

TILAPIA Thresholding

Cumulative Evaluation

7.30

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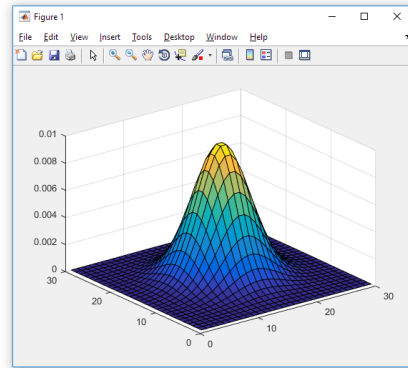
Goal

- Define YUV channel thresholds to:
 - Create separate YUV thresholds for Red, Green and Yellow traffic lights (TL)
 - Maximize True Positive (TP) TL's while avoiding False Positive (FP) and False Positive Pixels (FPP)
 - Better understand what values produce more False Positives
 - Determine what pixels within an image provide most influential values

Extracting Ground Truth Data

Three different techniques were used to develop thresholds when extracting pixel values of the ground truth labeled boxes:

- **Technique 1:** Including the Y,U,V channel values for each pixel inside of the ground truth bounding boxes
- **Technique 2:** Using a Gaussian weighting distribution, with the **center pixel** of each bounding box acting as the mean pixel for Gaussian weighting
- **Technique 3:** Using a Gaussian weighting distribution, with the **pixel of maximum Y channel value** of each bounding box acting as the mean pixel for Gaussian weighting



These three techniques were applied to two sets of images (however, further testing was held to normal images):

- **Normal:** Ground truth frames with no filters
- **Smoothed:** Ground truth frames with Gaussian smoothing kernel added (test for noise in sensor data)



Techniques for Testing Thresholds

- Three different techniques were used to test each threshold when applied to the ground truth data:
 - **Standard Deviation (SD)**: The upper bound of each channel (YUV) was the maximum pixel value found, and the lower bound was 1 SD below the mean.
 - **-10**: The upper bound of each channel (YUV) was the maximum pixel value found, and the lower bound was -10 pixel values below the mean.
 - **25th Percentile**: The upper bound of each channel (YUV) was the maximum pixel value found, and the lower bound was the 25th percentile of the data.

After 5 Sequences Tested

| RED | TP | FN | FPP |
|------------|-----------|-----------|------------|
| BB_10 | 0.712877 | 0.359345 | 3,356.395 |
| GMean_10 | 0.55851 | 0.573494 | 1,264.649 |
| GMax_10 | 0.421377 | 0.785188 | 571.6738 |
| BB_SD | 0.946358 | 0.252384 | 67,312.78 |
| GMean_SD | 0.866414 | 0.186518 | 15,753.73 |
| GMax_SD | 0.684626 | 0.372033 | 8,811.336 |

- Standard Deviation technique looks like the most viable option moving forward
- Gaussian Maximum threshold should no longer be tested

| GREEN | TP | FN | FPP |
|--------------|-----------|-----------|------------|
| BB_10 | 0.826261 | 0.270172 | 19,777.71 |
| GMean_10 | 0.676259 | 0.546012 | 310.1522 |
| GMax_10 | 0.680739 | 0.516405 | 433.1595 |
| BB_SD | 0.843921 | 0.480046 | 536,656.6 |
| GMean_SD | 0.678166 | 0.512507 | 172,671.1 |
| GMax_SD | 0.636644 | 0.610171 | 435,806.6 |

- Bounding Box threshold looks like the most viable option moving forward
- Gaussian Maximum threshold should no longer be tested

After 10 Sequences Tested

| RED | TP | FN | FPP |
|----------|----------|----------|----------|
| BB_10 | 0.7109 | 0.32005 | 3740.603 |
| GMean_10 | 0.615475 | 0.503059 | 1445.719 |
| BB_SD | 0.989272 | 0.035533 | 58526.25 |
| GMean_SD | 0.896855 | 0.165529 | 14266.02 |

| GREEN | TP | FN | FPP |
|----------|----------|-------------|----------|
| BB_10 | 0.833354 | 0.316752471 | 13690.4 |
| GMean_10 | 0.747203 | 0.52418109 | 1028.289 |
| BB_SD | 0.876094 | 0.430089936 | 303316.3 |
| GMean_SD | 0.692304 | 0.46170522 | 97742.39 |

Expanded Testing

- We expanded our testing methodology to incorporate the following:
 - Test on more sequences
 - Test on green lights and red lights
 - Test on nighttime and daytime sequences
 - Segment each image frame, developing and testing different thresholds across each image segment

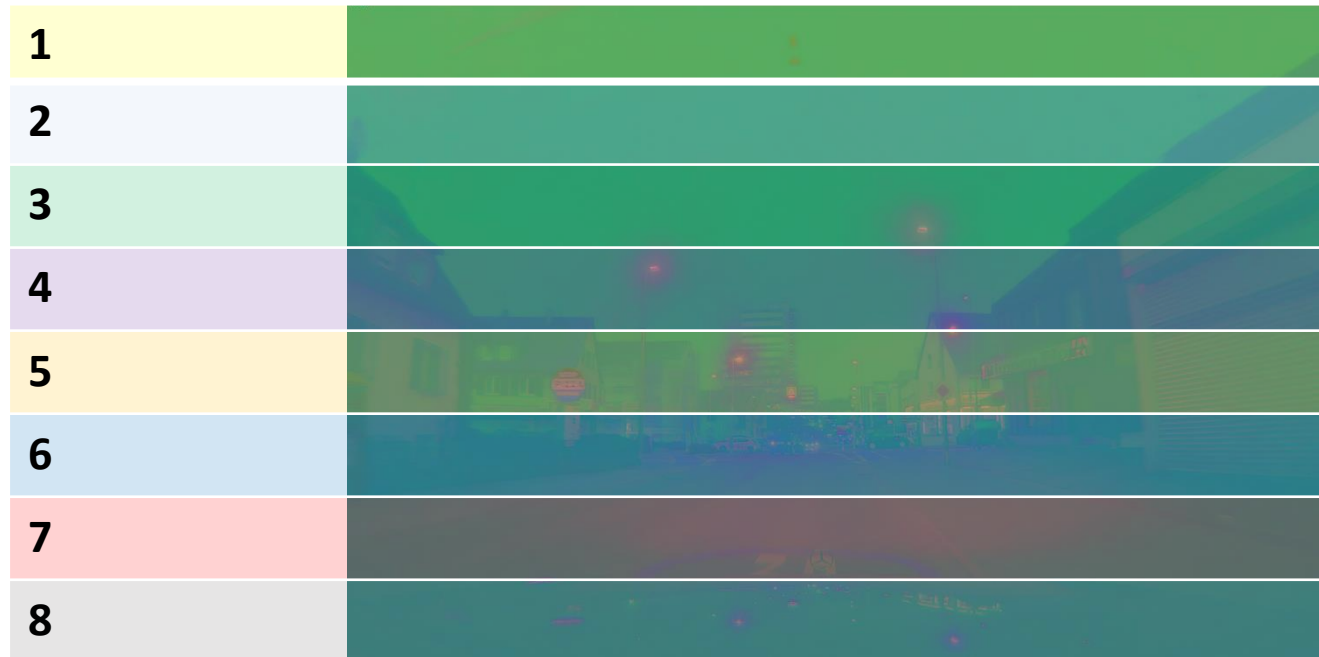
Incorporating Segmentation

Segmentation Method Process

- Segment our image into 8 separate images, each of which we extract true positive (TP) traffic light pixel YUV values from
- Apply statistical methodology (Gaussian weighting) to each segment
 - Analyze initial thresholds
 - Test initial thresholds
- Aggregate thresholds from across 8 sequences to develop new, global thresholds for each segment
 - Analyze global thresholds
 - Test global thresholds

Segmenting Images

- Each frame is 1280 x 1920 pixels
- Divide frame into 8 160 x 1920 pixel images
- Extract TP pixel values from all segments



Initial Thresholds

- Developed 6 thresholds for each segment
 1. Using all pixels within Bounding Boxes
 - (Y channel MAX, Y channel MEAN MINUS 10, U channel MAX, U channel MEAN MINUS 10, V channel MAX, V channel MEAN MINUS 10)
 - (Y channel MAX, Y channel MEAN MINUS ONE SD, U channel MAX, U channel MEAN MINUS ONE SD, V channel MAX, V channel MEAN MINUS ONE SD)
 2. Using Gaussian weighting around center pixel of bounding box
 - (Y channel MAX, Y channel MEAN MINUS 10, U channel MAX, U channel MEAN MINUS 10, V channel MAX, V channel MEAN MINUS 10)
 - (Y channel MAX, Y channel MEAN MINUS ONE SD, U channel MAX, U channel MEAN MINUS ONE SD, V channel MAX, V channel MEAN MINUS ONE SD)
 3. Using Gaussian weighting around maximum Y channel pixel of bounding box
 - (Y channel MAX, Y channel MEAN MINUS 10, U channel MAX, U channel MEAN MINUS 10, V channel MAX, V channel MEAN MINUS 10)
 - (Y channel MAX, Y channel MEAN MINUS ONE SD, U channel MAX, U channel MEAN MINUS ONE SD, V channel MAX, V channel MEAN MINUS ONE SD)

Initial Thresholds

| Sequence | Color | Type | Segment | Threshold |
|----------|-------|----------|---------|-----------------------------|
| 9428 | Green | BB-10 | 5 | 237, 104, 155, 128, 126, 76 |
| 9428 | Green | BB-10 | 4 | 233, 94, 156, 130, 125, 68 |
| 9428 | Green | BB-10 | 3 | 167, 76, 152, 129, 126, 72 |
| 9428 | Green | BB-10 | 2 | 146, 68, 147, 128, 125, 73 |
| 9428 | Green | BB-10 | 1 | 127, 63, 145, 128, 126, 73 |
| 9428 | Green | Gmean-10 | 5 | 235, 117, 152, 127, 126, 79 |
| 9428 | Green | Gmean-10 | 4 | 226, 117, 153, 129, 123, 72 |
| 9428 | Green | Gmean-10 | 3 | 161, 93, 152, 130, 118, 67 |
| 9428 | Green | Gmean-10 | 2 | 140, 94, 145, 131, 114, 61 |
| 9428 | Green | Gmean-10 | 1 | 118, 87, 144, 131, 122, 64 |
| 9428 | Green | Gmax-10 | 5 | 233, 112, 152, 128, 123, 82 |
| 9428 | Green | Gmax-10 | 4 | 228, 115, 155, 130, 125, 74 |
| 9428 | Green | Gmax-10 | 3 | 162, 82, 152, 129, 126, 76 |
| 9428 | Green | Gmax-10 | 2 | 139, 80, 144, 131, 108, 73 |
| 9428 | Green | Gmax-10 | 1 | 118, 75, 144, 130, 105, 72 |
| 9428 | Green | BB-SD | 5 | 237, 80, 155, 130, 126, 71 |
| 9428 | Green | BB-SD | 4 | 233, 85, 156, 131, 125, 62 |
| 9428 | Green | BB-SD | 3 | 167, 71, 152, 130, 126, 60 |
| 9428 | Green | BB-SD | 2 | 146, 60, 147, 130, 125, 60 |
| 9428 | Green | BB-SD | 1 | 127, 60, 145, 131, 126, 62 |
| 9428 | Green | Gmean-SD | 5 | 235, 84, 152, 133, 126, 73 |
| 9428 | Green | Gmean-SD | 4 | 226, 91, 153, 135, 123, 64 |
| 9428 | Green | Gmean-SD | 3 | 161, 75, 152, 136, 118, 61 |
| 9428 | Green | Gmean-SD | 2 | 140, 90, 145, 139, 114, 63 |
| 9428 | Green | Gmean-SD | 1 | 118, 81, 144, 138, 122, 65 |
| 9428 | Green | Gmax-SD | 5 | 233, 78, 152, 134, 123, 75 |
| 9428 | Green | Gmax-SD | 4 | 228, 85, 155, 135, 125, 67 |
| 9428 | Green | Gmax-SD | 3 | 162, 65, 152, 134, 126, 70 |
| 9428 | Green | Gmax-SD | 2 | 139, 69, 144, 138, 108, 74 |
| 9428 | Green | Gmax-SD | 1 | 118, 65, 144, 135, 105, 71 |

After testing initial thresholds, we again discovered that using Gaussian weighting around the maximum Y channel pixel of each bounding box produced the worst TP results. So, we will **NOT** consider that technique for further testing.

