13 | Yes | Yes | No | No | No | Yes | No | Yes |
| Input14 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Input15 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Input16 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Input17 | No | No | No | No | No | No | No | No |
| Input18 | No | No | Yes | No | No | Yes | Yes | No |
| Input19 | No | No | Yes | Yes | Yes | Yes | No | Yes |
| Input20 | No | No | Yes | Yes | Yes | Yes | No | Yes |
| Hit Rate | 16 | 16 | 16 | 15 | 14 | 19 | 12 | 17 |

## C Code:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Images (.bmps) | April Tag Baseline | April Tag Baseline Optimized | Ravven Tag MagTheta | Py April Tag | Ravven Tag CCA |
| Input1 | 1 | 1 | 1 | 1 | 1 |
| Input2 | 1 | 1 | 1 | 0 | 1 |
| Input3 | 1 | 1 | 1 | 1 | 1 |
| Input4 | 1 | 1 | 1 | 1 | 1 |
| Input5 | 1 | 1 | 1 | 1 | 1 |
| Input6 | 1 | 1 | 1 | 1 | 0 |
| Input7 | 1 | 1 | 1 | 1 | 1 |
| Input8 | 1 | 1 | 1 | 1 | 1 |
| Input9 | 1 | 1 | 1 | 1 | 1 |
| Input10 | 1 | 1 | 1 | 1 | 1 |
| Input11 | 1 | 1 | 1 | 1 | 1 |
| Input12 | 1 | 1 | 1 | 1 | 1 |
| Input13 | 1 | 1 | 1 | 1 | 1 |
| Input14 | 1 | 1 | 1 | 1 | 1 |
| Input15 | 1 | 1 | 1 | 1 | 1 |
| Input16 | 1 | 1 | 1 | 1 | 1 |
| Input17 | 0 | 0 | 0 | 0 | 1 |
| Input18 | 1 | 1 | 1 | 1 | 1 |
| Input19 | 1 | 1 | 1 | 1 | 1 |
| Input20 | 1 | 1 | 1 | 1 | 1 |
| Hit Rate | 19/20 | 19/20 | 19/20 | 18/20 | 19/20 |

## Simulink + Matlab

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Images (.bmps) |  | Algorithms | |  |
| M/L + Off | M/L + Acc | F/L + Off | F/L + Acc |
| Input1 | Yes | Yes | Yes | Yes |
| Input2 | Yes | Yes | No | Yes |
| Input3 | Yes | Yes | No | Yes |
| Input4 | Yes | Yes | No | Yes |
| Input5 | Yes | Yes | No | Yes |
| Input6 | No | No | No | Yes |
| Input7 | Yes | Yes | Yes | Yes |
| Input8 | Yes | Yes | Yes | Yes |
| Input9 | Yes | Yes | Yes | Yes |
| Input10 | Yes | Yes | Yes | Yes |
| Input11 | Yes | Yes | Yes | Yes |
| Input12 | Yes | Yes | Yes | Yes |
| Input13 | Yes | Yes | Yes | Yes |
| Input14 | Yes | Yes | Yes | Yes |
| Input15 | Yes | Yes | Yes | Yes |
| Input16 | Yes | Yes | No | Yes |
| Input17 | No | No | No | Yes |
| Input18 | No | Yes | No | Yes |
| Input19 | No | Yes | No | Yes |
| Input20 | Yes | Yes | No | Yes |
| Hit Rate | 16 | 18 | 10 | 20 |

# Timing:

Below is a table with each algorithm’s timing reports with means of 100 runs. Instead of using the baseline Ravven Detect 2, it will be compared against April Tag baseline, April Tag baseline slight optimized, Ravven Tag MagTheta, and Py April Tag. This version is Ravven Tag CCA. All the times reported are in milliseconds.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Input Images | April Tag Baseline | April Tag Baseline Optimized | Ravven Tag MagTheta | Py April Tag | Ravven Tag CCA |
| Input1.bmp | 458.449 | 418.511 | 1316.22 | 67.1420 | 24.4059 |
| Input2.bmp | 321.014 | 259.299 | 1238.10 | 69.4775 | 23.4108 |
| Input6.bmp | 528.044 | 466.903 | 1710.77 | 80.0875 | 21.6880 |
| Input7.bmp | 722.283 | 685.026 | 1970.22 | 77.2884 | 25.0279 |
| Input10.bmp | 431.674 | 382.988 | 1577.19 | 76.8743 | 21.5577 |
| Input20.bmp | 310.380 | 260.735 | 1239.83 | 70.8103 | 23.3272 |

Stats for input1.bmp

Statistics for AprilTag Baseline:

Mean: 0.45844931

Median: 0.4577505

Max: 0.461407

Min: 0.456304

STD: 0.00156156398969

Variance: 2.4384820939e-06

Statistics for AprilTag Baseline Optimized:

Mean: 0.41851115942

Median: 0.41851246357

Max: 0.422622919083

Min: 0.417119026184

STD: 0.000702595755216

Variance: 4.93640795247e-07

Statistics for Ravven Tag MagTheta:

Mean: 1.31621585369

Median: 1.31646203995

Max: 1.32118606567

Min: 1.31264781952

STD: 0.0018885970465

Variance: 3.56679880404e-06

Statistics for PyAprilTag:

Mean: 0.0671419525146

Median: 0.0665935277939

Max: 0.0765628814697

Min: 0.0624060630798

STD: 0.00300975153888

Variance: 9.05860432581e-06

Statistics for Ravven Tag CCA:

Mean: 0.0244058990479

Median: 0.0110079050064

Max: 0.344959974289

Min: 0.0109028816223

STD: 0.0653667822179

Variance: 0.00427281621753

Stats for input2.bmp

Statistics for AprilTag Baseline:

Mean: 0.32101381

Median: 0.320971

Max: 0.322462

Min: 0.320213

STD: 0.000439125442101

Variance: 1.928311539e-07

Statistics for AprilTag Baseline Optimized:

Mean: 0.259298732281

Median: 0.259066581726

Max: 0.26279592514

Min: 0.258084058762

STD: 0.000931707323736

Variance: 8.68078537104e-07

Statistics for Ravven Tag MagTheta:

Mean: 1.23810094118

Median: 1.23582839966

Max: 1.24758696556

Min: 1.2317712307

STD: 0.00433388570053

Variance: 1.87825652652e-05

Statistics for PyAprilTag:

Mean: 0.0694775056839

Median: 0.0686099529266

Max: 0.0805749893188

Min: 0.0659189224243

STD: 0.00314779078689

Variance: 9.90858683801e-06

Statistics for Ravven Tag CCA:

Mean: 0.0234108090401

Median: 0.0100469589233

Max: 0.343581914902

Min: 0.00999093055725

STD: 0.0653301525431

Variance: 0.00426802883131

Stats for input6.bmp

Statistics for AprilTag Baseline:

Mean: 0.52804396

Median: 0.5279605

Max: 0.530307

Min: 0.526992

STD: 0.000649106800457

Variance: 4.213396384e-07

Statistics for AprilTag Baseline Optimized:

Mean: 0.466902894974

Median: 0.46622800827

Max: 0.47127699852

Min: 0.464689970016

STD: 0.0016013985672

Variance: 2.56447737102e-06

Statistics for Ravven Tag MagTheta:

Mean: 1.71077052116

Median: 1.70793092251

Max: 1.72504019737

Min: 1.70315694809

STD: 0.00566014846737

Variance: 3.20372806726e-05

Statistics for PyAprilTag:

Mean: 0.0800874519348

Median: 0.0801091194153

Max: 0.086256980896

Min: 0.0759069919586

STD: 0.00251737527784

Variance: 6.3371782895e-06

Statistics for Ravven Tag CCA:

Mean: 0.0216880297661

Median: 0.00500750541687

Max: 0.338636875153

Min: 0.00493502616882

STD: 0.0726774121006

Variance: 0.00528200622965

Stats for input7.bmp

Statistics for AprilTag Baseline:

Mean: 0.72228349

Median: 0.719602

Max: 0.733952

Min: 0.712926

STD: 0.00779760163191

Variance: 6.08025912099e-05

Statistics for AprilTag Baseline Optimized:

Mean: 0.685026466846

Median: 0.684951424599

Max: 0.689369916916

Min: 0.68341088295

STD: 0.000808033000089

Variance: 6.52917329234e-07

Statistics for Ravven Tag MagTheta:

Mean: 1.97021743536

Median: 1.96981096268

Max: 1.9759478569

Min: 1.96569013596

STD: 0.00231839184543

Variance: 5.37494074894e-06

Statistics for PyAprilTag:

Mean: 0.0772884440422

Median: 0.0777744054794

Max: 0.0857670307159

Min: 0.0720348358154

STD: 0.00345355308055

Variance: 1.19270288802e-05

Statistics for Ravven Tag CCA:

Mean: 0.0250279140472

Median: 0.0216799974442

Max: 0.355134010315

Min: 0.0214190483093

STD: 0.0331770999377

Variance: 0.00110071996027

Stats for input10.bmp

Statistics for AprilTag Baseline:

Mean: 0.43167393

Median: 0.4302375

Max: 0.438751

Min: 0.426107

STD: 0.00445417395542

Variance: 1.98396656251e-05

Statistics for AprilTag Baseline Optimized:

Mean: 0.382988238335

Median: 0.382972955704

Max: 0.385190010071

Min: 0.381927013397

STD: 0.000528686009458

Variance: 2.79508896597e-07

Statistics for Ravven Tag MagTheta:

Mean: 1.57719495058

Median: 1.57677793503

Max: 1.58647298813

Min: 1.5734398365

STD: 0.00205772476261

Variance: 4.23423119866e-06

Statistics for PyAprilTag:

Mean: 0.0768742966652

Median: 0.075615644455

Max: 0.0894289016724

Min: 0.0718162059784

STD: 0.0038244910139

Variance: 1.46267315154e-05

Statistics for Ravven Tag CCA:

Mean: 0.0215576720238

Median: 0.00819957256317

Max: 0.341835021973

Min: 0.00812816619873

STD: 0.0653409286028

Variance: 0.00426943695068

Stats for input20.bmp

Statistics for AprilTag Baseline:

Mean: 0.31037983

Median: 0.3100755

Max: 0.312852

Min: 0.309049

STD: 0.00106732043975

Variance: 1.1391729211e-06

Statistics for AprilTag Baseline Optimized:

Mean: 0.260735223293

Median: 0.260682106018

Max: 0.262679100037

Min: 0.260349035263

STD: 0.000309111000429

Variance: 9.5549610586e-08

Statistics for Ravven Tag MagTheta:

Mean: 1.239834342

Median: 1.23992741108

Max: 1.2440841198

Min: 1.23625183105

STD: 0.00170202320141

Variance: 2.89688297814e-06

Statistics for PyAprilTag:

Mean: 0.0708103370667

Median: 0.0691084861755

Max: 0.0819458961487

Min: 0.0660860538483

STD: 0.0039537742802

Variance: 1.56323310588e-05

Statistics for Ravven Tag CCA:

Mean: 0.023327229023

Median: 0.00993037223816

Max: 0.343726873398

Min: 0.00983905792236

STD: 0.065354093623

Variance: 0.00427115755328