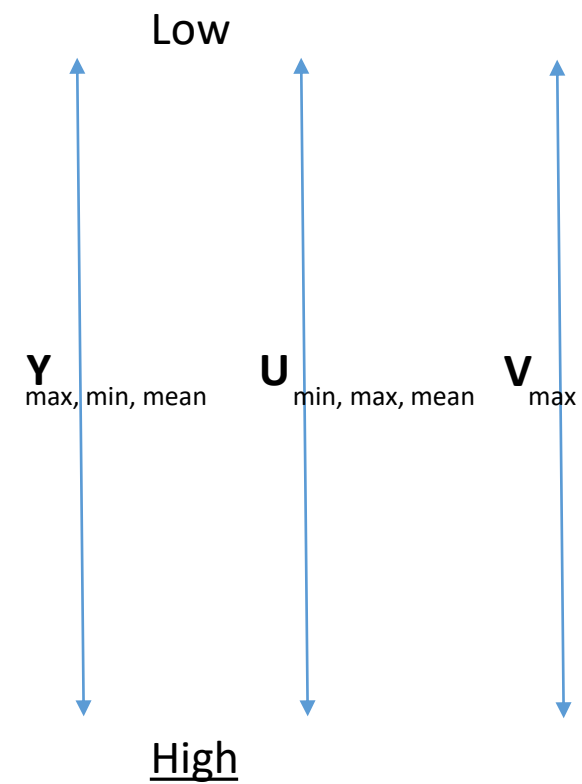
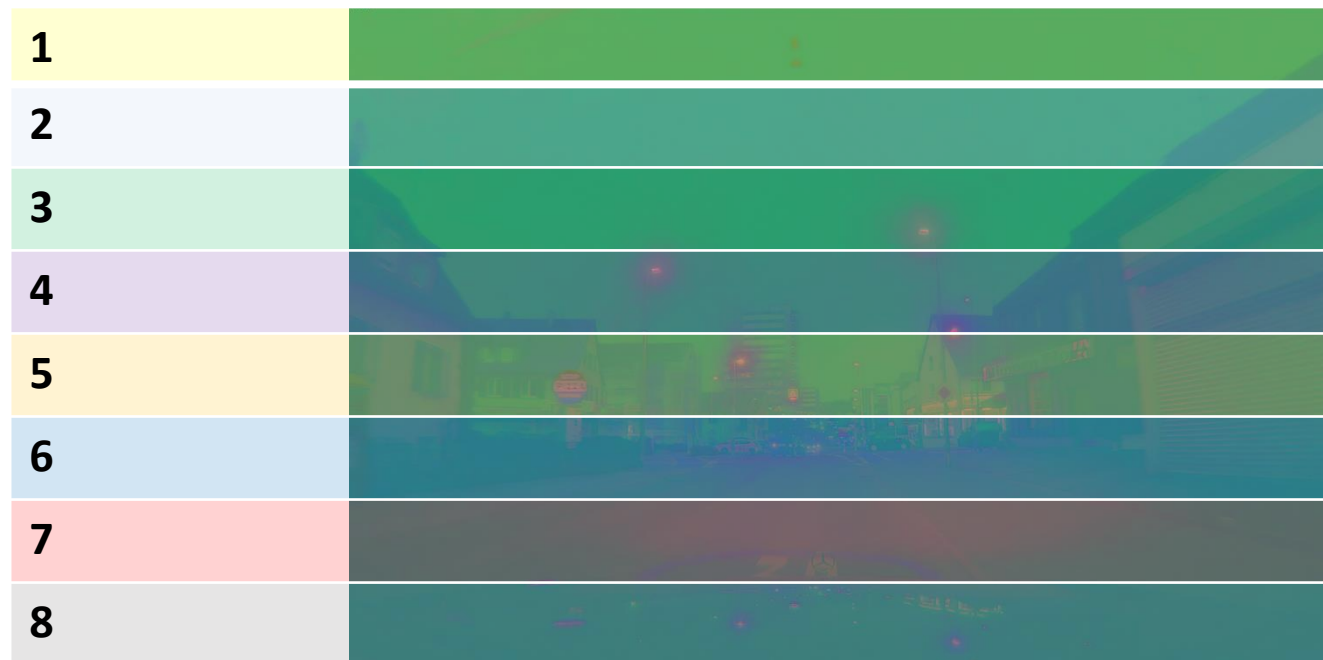
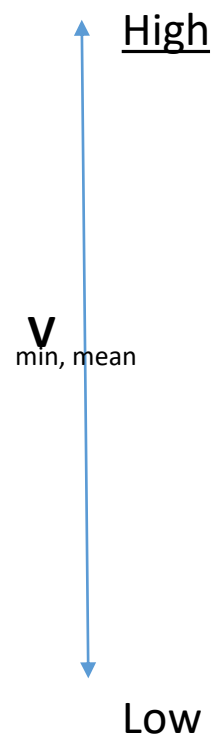
Global Thresholds - Testing

- After testing our four different global thresholds on both red and green lights, across daytime and nighttime sequences, it was quick to see that both BB-10 and Gmean-10 thresholds produced TP results that were far from acceptable, so we only compared BB_SD and Gmean_SD thresholds
- After comparing BB_SD and Gmean_SD thresholds, we noticed two trends:
 - BB_SD ALWAYS produced worse FPP results
 - Gmean_SD usually produced better TP results
 - With the introduction of segmentation, the behavior of channel values differs for red and green traffic lights, and for daytime and nighttime sequences
 - Further testing was needed dependent on channel value behavior

Channel Behavior

Initial Thresholds (Green & Red, Daytime)

- In looking at the initial thresholds for our segmentation technique, some trends appeared:
 - MAX, MIN and MEAN Y channel values INCREASE as you move down an image
 - MAX, MIN and MEAN U channel values INCREASE as you move down an image, although not as much growth as exhibited in the Y channel
 - V channel MAX values INCREASE as you move down an image, while V channel MIN, MEAN values DECREASE as you move up an image



Y Channel

| Type | Segment | Min | Max | Mean | Standard Deviation |
|----------|---------|-----|-----|------|--------------------|
| BB-10 | 6 | | | | |
| BB-10 | 5 | 89 | 220 | 156 | 54 |
| BB-10 | 4 | 43 | 207 | 132 | 52 |
| BB-10 | 3 | 57 | 196 | 124 | 50 |
| BB-10 | 2 | 40 | 197 | 86 | 52 |
| BB-10 | 1 | 32 | 133 | 71 | 37 |
| | | | | | |
| Gmean-10 | 6 | | | | |
| Gmean-10 | 5 | 113 | 214 | 165 | 41 |
| Gmean-10 | 4 | 48 | 197 | 134 | 46 |
| Gmean-10 | 3 | 59 | 188 | 122 | 46 |
| Gmean-10 | 2 | 46 | 190 | 88 | 47 |
| Gmean-10 | 1 | 31 | 129 | 71 | 32 |
| | | | | | |
| BB-SD | 6 | | | | |
| BB-SD | 5 | 79 | 220 | 150 | 63 |
| BB-SD | 4 | 33 | 207 | 125 | 58 |
| BB-SD | 3 | 47 | 196 | 118 | 56 |
| BB-SD | 2 | 40 | 197 | 84 | 53 |
| BB-SD | 1 | 35 | 133 | 71 | 37 |
| | | | | | |
| Gmean-SD | 6 | | | | |
| Gmean-SD | 5 | 77 | 214 | 149 | 58 |
| Gmean-SD | 4 | 36 | 197 | 123 | 56 |
| Gmean-SD | 3 | 29 | 188 | 111 | 57 |
| Gmean-SD | 2 | 37 | 190 | 83 | 50 |
| Gmean-SD | 1 | 40 | 129 | 70 | 32 |



U Channel

| Type | Segment | Min | Max | Mean | Standard Deviation |
|----------|---------|-----|-----|------|--------------------|
| BB-10 | 6 | | | | |
| BB-10 | 5 | 125 | 159 | 143 | 14 |
| BB-10 | 4 | 121 | 157 | 139 | 14 |
| BB-10 | 3 | 120 | 154 | 135 | 14 |
| BB-10 | 2 | 118 | 154 | 128 | 11 |
| BB-10 | 1 | 118 | 140 | 126 | 8 |
| | | | | | |
| Gmean-10 | 6 | | | | |
| Gmean-10 | 5 | 129 | 156 | 142 | 12 |
| Gmean-10 | 4 | 122 | 156 | 139 | 13 |
| Gmean-10 | 3 | 121 | 153 | 135 | 13 |
| Gmean-10 | 2 | 117 | 144 | 126 | 9 |
| Gmean-10 | 1 | 118 | 140 | 126 | 8 |
| | | | | | |
| BB-SD | 6 | | | | |
| BB-SD | 5 | 130 | 159 | 144 | 13 |
| BB-SD | 4 | 126 | 157 | 141 | 13 |
| BB-SD | 3 | 125 | 154 | 137 | 12 |
| BB-SD | 2 | 109 | 154 | 128 | 12 |
| BB-SD | 1 | 109 | 140 | 127 | 9 |
| | | | | | |
| Gmean-SD | 6 | | | | |
| Gmean-SD | 5 | 132 | 156 | 145 | 10 |
| Gmean-SD | 4 | 128 | 156 | 141 | 11 |
| Gmean-SD | 3 | 127 | 153 | 137 | 11 |
| Gmean-SD | 2 | 125 | 144 | 130 | 5 |
| Gmean-SD | 1 | 126 | 140 | 130 | 4 |



V Channel

| Type | Segment | Min | Max | Mean | Standard Deviation |
|----------|---------|-----|-----|------|--------------------|
| BB-10 | 6 | | | | |
| BB-10 | 5 | 52 | 134 | 94 | 38 |
| BB-10 | 4 | 50 | 128 | 97 | 34 |
| BB-10 | 3 | 53 | 127 | 101 | 29 |
| BB-10 | 2 | 85 | 127 | 112 | 16 |
| BB-10 | 1 | 98 | 127 | 117 | 12 |
| | | | | | |
| Gmean-10 | 6 | | | | |
| Gmean-10 | 5 | 42 | 128 | 87 | 38 |
| Gmean-10 | 4 | 38 | 125 | 85 | 36 |
| Gmean-10 | 3 | 42 | 126 | 97 | 31 |
| Gmean-10 | 2 | 71 | 126 | 108 | 19 |
| Gmean-10 | 1 | 88 | 123 | 111 | 13 |
| | | | | | |
| BB-SD | 6 | | | | |
| BB-SD | 5 | 36 | 134 | 88 | 44 |
| BB-SD | 4 | 40 | 128 | 99 | 35 |
| BB-SD | 3 | 50 | 127 | 97 | 32 |
| BB-SD | 2 | 65 | 127 | 109 | 22 |
| BB-SD | 1 | 97 | 127 | 116 | 13 |
| | | | | | |
| Gmean-SD | 6 | | | | |
| Gmean-SD | 5 | 28 | 128 | 79 | 48 |
| Gmean-SD | 4 | 32 | 133 | 89 | 42 |
| Gmean-SD | 3 | 34 | 126 | 91 | 36 |
| Gmean-SD | 2 | 53 | 126 | 107 | 24 |
| Gmean-SD | 1 | 85 | 123 | 112 | 14 |



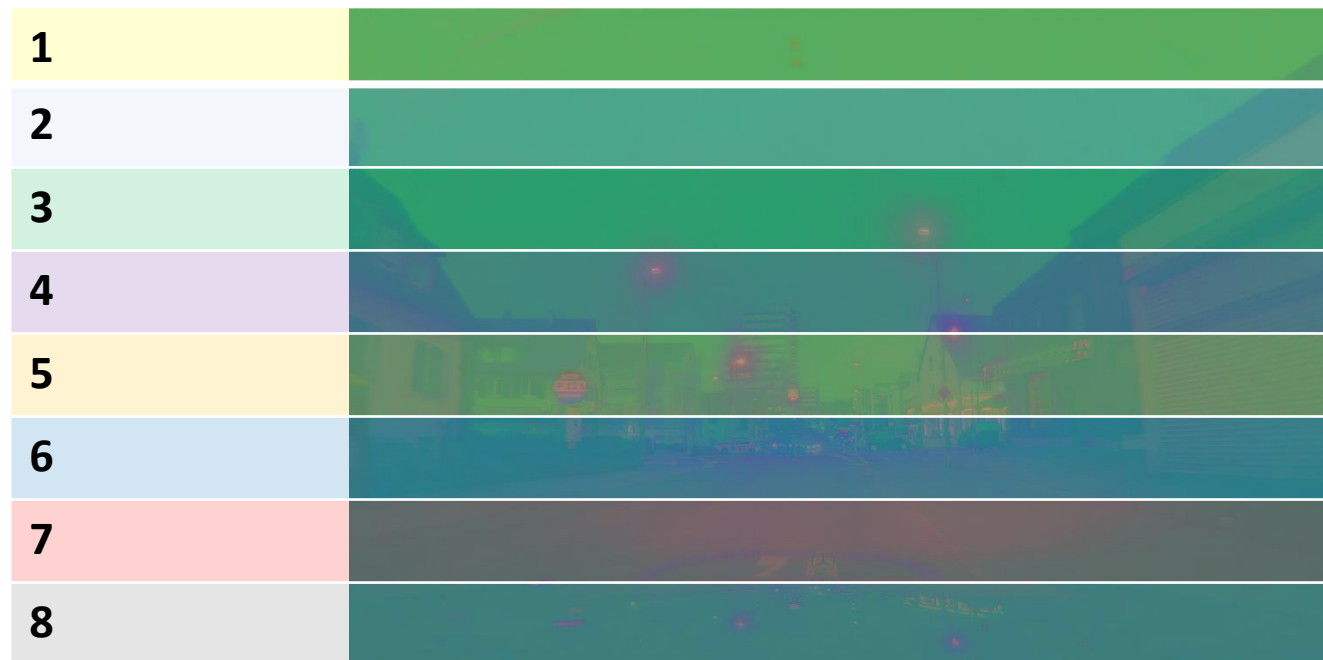
Initial Thresholds (Green, Nighttime)

- In looking at the initial thresholds for our segmentation technique, some trends appeared:
 - MAX and MEAN Y channel values INCREASE as you move down an image frame
 - MIN, MAX and MEAN V channel values INCREASE as you move down an image frame
 - U channel MAX and MEAN values remain fairly consistent across segments, while MIN values tend to DECREASE as you move down an image frame

High

U_{\min}

Low



Low

$Y_{\max, \text{mean}}$

$V_{\min, \max, \text{mean}}$

High

Y Channel

| Type | Segment | Min | Max | Mean | Standard Deviation |
|----------|---------|-----|-----|------|--------------------|
| BB-10 | 6 | 80 | 236 | 165 | 61 |
| BB-10 | 5 | 80 | 237 | 164 | 57.89 |
| BB-10 | 4 | 77 | 233 | 162 | 57.66 |
| BB-10 | 3 | 61 | 227 | 141 | 55.24 |
| BB-10 | 2 | 68 | 181 | 120 | 42.49 |
| BB-10 | 1 | | | | |
| Gmean-10 | 6 | 83 | 237 | 136 | 15.49 |
| Gmean-10 | 5 | 87 | 235 | 165 | 49.87 |
| Gmean-10 | 4 | 96 | 226 | 170 | 45.98 |
| Gmean-10 | 3 | 74 | 199 | 131 | 43.76 |
| Gmean-10 | 2 | 82 | 169 | 124 | 31.93 |
| Gmean-10 | 1 | | | | |
| BB-SD | 6 | 65 | 236 | 157 | 69.98 |
| BB-SD | 5 | 70 | 237 | 156 | 65.81 |
| BB-SD | 4 | 77 | 233 | 161 | 58.83 |
| BB-SD | 3 | 61 | 207 | 129 | 52.73 |
| BB-SD | 2 | 76 | 181 | 126 | 44.11 |
| BB-SD | 1 | | | | |
| Gmean-SD | 6 | 56 | 237 | 156 | 77.25 |
| Gmean-SD | 5 | 68 | 235 | 153 | 62.08 |
| Gmean-SD | 4 | 82 | 226 | 160 | 54.97 |
| Gmean-SD | 3 | 71 | 199 | 123 | 48.82 |
| Gmean-SD | 2 | 68 | 169 | 120 | 36.54 |
| Gmean-SD | 1 | | | | |



U Channel

| Type | Segment | Min | Max | Mean | Standard Deviation |
|----------|---------|-----|-----|------|--------------------|
| BB-10 | 6 | 118 | 150 | 136 | 15.47 |
| BB-10 | 5 | 121 | 155 | 138 | 14.21 |
| BB-10 | 4 | 126 | 156 | 140 | 12.82 |
| BB-10 | 3 | 126 | 152 | 139 | 11.44 |
| BB-10 | 2 | 128 | 152 | 139 | 10.47 |
| BB-10 | 1 | | | | |
| Gmean-10 | 6 | 119 | 152 | 136 | 15.49 |
| Gmean-10 | 5 | 121 | 153 | 137 | 13.32 |
| Gmean-10 | 4 | 125 | 153 | 139 | 11.56 |
| Gmean-10 | 3 | 129 | 152 | 139 | 9.88 |
| Gmean-10 | 2 | 130 | 151 | 140 | 8.62 |
| Gmean-10 | 1 | | | | |
| BB-SD | 6 | 120 | 150 | 137 | 14.56 |
| BB-SD | 5 | 111 | 155 | 139 | 14.59 |
| BB-SD | 4 | 126 | 156 | 141 | 12.64 |
| BB-SD | 3 | 127 | 152 | 139 | 11.41 |
| BB-SD | 2 | 129 | 152 | 140 | 9.43 |
| BB-SD | 1 | | | | |
| Gmean-SD | 6 | 124 | 152 | 141 | 12.29 |
| Gmean-SD | 5 | 126 | 152 | 140 | 10 |
| Gmean-SD | 4 | 131 | 153 | 142 | 8.21 |
| Gmean-SD | 3 | 136 | 152 | 142 | 6.55 |
| Gmean-SD | 2 | 137 | 151 | 143 | 5.05 |
| Gmean-SD | 1 | | | | |



V Channel

| Type | Segment | Min | Max | Mean | Standard Deviation |
|----------|---------|-----|-----|------|--------------------|
| BB-10 | 6 | 87 | 157 | 115 | 25.82 |
| BB-10 | 5 | 72 | 148 | 108 | 27.27 |
| BB-10 | 4 | 67 | 125 | 97 | 26.03 |
| BB-10 | 3 | 72 | 126 | 99 | 25.23 |
| BB-10 | 2 | 55 | 125 | 92 | 31.81 |
| BB-10 | 1 | | | | |
| Gmean-10 | 6 | 87 | 150 | 113 | 23.91 |
| Gmean-10 | 5 | 73 | 146 | 106 | 23.36 |
| Gmean-10 | 4 | 56 | 123 | 91 | 23.1 |
| Gmean-10 | 3 | 63 | 118 | 89 | 23.4 |
| Gmean-10 | 2 | 40 | 118 | 85 | 33.18 |
| Gmean-10 | 1 | | | | |
| BB-SD | 6 | 85 | 157 | 114 | 26.64 |
| BB-SD | 5 | 69 | 148 | 107 | 28.73 |
| BB-SD | 4 | 62 | 125 | 96 | 27.3 |
| BB-SD | 3 | 60 | 126 | 96 | 29 |
| BB-SD | 2 | 40 | 122 | 88 | 9.43 |
| BB-SD | 1 | | | | |
| Gmean-SD | 6 | 73 | 150 | 110 | 28.18 |
| Gmean-SD | 5 | 68 | 146 | 103 | 25.33 |
| Gmean-SD | 4 | 56 | 123 | 90 | 24.18 |
| Gmean-SD | 3 | 55 | 118 | 87 | 25.63 |
| Gmean-SD | 2 | 37 | 118 | 84 | 34.37 |
| Gmean-SD | 1 | | | | |



Initial Thresholds (Red, Nighttime)

- In looking at the initial thresholds for our segmentation technique, there wasn't any hard trends for red traffic lights. The one trend that we noticed was the highest Y,U, and V channel values seem to be located in the central image segments (4,5).

Testing Best Thresholds

Best Result Testing

- Through this point in testing, it was determined that using a threshold for each channel where the upper bound was the MAX channel value, and the lower bound was 1 SD below the MEAN channel value was the most viable method for product implementation (of the methods tested)
- We also wanted to test opening up channel thresholds (255, 0) on each segment to see if we could improve upon our results

Green Lights

Nighttime

Global Thresholds – By Segment (Gmean_SD TP)

| | True Positive % (TP + FN/FN) |
|---|------------------------------|
| 1 | 94% |
| 2 | 100% |
| 3 | 98% |
| 4 | 69% |
| 5 | 86% |
| 6 | 88% |
| 7 | N/A |
| 8 | N/A |

Global Thresholds – By Segment (Gmean_SD TP V Channel Opened)

| | True Positive % (TP + FN/FN) |
|---|------------------------------|
| 1 | 94% |
| 2 | 100% |
| 3 | 98% |
| 4 | 90% |
| 5 | 95% |
| 6 | 89% |
| 7 | N/A |
| 8 | N/A |

Green Synopsis

- Opening V Channel threshold (255, 0) greatly improves some sequence TP rate, while introducing no incorrect TL and a negligible amount of new FPP

| Time of Day | Sequence | Traffic Light Color | Channel Opened? | Lower Bound | TP % | FN % | FPP (per frame) | Incorrect TL Color (#/color) |
|-------------|----------|---------------------|-----------------|-------------|------|------|-----------------|------------------------------|
| Nighttime | 9397 | Green | No | Gmean - SD | 99 | <1 | 771273 | N/A |
| Nighttime | 9397 | Green | V | Gmean - SD | 99 | <1 | 778153 | N/A |
| Nighttime | 9402 | Green | No | Gmean - SD | 98 | 2 | 24545 | 0 |
| Nighttime | 9402 | Green | V | Gmean - SD | 99 | 1 | 27317 | 0 |
| Nighttime | 9405 | Green | No | Gmean - SD | 99 | <1 | 14011 | 0 |
| Nighttime | 9405 | Green | V | Gmean - SD | 99 | <1 | 14300 | 0 |
| Nighttime | 9415 | Green | No | Gmean - SD | 63 | 27 | 334385 | 0 |
| Nighttime | 9415 | Green | V | Gmean - SD | 85 | 15 | 344644 | 0 |
| Nighttime | 9423 | Green | No | Gmean - SD | 54 | 46 | 22876 | 0 |
| Nighttime | 9423 | Green | V | Gmean - SD | 94 | 6 | 23200 | 0 |
| Nighttime | 9428 | Green | No | Gmean - SD | 87 | 13 | 5501 | 0 |
| Nighttime | 9428 | Green | V | Gmean - SD | 99 | 1 | 8806 | 0 |
| Nighttime | 9431 | Green | No | Gmean - SD | 99 | <1 | 12771 | 0 |
| Nighttime | 9431 | Green | V | Gmean - SD | 99 | <1 | 15940 | 0 |
| Nighttime | 9437 | Green | No | Gmean - SD | 71 | 29 | 386939 | 0 |
| Nighttime | 9437 | Green | V | Gmean - SD | 72 | 28 | 395916 | 0 |

Red Lights

Nighttime

Global Thresholds – By Segment (Gmean_SD TP U Channel Opened)

| | True Positive % (TP + FN/FN) |
|---|------------------------------|
| 1 | N/A |
| 2 | 100% |
| 3 | 95% |
| 4 | 89% |
| 5 | 86% |
| 6 | 89% |
| 7 | N/A |
| 8 | N/A |

Global Thresholds – By Segment (Gmean_SD TP U Channel Opened)

| | True Positive % (TP + FN/FN) |
|---|------------------------------|
| 1 | N/A |
| 2 | 100% |
| 3 | 97% |
| 4 | 97% |
| 5 | 91% |
| 6 | 98% |
| 7 | N/A |
| 8 | N/A |

Red Synopsis

- Opening U Channel threshold (255, 0) greatly improves some sequence TP rate, while introducing a large amount of incorrectly identified yellow TL, and a greater amount of new FPP

| Time of Day | Sequence | Traffic Light Color | Channel Opened? | Lower Bound | TP % | FN % | FPP (per frame) | Incorrect TL Color (#/color) |
|-------------|----------|---------------------|-----------------|-------------|------|------|-----------------|------------------------------|
| Nighttime | 9402 | Red | No | Gmean - SD | 76 | 24 | 30718 | 0 |
| Nighttime | 9402 | Red | U | Gmean - SD | 76 | 24 | 37798 | 57 yellow |
| Nighttime | 9405 | Red | No | Gmean - SD | 75 | 25 | 12042 | 0 |
| Nighttime | 9405 | Red | U | Gmean - SD | 85 | 15 | 15386 | 8 yellow |
| Nighttime | 9407 | Red | No | Gmean - SD | 91 | 9 | 8048 | N/A |
| Nighttime | 9407 | Red | U | Gmean - SD | 92 | 8 | 9181 | N/A |
| Nighttime | 9418 | Red | No | Gmean - SD | 89 | 11 | 33321 | 0 |
| Nighttime | 9418 | Red | U | Gmean - SD | 97 | 3 | 41996 | 11 yellow |
| Nighttime | 9419 | Red | No | Gmean - SD | 88 | 12 | 5726 | N/A |
| Nighttime | 9419 | Red | U | Gmean - SD | 89 | 11 | 42815 | N/A |
| Nighttime | 9423 | Red | No | Gmean - SD | 99 | <1 | 29158 | 0 |
| Nighttime | 9423 | Red | U | Gmean - SD | 99 | <1 | 33930 | 60 yellow |
| Nighttime | 9428 | Red | No | Gmean - SD | 75 | 25 | 4219 | 0 |
| Nighttime | 9428 | Red | U | Gmean - SD | 87 | 13 | 6589 | 124 yellow |

Red Synopsis

- To better understand the behavior of FP yellow TL, we analyzed the YUV channel values of those lights falsely identified as TP red. Below are the statistics of those FP yellow TL (using Gaussian mean).

| Color | Image_Segment | min_y_channel_gaus | max_y_channel_gaus | mean_y_channel_gaus | std_y_channel_gaus |
|--------|---------------|--------------------|--------------------|---------------------|--------------------|
| yellow | 2 | 59 | 165 | 130 | 27 |
| yellow | 4 | 65 | 183 | 140 | 26 |
| yellow | 5 | 43 | 171 | 118 | 31 |

| Color | Image_Segment | min_u_channel_gaus | max_u_channel_gaus | mean_u_channel_gaus | std_u_channel_gaus |
|--------|---------------|--------------------|--------------------|---------------------|--------------------|
| yellow | 2 | 51 | 126 | 72 | 19 |
| yellow | 4 | 50 | 139 | 85 | 15 |
| yellow | 5 | 62 | 140 | 97 | 17 |

| Color | Image_Segment | min_v_channel_gaus | max_v_channel_gaus | mean_v_channel_gaus | std_v_channel_gaus |
|--------|---------------|--------------------|--------------------|---------------------|--------------------|
| yellow | 2 | 112 | 155 | 148 | 11 |
| yellow | 4 | 63 | 157 | 141 | 10 |
| yellow | 5 | 89 | 160 | 140 | 9 |

Green Lights

Daytime

Global Thresholds – By Segment (Gmean_SD TP)

| | True Positive % (TP + FN/FN) |
|---|------------------------------|
| 1 | 98% |
| 2 | 100% |
| 3 | 95% |
| 4 | 90% |
| 5 | 83% |
| 6 | N/A |
| 7 | N/A |
| 8 | N/A |

Global Thresholds – By Segment (Gmean_SD TP Y Channel Opened)

| | True Positive % (TP + FN/FN) |
|---|------------------------------|
| 1 | 98% |
| 2 | 100% |
| 3 | 99% |
| 4 | 97% |
| 5 | 87% |
| 6 | N/A |
| 7 | N/A |
| 8 | N/A |

Green Synopsis

- Opening Y Channel Thresholds (255, 0) improves some sequence TP results, without introducing incorrect TP traffic lights, and a negligible amount of additional FPP

| Time of Day | Sequence | Traffic Light Color | Channel Opened? | Lower Bound | TP % | FN % | FPP (per frame) | Incorrect TL Color (#/color) |
|-------------|----------|---------------------|-----------------|-------------|------|------|-----------------|------------------------------|
| Daytime | 9375 | Green | No | Gmean - SD | 99 | <1 | 505404 | 0 |
| Daytime | 9375 | Green | Y | Gmean - SD | 99 | <1 | 823106 | 0 |
| Daytime | 9388 | Green | No | Gmean - SD | 78 | 22 | 514094 | 0 |
| Daytime | 9388 | Green | Y | Gmean - SD | 82 | 18 | 588553 | 0 |
| Daytime | 9443 | Green | No | Gmean - SD | 96 | 4 | 313141 | 0 |
| Daytime | 9443 | Green | Y | Gmean - SD | 98 | 2 | 383256 | 3 red |
| Daytime | 9450 | Green | No | Gmean - SD | 91 | 9 | 377851 | 0 |
| Daytime | 9450 | Green | Y | Gmean - SD | 99 | <1 | 424029 | 0 |
| Daytime | 9471 | Green | No | Gmean - SD | 99 | <1 | 667867 | 0 |
| Daytime | 9471 | Green | Y | Gmean - SD | 99 | <1 | 826974 | 0 |

Red Lights

Daytime

Global Thresholds – By Segment (Gmean_SD TP)

| | True Positive % (TP + FN/FN) |
|---|--------------------------------|
| 1 | N/A |
| 2 | 100% |
| 3 | 60% (one sequence with 317 FP) |
| 4 | 77% |
| 5 | 93% |
| 6 | N/A |
| 7 | N/A |
| 8 | N/A |

Global Thresholds – By Segment (Gmean_SD TP with U Channel Opened)

| | True Positive % (TP + FN/FN) |
|---|------------------------------|
| 1 | N/A |
| 2 | 100% |
| 3 | 99% |
| 4 | 95% |
| 5 | 96% |
| 6 | N/A |
| 7 | N/A |
| 8 | N/A |

Red Synopsis

- Opening U Channel Thresholds improves some sequence TP results, while introducing many incorrectly identified yellow TL, and a negligible amount of additional FPP

| Time of Day | Sequence | Traffic Light Color | Channel Opened? | Lower Bound | TP % | FN % | FPP (per frame) | Incorrect TL Color (#/color) |
|-------------|----------|---------------------|-----------------|-------------|------|------|-----------------|------------------------------|
| Daytime | 9375 | Red | No | Gmean - SD | 83 | 17 | 103466 | 0 |
| Daytime | 9375 | Red | U | Gmean - SD | 83 | 17 | 105553 | 15 yellow |
| Daytime | 9376 | Red | No | Gmean - SD | 67 | 33 | 17207 | N/A |
| Daytime | 9376 | Red | U | Gmean - SD | 100 | 0 | 18036 | N/A |
| Daytime | 9387 | Red | No | Gmean - SD | 99 | <1 | 5253 | N/A |
| Daytime | 9387 | Red | U | Gmean - SD | 99 | <1 | 6633 | N/A |
| Daytime | 9288 | Red | No | Gmean - SD | 100 | 0 | 15705 | |
| Daytime | 9388 | Red | U | Gmean - SD | 100 | 0 | 17033 | 109 yellow |
| Daytime | 9443 | Red | No | Gmean - SD | 90 | 10 | 4318 | 0 |
| Daytime | 9443 | Red | U | Gmean - SD | 93 | 7 | 4999 | 7 yellow |
| Daytime | 9447 | Red | No | Gmean - SD | 78 | 22 | 28174 | 0 |
| Daytime | 9447 | Red | U | Gmean - SD | 78 | 22 | 32201 | 147 yellow |
| Daytime | 9450 | Red | No | Gmean - SD | 99 | <1 | 10160 | 0 |
| Daytime | 9450 | Red | U | Gmean - SD | 99 | <1 | 14310 | 50 yellow |
| Daytime | 9466 | Red | No | Gmean - SD | 96 | 4 | 6163 | 0 |
| Daytime | 9466 | Red | U | Gmean - SD | 100 | 0 | 14304 | 172 yellow |
| Daytime | 9470 | Red | No | Gmean - SD | 87 | 13 | 8056 | N/A |
| Daytime | 9470 | Red | U | Gmean - SD | 87 | 13 | 8350 | N/A |
| Daytime | 9471 | Red | No | Gmean - SD | 96 | 4 | 6583 | 0 |
| Daytime | 9471 | Red | U | Gmean - SD | 96 | 4 | 18686 | 0 |
| Daytime | 9474 | Red | No | Gmean - SD | 100 | 0 | 13030 | N/A |
| Daytime | 9474 | Red | U | Gmean - SD | 100 | 0 | 18636 | N/A |

Red Synopsis

- To better understand the behavior of FP yellow TL, we analyzed the YUV channel values of those lights falsely identified as TP red. Below are the statistics of those FP yellow TL (using Gaussian mean).

| Color | Image_Segment | min_y_channel_gaus | max_y_channel_gaus | mean_y_channel_gaus | std_y_channel_gaus |
|--------|---------------|--------------------|--------------------|---------------------|--------------------|
| yellow | 3 | 37 | 116 | 83 | 25 |
| yellow | 4 | 47 | 185 | 107 | 36 |
| yellow | 5 | 49 | 209 | 136 | 40 |
| yellow | 6 | 45 | 142 | 92 | 25 |

| Color | Image_Segment | min_u_channel_gaus | max_u_channel_gaus | mean_u_channel_gaus | std_u_channel_gaus |
|--------|---------------|--------------------|--------------------|---------------------|--------------------|
| yellow | 3 | 92 | 106 | 107 | 10 |
| yellow | 4 | 54 | 121 | 91 | 17 |
| yellow | 5 | 34 | 123 | 80 | 19 |
| yellow | 6 | 95 | 125 | 112 | 4 |

| Color | Image_Segment | min_v_channel_gaus | max_v_channel_gaus | mean_v_channel_gaus | std_v_channel_gaus |
|--------|---------------|--------------------|--------------------|---------------------|--------------------|
| yellow | 3 | 128 | 155 | 143 | 7 |
| yellow | 4 | 130 | 170 | 146 | 9 |
| yellow | 5 | 128 | 165 | 140 | 7 |
| yellow | 6 | 127 | 144 | 134 | 4 |

Current Recommendations

- Extract threshold values from sequences using Gaussian mean weighting (current weighting is .05)
- Use an upper bound of the MAX channel for global thresholds, and a lower bound of the channel MEAN value MINUS 1 SD
- Segment each image to have more exact thresholds for image regions
- Utilize different thresholds for daytime and nighttime
 - For nighttime green TL thresholds, open up V channel threshold
 - For daytime green TL thresholds, open up Y channel threshold

Current Results (Daytime)

Green

| | True Positive |
|---|---------------|
| 1 | 98% |
| 2 | 100% |
| 3 | 99% |
| 4 | 97% |
| 5 | 87% |
| 6 | N/A |
| 7 | N/A |
| 8 | N/A |

| | Thresholds |
|---|---------------------------|
| 1 | 255, 0, 140, 126, 123, 98 |
| 2 | 255, 0, 144, 125, 126, 83 |
| 3 | 255, 0, 153, 126, 126, 55 |
| 4 | 255, 0, 156, 130, 133, 47 |
| 5 | 255, 0, 156, 135, 128, 31 |
| 6 | 255, 0, 156, 135, 128, 31 |
| 7 | 255, 0, 156, 135, 128, 31 |
| 8 | 255, 0, 156, 135, 128, 31 |

[Ymax, Ymean – SD, 255, 0, Vmax, Vmean – SD]*

Current Results (Daytime)

Red

| | Thresholds |
|---|---------------------------|
| 1 | 160, 42, 255, 0, 203, 142 |
| 2 | 160, 42, 255, 0, 203, 142 |
| 3 | 160, 42, 255, 0, 203, 142 |
| 4 | 185, 75, 255, 0, 210, 162 |
| 5 | 211, 82, 255, 0, 210, 141 |
| 6 | 211, 82, 255, 0, 210, 141 |
| 7 | 211, 82, 255, 0, 210, 141 |
| 8 | 211, 82, 255, 0, 210, 141 |

| | True Positive |
|---|---------------|
| 1 | N/A |
| 2 | 100% |
| 3 | 99% |
| 4 | 95% |
| 5 | 96% |
| 6 | N/A |
| 7 | N/A |
| 8 | N/A |

[255, 0, Umax, Umean – SD, Vmax, Vmean – SD]*

Current Results (Nighttime)

Green

| | True Positive |
|---|---------------|
| 1 | 94% |
| 2 | 100% |
| 3 | 98% |
| 4 | 90% |
| 5 | 95% |
| 6 | 89% |
| 7 | N/A |
| 8 | N/A |

| | Thresholds |
|---|----------------------------|
| 1 | 169, 83, 151, 138, 255, 0 |
| 2 | 169, 83, 151, 138, 255, 0 |
| 3 | 199, 74, 152, 135, 255, 0 |
| 4 | 226, 105, 153, 134, 255, 0 |
| 5 | 235, 91, 152, 130, 255, 0 |
| 6 | 237, 79, 152, 129, 255, 0 |
| 7 | 237, 79, 152, 129, 255, 0 |
| 8 | 237, 79, 152, 129, 255, 0 |

[Ymax, Ymean – SD, 255, 0, Vmax, Vmean – SD]*

Current Results (Nighttime)

Red

| | Thresholds |
|---|----------------------------|
| 1 | 188, 96, 255, 0, 177, 142 |
| 2 | 188, 96, 255, 0, 177, 142 |
| 3 | 188, 96, 255, 0, 177, 142 |
| 4 | 204, 106, 255, 0, 181, 139 |
| 5 | 209, 89, 255, 0, 201, 139 |
| 6 | 195, 65, 255, 0, 182, 137 |
| 7 | 195, 65, 255, 0, 182, 137 |
| 8 | 195, 65, 255, 0, 182, 137 |

| | True Positive |
|---|---------------|
| 1 | N/A |
| 2 | 100% |
| 3 | 97% |
| 4 | 97% |
| 5 | 91% |
| 6 | 98% |
| 7 | N/A |
| 8 | N/A |

[Ymax, Ymean – SD, 255, 0, Vmax, Vmean – SD]*

Future Recommendations

- Opening up U channel thresholds for red TL for daytime and nighttime increases TP %, but need to determine if detection of yellow TL is OK (are we ok if the system believes a yellow TL is a red TL?)
- Continue development of global thresholds and test on more sequences
- Do research into yellow TL
- Determine better way to identify False Positives

Appendix 1

Initial Threshold Testing

Sequence 9428

Thresholds

Bounding Box YUV Statistics

| Color | max_Y | mean_Y | max_U | mean_U | max_V | mean_V |
|--------|-------|-------------|-------|-------------|-------|-------------|
| red | 196 | 102.0798274 | 136 | 113.2824507 | 183 | 148.4875641 |
| green | 237 | 104.8908334 | 156 | 139.3072033 | 126 | 83.26130015 |
| yellow | 194 | 105.7548312 | 141 | 101.4593322 | 168 | 139.5871453 |

Gaussian Max Value YUV Statistics

| Color | max_y_channel_gaus_max | mean_y_channel_gaus_max |
|--------|------------------------|-------------------------|
| red | 196 | 113.7725694 |
| green | 233 | 121.0827601 |
| yellow | 189 | 111.5158562 |

| Color | max_u_channel_gaus_max | mean_u_channel_gaus_max |
|--------|------------------------|-------------------------|
| red | 135 | 116.8185265 |
| green | 155 | 138.8132337 |
| yellow | 140 | 103.83159 |

| Color | max_v_channel_gaus_max | mean_v_channel_gaus_max |
|--------|------------------------|-------------------------|
| red | 183 | 152.1726587 |
| green | 126 | 90.18922652 |
| yellow | 159 | 140.3061889 |

Gaussian Center YUV Statistics

| Color | max_y_channel_gaus | mean_y_channel_gaus |
|--------|--------------------|---------------------|
| red | 194 | 116.6697626 |
| green | 235 | 126.3242966 |
| yellow | 193 | 123.1554192 |

| Color | max_u_channel_gaus | mean_u_channel_gaus |
|--------|--------------------|---------------------|
| red | 132 | 111.5816993 |
| green | 153 | 138.5855412 |
| yellow | 140 | 97.07293797 |

| Color | max_v_channel_gaus | mean_v_channel_gaus |
|--------|--------------------|---------------------|
| red | 181 | 149.3157895 |
| green | 126 | 87.20230027 |
| yellow | 165 | 140.0027267 |

Example with Gaussian weighting threshold of 0.05 (only pixels with a weighted value \leq are used for threshold development)

Threshold Comparison

| Mean Values | Y | U | V |
|---------------|-------------|-------------|-------------|
| Bounding Box | 104.8908334 | 139.3072033 | 83.26130015 |
| Gaussian Mean | 126.3242966 | 138.5855412 | 87.20230027 |
| Gaussian Max | 121.0827601 | 138.8132337 | 90.18922652 |

| | Y | U | V |
|---------------|-------------|-------------|-------------|
| Bounding Box | 105.7548312 | 101.4593322 | 139.5871453 |
| Gaussian Mean | 123.1554192 | 97.07293797 | 140.0027267 |
| Gaussian Max | 111.5158562 | 103.83159 | 140.3061889 |

| | Y | U | V |
|---------------|-------------|-------------|-------------|
| Bounding Box | 102.0798274 | 113.2824507 | 148.4875641 |
| Gaussian Mean | 116.6697626 | 111.5816993 | 149.3157895 |
| Gaussian Max | 113.7725694 | 116.8185265 | 152.1726587 |

Threshold Testing

Applying the different thresholds to the sequence

Red

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 78 | 41.55727554 |
| green | 0 | 0 |
| yellow | 15 | 3.975460123 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 63.09865471 | 752.264574 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 285 | 38 | red | 38 |
| 0.882353 | 0.117647 | green | 541 |
| | | yellow | 162 |

Threshold Values Used: [196 95 136 103 183 138]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 73 | 32.74303406 |
| green | 0 | 0 |
| yellow | 10 | 2.202453988 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 49.03587444 | 411.7085202 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 239 | 84 | red | 84 |
| 0.739938 | 0.260062 | green | 541 |
| | | yellow | 163 |

Threshold Values Used: [194 106 132 101 181 139]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 51 | 20.45201238 |
| green | 0 | 0 |
| yellow | 6 | 0.588957055 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 30.05381166 | 388.9506726 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 118 | 205 | red | 205 |
| 0.365325 | 0.634675 | green | 541 |
| | | yellow | 163 |

Threshold Values Used: [196 103 135 106 183 142]

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax,Vmean – SD]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 123 | 66.74303406 |
| green | 0 | 0 |
| yellow | 68 | 31.07361963 |

Threshold Values Used: [196 63 136 99 183 133]

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 119.3856502 | 11761.21525 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 309 | 14 | | |
| 0.956656 | 0.043344 | red | 14 |
| | | green | 541 |
| | | yellow | 43 |

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 93 | 49.71517028 |
| green | 0 | 0 |
| yellow | 28 | 8.773006135 |

Threshold Values Used: [194 71 132 101 181 138]

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 78.42152466 | 2875.784753 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 300 | 23 | | |
| 0.928793 | 0.071207 | red | 23 |
| | | green | 541 |
| | | yellow | 154 |

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 70 | 30.6873065 |
| green | 0 | 0 |
| yellow | 16 | 3.042944785 |

Threshold Values Used: [196 67 135 108 183 140]

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 46.67264574 | 2942.251121 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 209 | 114 | | |
| 0.647059 | 0.352941 | red | 114 |
| | | green | 541 |
| | | yellow | 163 |

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax Y(25th) , Umax U(25th) , Vmax V(25th)]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 66 | 32.63467492 |
| green | 0 | 0 |
| yellow | 10 | 1.748466258 |

Threshold Values Used: [194 85 132 105 181 140]

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 48.5470852 | 911.2825112 |

| TP | FN | FN by Light Color | |
|----------|----------|----------------------|-----|
| 230 | 93 | red | 93 |
| 0.712074 | 0.287926 | green | 541 |
| | | yellow | 163 |

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 16 | 1.089783282 |
| green | 0 | 0 |
| yellow | 0 | 0 |

Threshold Values Used: [196 70 135 120 183 145]

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 1.578475336 | 257.9013453 |

| TP | FN | FN by Light Color | |
|----|-----|----------------------|-----|
| 0 | 323 | red | 323 |
| 0 | 1 | green | 541 |
| | | yellow | 163 |

FN defined as a bounding box
with less 25% of pixels identified

Green

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| green | 658 | 107.8280961 |
| yellow | 17 | 0.404907975 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 261.8878924 | 677.9730942 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 440 | 101 | red | 323 |
| 0.813309 | 0.186691 | green | 101 |
| | | yellow | 163 |

Threshold Values Used: [237 94 156 129 126 73]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| green | 561 | 73.5767098 |
| yellow | 1 | 0.006134969 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 178.5022422 | 263.4843049 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 254 | 287 | red | 323 |
| 0.469501 | 0.530499 | green | 287 |
| | | yellow | 163 |

Threshold Values Used: [235 116 153 128 126 77]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| green | 512 | 68.3974122 |
| yellow | 1 | 0.006134969 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 165.9372197 | 351.4080717 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 237 | 304 | red | 323 |
| 0.438078 | 0.561922 | green | 304 |
| | | yellow | 163 |

Threshold Values Used: [233 111 155 128 126 80]

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax,Vmean – SD]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| green | 2163 | 201.5064695 |
| yellow | 23 | 0.435582822 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 489.1748879 | 2148.874439 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 519 | 22 | | |
| 0.959335 | 0.040665 | red | 323 |
| | | green | 22 |
| | | yellow | 163 |

Threshold Values Used: [237 76 156 133 126 67]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| green | 1261 | 129.4066543 |
| yellow | 6 | 0.085889571 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 314.0044843 | 527.955157 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 412 | 129 | | |
| 0.761553 | 0.238447 | red | 323 |
| | | green | 129 |
| | | yellow | 163 |

Threshold Values Used: [235 85 153 134 126 70]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| green | 737 | 119.1275416 |
| yellow | 7 | 0.159509202 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 289.1210762 | 843.9865471 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 398 | 143 | | |
| 0.735675 | 0.264325 | red | 323 |
| | | green | 143 |
| | | yellow | 163 |

Threshold Values Used: [233 79 155 135 126 73]

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax Y(25th) , Umax U(25th) , Vmax V(25th)]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| green | 534 | 81.69316081 |
| yellow | 2 | 0.030674847 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 198.2107623 | 364.7533632 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 287 | 254 | | |
| 0.530499 | 0.469501 | red | 323 |
| | | green | 254 |
| | | yellow | 163 |

Threshold Values Used: [235 90 153 135 126 74]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| green | 388 | 53.02957486 |
| yellow | 4 | 0.055214724 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 128.690583 | 355.6591928 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 105 | 436 | | |
| 0.194085 | 0.805915 | red | 323 |
| | | green | 436 |
| | | yellow | 163 |

Threshold Values Used: [233 85 155 137 126 77]

FN defined as a bounding box
with less 25% of pixels identified

Analysis from Sequence 9428

Red Lights

- Gaussian Max threshold produces the worst results
- Gaussian Mean threshold might provide best balance of TP rate and low amount of FP pixels
- 25th percentile not a technique worth pursuing

Green Lights

- Gaussian Max threshold produces the worst results
- Using all pixels within each bounding box looks to produce best TP results, while other thresholds do not provide a viable option
- 25th percentile not a technique worth pursuing

Threshold Testing on Sequence 9419 (RED ONLY LIGHTS)

We will test -10 from mean and SD techniques on this sequence

Thresholds

Bounding Box YUV Statistics

| Color | GroupCount | min_Y | max_Y | mean_Y | min_U | max_U | mean_U | min_V | max_V | mean_V |
|-------|------------|-------|-------|-------------|-------|-------|-------------|-------|-------|-------------|
| red | 93219 | 35 | 204 | 131.8553192 | 81 | 135 | 117.9220223 | 130 | 184 | 147.9496133 |

Gaussian Max Value YUV Statistics

| Color | max_y_channel_gaus_max | mean_y_channel_gaus_max |
|-------|------------------------|-------------------------|
| red | 204 | 147.557638 |

| Color | max_u_channel_gaus_max | mean_u_channel_gaus_max |
|-------|------------------------|-------------------------|
| red | 132 | 119.2356721 |

| Color | max_v_channel_gaus_max | mean_v_channel_gaus_max |
|-------|------------------------|-------------------------|
| red | 184 | 147.9525014 |

Gaussian Center YUV Statistics

| Color | max_y_channel_gaus | mean_y_channel_gaus |
|-------|--------------------|---------------------|
| red | 204 | 146.5469779 |

| Color | max_u_channel_gaus | mean_u_channel_gaus |
|-------|--------------------|---------------------|
| red | 128 | 119.4951127 |

| Color | max_v_channel_gaus | mean_v_channel_gaus |
|-------|--------------------|---------------------|
| red | 180 | 146.6453222 |

Change from 9428

> 10

< 10

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 396 | 92.37342908 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 214.3833333 | 817.9291667 |

| TP | FN |
|----------|----------|
| 455 | 102 |
| 0.816876 | 0.183124 |

Threshold Values Used: [196 95 136 103 183 138]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 353 | 77.44883303 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 179.7458333 | 493.4083333 |

| TP | FN |
|----------|----------|
| 399 | 158 |
| 0.716338 | 0.283662 |

Threshold Values Used: [194 106 132 101 181 139]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 315 | 63.70017953 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 147.8375 | 443.425 |

| TP | FN |
|----------|----------|
| 327 | 230 |
| 0.587074 | 0.412926 |

Threshold Values Used: [196 103 135 106 183 142]

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax,Vmean – SD]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 522 | 154.4021544 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 358.3416667 | 122505.125 |

| TP | FN |
|-----|----|
| 557 | 0 |
| 1 | 0 |

Threshold Values Used: [196 63 136 99 183 133]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 459 | 113.2477558 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 262.8291667 | 12202.5625 |

| TP | FN |
|----------|----------|
| 515 | 42 |
| 0.924596 | 0.075404 |

Threshold Values Used: [194 71 132 101 181 138]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 419 | 94.22082585 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 218.6708333 | 2999.208333 |

| TP | FN |
|----------|----------|
| 448 | 109 |
| 0.804309 | 0.195691 |

Threshold Values Used: [196 67 135 108 183 140]

FN defined as a bounding box with less 25% of pixels identified

Threshold Testing on Sequence 9397(GREEN ONLY LIGHTS)

We will test -10 from mean and SD techniques on this sequence

Thresholds

Bounding Box YUV Statistics

| Color | GroupCount | min_Y | max_Y | mean_Y | min_U | max_U | mean_U | min_V | max_V | mean_V |
|-------|------------|-------|-------|-------------|-------|-------|-------------|-------|-------|-------------|
| green | 13050 | 58 | 230 | 133.4091954 | 122 | 150 | 133.8824521 | 55 | 127 | 99.31517241 |

Gaussian Max Value YUV Statistics

| Color | max_y_channel_gaus_max | mean_y_channel_gaus_max |
|-------|------------------------|-------------------------|
| green | 228 | 135.7809371 |

| Color | max_u_channel_gaus_max | mean_u_channel_gaus_max |
|-------|------------------------|-------------------------|
| green | 149 | 134.7957041 |

| Color | max_v_channel_gaus_max | mean_v_channel_gaus_max |
|-------|------------------------|-------------------------|
| green | 127 | 105.2892515 |

Gaussian Center YUV Statistics

| Color | max_y_channel_gaus | mean_y_channel_gaus |
|-------|--------------------|---------------------|
| green | 224 | 140.6760563 |

| Color | max_u_channel_gaus | mean_u_channel_gaus |
|-------|--------------------|---------------------|
| green | 150 | 134.2468701 |

| Color | max_v_channel_gaus | mean_v_channel_gaus |
|-------|--------------------|---------------------|
| green | 127 | 99.41549296 |

Change from 9428

> 10

< 10

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| green | 58 | 32.82042254 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 131.2816901 | 78833.08451 |

| TP | FN |
|----------|----------|
| 283 | 1 |
| 0.996479 | 0.003521 |

Threshold Values Used: [237 94 156 129 126 73]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| green | 44 | 22.53873239 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 90.15492958 | 157.4929577 |

| TP | FN |
|----------|----------|
| 282 | 2 |
| 0.992958 | 0.007042 |

Threshold Values Used: [235 116 153 128 126 77]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| green | 47 | 23.51760563 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 94.07042254 | 240.1971831 |

| TP | FN |
|----------|----------|
| 283 | 1 |
| 0.996479 | 0.003521 |

Threshold Values Used: [233 111 155 128 126 80]

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax,Vmean – SD]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| green | 52 | 21.52112676 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 86.08450704 | 1252666.873 |

| TP | FN |
|----------|----------|
| 233 | 51 |
| 0.820423 | 0.179577 |

Threshold Values Used: [237 76 156 133 126 67]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| green | 42 | 15.06690141 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 60.26760563 | 635973.2394 |

| TP | FN |
|----------|----------|
| 175 | 109 |
| 0.616197 | 0.383803 |

Threshold Values Used: [235 85 153 134 126 70]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| green | 35 | 11.26408451 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 45.05633803 | 1141510.394 |

| TP | FN |
|----------|----------|
| 130 | 154 |
| 0.457746 | 0.542254 |

Threshold Values Used: [233 79 155 135 126 73]

FN defined as a bounding box with less 25% of pixels identified

Threshold Testing on Sequence 9405

We will test -10 from mean and SD techniques on this sequence

Thresholds

Bounding Box YUV Statistics

| Color | max_Y | mean_Y | max_U | mean_U | max_V | mean_V |
|--------|-------|-------------|-------|-------------|-------|-------------|
| yellow | 192 | 125.7756614 | 130 | 109.7068783 | 152 | 136.6 |
| red | 201 | 110.6466932 | 146 | 115.7395117 | 198 | 148.9156472 |
| green | 209 | 108.4132379 | 152 | 138.8593918 | 132 | 88.01224409 |

Gaussian Max Value YUV Statistics

| Color | max_y_channel_gaus_max | mean_y_channel_gaus_max |
|--------|------------------------|-------------------------|
| yellow | 190 | 131.2407407 |
| red | 198 | 109.0308561 |
| green | 209 | 109.5141762 |

| Color | max_u_channel_gaus_max | mean_u_channel_gaus_max |
|--------|------------------------|-------------------------|
| yellow | 130 | 111.7560976 |
| red | 139 | 119.4428312 |
| green | 151 | 137.707196 |

| Color | max_v_channel_gaus_max | mean_v_channel_gaus_max |
|--------|------------------------|-------------------------|
| yellow | 151 | 136.0188679 |
| red | 196 | 150.3153259 |
| green | 130 | 95.57809111 |

Gaussian Center YUV Statistics

| Color | max_y_channel_gaus | mean_y_channel_gaus |
|--------|--------------------|---------------------|
| yellow | 188 | 130.6215278 |
| red | 199 | 110.4317993 |
| green | 209 | 128.0687135 |

| Color | max_u_channel_gaus | mean_u_channel_gaus |
|--------|--------------------|---------------------|
| yellow | 129 | 108.7673611 |
| red | 138 | 116.7692786 |
| green | 149 | 138.0730994 |

| Color | max_v_channel_gaus | mean_v_channel_gaus |
|--------|--------------------|---------------------|
| yellow | 150 | 136.5069444 |
| red | 188 | 147.4869403 |
| green | 123 | 90.82236842 |

Change from 9428

> 10

< 10

Red

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 11 | 1.875 |
| red | 372 | 33.83768657 |
| green | 0 | 0 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 108.9640719 | 1797.934132 |

| TP | FN | FN by Light Color |
|----------|----------|-------------------|
| 323 | 213 | |
| 0.602612 | 0.397388 | red 213 |
| | | green 152 |
| | | yellow 30 |

Threshold Values Used: [196 95 136 103 183 138]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 11 | 1.28125 |
| red | 309 | 25.92350746 |
| green | 0 | 0 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 83.4491018 | 678.8323353 |

| TP | FN | FN by Light Color |
|----------|----------|-------------------|
| 185 | 351 | |
| 0.345149 | 0.654851 | red 351 |
| | | green 152 |
| | | yellow 29 |

Threshold Values Used: [194 106 132 101 181 139]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 2 | 0.0625 |
| red | 299 | 16.1641791 |
| green | 0 | 0 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 51.89221557 | 510.7005988 |

| TP | FN | FN by Light Color |
|----------|----------|-------------------|
| 55 | 481 | |
| 0.102612 | 0.897388 | red 481 |
| | | green 152 |
| | | yellow 32 |

Threshold Values Used: [196 103 135 106 183 142]

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax,Vmean – SD]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 30 | 18.09375 |
| red | 446 | 78.95895522 |
| green | 0 | 0 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 256.8922156 | 53451.52695 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 516 | 20 | | |
| 0.962687 | 0.037313 | red | 20 |
| | | green | 152 |
| | | yellow | 0 |

Threshold Values Used: [196 63 136 99 183 133]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 14 | 2.8125 |
| red | 415 | 50.2108209 |
| green | 0 | 0 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 161.6946108 | 10028.4491 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 453 | 83 | | |
| 0.845149 | 0.154851 | red | 83 |
| | | green | 152 |
| | | yellow | 28 |

Threshold Values Used: [194 71 132 101 181 138]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 3 | 0.53125 |
| red | 392 | 35.11753731 |
| green | 0 | 0 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 112.8143713 | 5549.401198 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 359 | 177 | | |
| 0.669776 | 0.330224 | red | 177 |
| | | green | 152 |
| | | yellow | 32 |

Threshold Values Used: [196 67 135 108 183 140]

FN defined as a bounding box with less 25% of pixels identified

Green

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 0 | 0 |
| red | 0 | 0 |
| green | 123 | 59.63157895 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 54.2754491 | 3002.371257 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 125 | 27 | | |
| 0.822368 | 0.177632 | red | 536 |
| | | green | 27 |
| | | yellow | 32 |

Threshold Values Used: [237 94 156 129 126 73]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 0 | 0 |
| red | 0 | 0 |
| green | 90 | 38.78947368 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 35.30538922 | 787.9461078 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 122 | 30 | | |
| 0.802632 | 0.197368 | red | 536 |
| | | green | 30 |
| | | yellow | 32 |

Threshold Values Used: [235 116 153 128 126 77]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 0 | 0 |
| red | 0 | 0 |
| green | 83 | 37.45394737 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 34.08982036 | 961.0838323 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 117 | 35 | | |
| 0.769737 | 0.230263 | red | 536 |
| | | green | 35 |
| | | yellow | 32 |

Threshold Values Used: [233 111 155 128 126 80]

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax,Vmean – SD]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 0 | 0 |
| red | 0 | 0 |
| green | 278 | 99.88157895 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 90.91017964 | 4578.904192 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 151 | 1 | | |
| 0.993421 | 0.006579 | red | 536 |
| | | green | 1 |
| | | yellow | 32 |

Threshold Values Used: [237 76 156 133 126 67]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 0 | 0 |
| red | 0 | 0 |
| green | 167 | 69.78289474 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 63.51497006 | 1317.652695 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 135 | 17 | | |
| 0.888158 | 0.111842 | red | 536 |
| | | green | 17 |
| | | yellow | 32 |

Threshold Values Used: [235 85 153 134 126 70]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 0 | 0 |
| red | 0 | 0 |
| green | 160 | 65.97368421 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 60.04790419 | 2040.904192 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 127 | 25 | | |
| 0.835526 | 0.164474 | red | 536 |
| | | green | 25 |
| | | yellow | 32 |

Threshold Values Used: [233 79 155 135 126 73]

FN defined as a bounding box with less 25% of pixels identified

Analysis through 3 sequences for Red, Green

Red Lights

- Gaussian Max threshold produces the worst results
- Using a standard deviation technique on the Gaussian Mean threshold might provide best balance of TP rate and low amount of FP pixels

Green Lights

- Gaussian Max threshold produces the worst results
- More sequences need to be tested to determine what technique and threshold is a more viable option

Threshold Testing on Sequence 9437

Thresholds

Bounding Box YUV Statistics

| Color | max_Y | mean_Y | max_U | mean_U | max_V | mean_V |
|--------|-------|-------------|-------|-------------|-------|-------------|
| red | 255 | 100.718251 | 255 | 115.0743705 | 186 | 146.0911185 |
| green | 213 | 103.8181865 | 152 | 130.9956551 | 157 | 106.6274246 |
| yellow | 151 | 99.72897196 | 122 | 102.4158879 | 162 | 141.5934579 |

Gaussian Max Value YUV Statistics

| Color | max_y_channel_gaus_max | mean_y_channel_gaus_max |
|--------|------------------------|-------------------------|
| red | 255 | 100.6598922 |
| green | 206 | 101.23762 |
| yellow | 151 | 105.3285714 |

| Color | max_u_channel_gaus_max | mean_u_channel_gaus_max |
|--------|------------------------|-------------------------|
| red | 255 | 115.3945774 |
| green | 151 | 131.1394558 |
| yellow | 122 | 102.5438596 |

| Color | max_v_channel_gaus_max | mean_v_channel_gaus_max |
|--------|------------------------|-------------------------|
| red | 182 | 147.8874459 |
| green | 149 | 111.2377232 |
| yellow | 162 | 143.06 |

Gaussian Center YUV Statistics

| Color | max_y_channel_gaus | mean_y_channel_gaus |
|--------|--------------------|---------------------|
| red | 255 | 104.3325604 |
| green | 205 | 103.8288591 |
| yellow | 151 | 98.06666667 |

| Color | max_u_channel_gaus | mean_u_channel_gaus |
|--------|--------------------|---------------------|
| red | 255 | 114.6695652 |
| green | 150 | 130.4802386 |
| yellow | 122 | 103.9 |

| Color | max_v_channel_gaus | mean_v_channel_gaus |
|--------|--------------------|---------------------|
| red | 184 | 144.7341454 |
| green | 150 | 108.7878449 |
| yellow | 162 | 142.2111111 |

Change from 9428

> 10

< 10

Red

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 86 | 14.87826087 |
| green | 7 | 0.130872483 |
| yellow | 9 | 3.2 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 36.55084746 | 7197.521186 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 315 | 260 | red | 260 |
| 0.547826 | 0.452174 | green | 298 |
| | | yellow | 7 |

Threshold Values Used: [196 95 136 103 183 138]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 63 | 12.02956522 |
| green | 5 | 0.073825503 |
| yellow | 9 | 2.5 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 29.50847458 | 3747.177966 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 227 | 348 | red | 348 |
| 0.394783 | 0.605217 | green | 298 |
| | | yellow | 8 |

Threshold Values Used: [194 106 132 101 181 139]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 55 | 8.245217391 |
| green | 1 | 0.013422819 |
| yellow | 2 | 0.4 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 20.12288136 | 1095.847458 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 131 | 444 | red | 444 |
| 0.227826 | 0.772174 | green | 298 |
| | | yellow | 10 |

Threshold Values Used: [196 103 135 106 183 142]

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax,Vmean – SD]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 152 | 28.94782609 |
| green | 18 | 0.55704698 |
| yellow | 12 | 8.1 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 71.57627119 | 27254.67373 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 572 | 3 | | |
| 0.994783 | 0.005217 | red | 3 |
| | | green | 296 |
| | | yellow | 1 |

Threshold Values Used: [196 63 136 99 183 133]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 123 | 19.75826087 |
| green | 9 | 0.201342282 |
| yellow | 10 | 3.4 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 48.53813559 | 14072.49576 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 419 | 156 | | |
| 0.728696 | 0.271304 | red | 156 |
| | | green | 298 |
| | | yellow | 7 |

Threshold Values Used: [194 71 132 101 181 138]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 103 | 14.76695652 |
| green | 6 | 0.090604027 |
| yellow | 4 | 0.7 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 36.12288136 | 11144.0678 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 283 | 292 | | |
| 0.492174 | 0.507826 | red | 292 |
| | | green | 298 |
| | | yellow | 10 |

Threshold Values Used: [196 67 135 108 183 140]

FN defined as a bounding box with less 25% of pixels identified

Green

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 5 | 0.008695652 |
| green | 69 | 24.01677852 |
| yellow | 0 | 0 |

Threshold Values Used: [237 94 156 129 126 73]

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 30.34745763 | 7361.563559 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 182 | 116 | red | 575 |
| 0.610738 | 0.389262 | green | 116 |
| | | yellow | 10 |

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 5 | 0.008695652 |
| green | 47 | 15.76845638 |
| yellow | 0 | 0 |

Threshold Values Used: [235 116 153 128 126 77]

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 19.93220339 | 84.61016949 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 124 | 174 | red | 575 |
| 0.416107 | 0.583893 | green | 174 |
| | | yellow | 10 |

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 5 | 0.008695652 |
| green | 50 | 17.16107383 |
| yellow | 0 | 0 |

Threshold Values Used: [233 111 155 128 126 80]

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 21.69067797 | 92.19915254 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 157 | 141 | red | 575 |
| 0.526846 | 0.473154 | green | 141 |
| | | yellow | 10 |

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax, Vmean – SD]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 5 | 0.008695652 |
| green | 96 | 17.18120805 |
| yellow | 0 | 0 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 21.71610169 | 766895.6907 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 106 | 192 | | |
| 0.355705 | 0.644295 | red | 575 |
| | | green | 192 |
| | | yellow | 10 |

Threshold Values Used: [237 76 156 133 126 67]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 5 | 0.008695652 |
| green | 74 | 11.34563758 |
| yellow | 0 | 0 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 14.34745763 | 148942.4661 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 79 | 219 | | |
| 0.265101 | 0.734899 | red | 575 |
| | | green | 219 |
| | | yellow | 10 |

Threshold Values Used: [235 85 153 134 126 70]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 5 | 0.008695652 |
| green | 60 | 9.006711409 |
| yellow | 0 | 0 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 11.3940678 | 603564.0212 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 55 | 243 | | |
| 0.184564 | 0.815436 | red | 575 |
| | | green | 243 |
| | | yellow | 10 |

Threshold Values Used: [233 79 155 135 126 73]

FN defined as a bounding box with less 25% of pixels identified

Threshold Testing on Sequence 9415 (GREEN ONLY LIGHTS)

Thresholds

Bounding Box YUV Statistics

| Color | max_Y | mean_Y | max_U | mean_U | max_V | mean_V |
|--------|-------|-------------|-------|-------------|-------|-------------|
| yellow | 211 | 148.8829947 | 119 | 92.07754011 | 157 | 141.1702674 |
| green | 154 | 90.08133154 | 148 | 131.1572272 | 148 | 94.22592669 |

Gaussian Max Value YUV Statistics

| Color | max_y_channel_gaus_max | mean_y_channel_gaus_max |
|--------|------------------------|-------------------------|
| yellow | 204 | 155.2619048 |
| green | 154 | 94.08643617 |

| Color | max_u_channel_gaus_max | mean_u_channel_gaus_max |
|--------|------------------------|-------------------------|
| yellow | 119 | 93.6066482 |
| green | 148 | 131.1804087 |

| Color | max_v_channel_gaus_max | mean_v_channel_gaus_max |
|--------|------------------------|-------------------------|
| yellow | 154 | 142.6811224 |
| green | 145 | 103.3997478 |

Gaussian Center YUV Statistics

| Color | max_y_channel_gaus | mean_y_channel_gaus |
|--------|--------------------|---------------------|
| yellow | 203 | 155.0767677 |
| green | 154 | 97.64583333 |

| Color | max_u_channel_gaus | mean_u_channel_gaus |
|--------|--------------------|---------------------|
| yellow | 118 | 91.37575758 |
| green | 146 | 131.8036616 |

| Color | max_v_channel_gaus | mean_v_channel_gaus |
|--------|--------------------|---------------------|
| yellow | 155 | 142.4181818 |
| green | 146 | 93.66287879 |

Change from 9428

> 10

< 10

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 0 | 0 |
| green | 99 | 34.38636364 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 68.77272727 | 9013.556818 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|----|
| 142 | 34 | red | 0 |
| 0.806818 | 0.193182 | green | 34 |
| | | yellow | 55 |

Threshold Values Used: [237 94 156 129 126 73]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 0 | 0 |
| green | 51 | 19.17613636 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 38.35227273 | 257.2272727 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 65 | 111 | red | 0 |
| 0.369318 | 0.630682 | green | 111 |
| | | yellow | 55 |

Threshold Values Used: [235 116 153 128 126 77]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 0 | 0 |
| green | 54 | 19.69318182 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 39.38636364 | 520.9090909 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|----|
| 80 | 96 | red | 0 |
| 0.454545 | 0.545455 | green | 96 |
| | | yellow | 55 |

Threshold Values Used: [233 111 155 128 126 80]

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax,Vmean – SD]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 0 | 0 |
| green | 197 | 41.63068182 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 83.26136364 | 656992.8636 |

| TP | FN | FN by Light Color |
|----------|----------|-------------------|
| 107 | 69 | |
| 0.607955 | 0.392045 | |
| | | red |
| | | green |
| | | yellow |

| |
|----|
| 0 |
| 69 |
| 55 |

Threshold Values Used: [237 76 156 133 126 67]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 0 | 0 |
| green | 150 | 28.8125 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 57.625 | 76594.07955 |

| TP | FN | FN by Light Color |
|----------|----------|-------------------|
| 73 | 103 | |
| 0.414773 | 0.585227 | |
| | | red |
| | | green |
| | | yellow |

| |
|-----|
| 0 |
| 103 |
| 55 |

Threshold Values Used: [235 85 153 134 126 70]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| yellow | 0 | 0 |
| green | 96 | 21.27840909 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 42.55681818 | 431073.9091 |

| TP | FN | FN by Light Color |
|----------|----------|-------------------|
| 41 | 135 | |
| 0.232955 | 0.767045 | |
| | | red |
| | | green |
| | | yellow |

| |
|-----|
| 0 |
| 135 |
| 55 |

Threshold Values Used: [233 79 155 135 126 73]

FN defined as a bounding box with less 25% of pixels identified

Threshold Testing on Sequence 9435 (RED ONLY LIGHTS)

Thresholds

Bounding Box YUV Statistics

| Color | max_Y | mean_Y | max_U | mean_U | max_V | mean_V |
|-------|-------|-------------|-------|-------------|-------|-------------|
| red | 206 | 127.7311118 | 136 | 117.3524967 | 170 | 142.7415191 |

Gaussian Max Value YUV Statistics

| Color | max_y_channel_gaus_max | mean_y_channel_gaus_max |
|-------|------------------------|-------------------------|
| red | 206 | 143.692731 |

| Color | max_u_channel_gaus_max | mean_u_channel_gaus_max |
|-------|------------------------|-------------------------|
| red | 134 | 118.8532751 |

| Color | max_v_channel_gaus_max | mean_v_channel_gaus_max |
|-------|------------------------|-------------------------|
| red | 170 | 143.9473358 |

Gaussian Center YUV Statistics

| Color | max_y_channel_gaus | mean_y_channel_gaus |
|-------|--------------------|---------------------|
| red | 206 | 146.8072917 |

| Color | max_u_channel_gaus | mean_u_channel_gaus |
|-------|--------------------|---------------------|
| red | 133 | 117.4412616 |

| Color | max_v_channel_gaus | mean_v_channel_gaus |
|-------|--------------------|---------------------|
| red | 168 | 141.1805556 |

Change from 9428

> 10

< 10

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 43 | 17.75260417 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 53.2578125 | 6216.328125 |

| TP | FN |
|----------|----------|
| 262 | 122 |
| 0.682292 | 0.317708 |

Threshold Values Used: [196 95 136 103 183 138]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 29 | 9.677083333 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 29.03125 | 992.1171875 |

| TP | FN |
|----------|----------|
| 117 | 267 |
| 0.304688 | 0.695313 |

Threshold Values Used: [194 106 132 101 181 139]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 22 | 4.197916667 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 12.59375 | 419.4453125 |

| TP | FN |
|---------|---------|
| 12 | 372 |
| 0.03125 | 0.96875 |

Threshold Values Used: [196 103 135 106 183 142]

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax,Vmean – SD]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 94 | 47.65625 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 142.96875 | 121591.375 |

| TP | FN |
|-----|----|
| 384 | 0 |
| 1 | 0 |

Threshold Values Used: [196 63 136 99 183 133]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 84 | 28.1171875 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 84.3515625 | 39589.38281 |

| TP | FN |
|----------|----------|
| 353 | 31 |
| 0.919271 | 0.080729 |

Threshold Values Used: [194 71 132 101 181 138]

Gaussian Max True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 75 | 20.4921875 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 61.4765625 | 21421.75 |

| TP | FN |
|----------|----------|
| 282 | 102 |
| 0.734375 | 0.265625 |

Threshold Values Used: [196 67 135 108 183 140]

FN defined as a bounding box with less 25% of pixels identified

Second Threshold Testing Procedure

Only BB and Gaussian Mean Thresholds

Threshold Testing on Sequence 9402

Thresholds

Bounding Box YUV Statistics

| Color | max_Y | mean_Y | max_U | mean_U | max_V | mean_V |
|--------|-------|-------------|-------|-------------|-------|-------------|
| red | 191 | 138.1946353 | 134 | 111.3674353 | 189 | 157.6344471 |
| yellow | 209 | 129.521897 | 144 | 89.63398649 | 163 | 139.3602662 |
| green | 220 | 138.3349105 | 154 | 138.6119514 | 138 | 75.37987353 |

Gaussian Max Value YUV Statistics

| Color | max_y_channel_gaus_max | mean_y_channel_gaus_max |
|--------|------------------------|-------------------------|
| red | 189 | 133.5228758 |
| yellow | 187 | 136.4772313 |
| green | 217 | 139.9281904 |

| Color | max_u_channel_gaus_max | mean_u_channel_gaus_max |
|--------|------------------------|-------------------------|
| red | 130 | 113.5688073 |
| yellow | 144 | 101.9774648 |
| green | 154 | 139.5904375 |

| Color | max_v_channel_gaus_max | mean_v_channel_gaus_max |
|--------|------------------------|-------------------------|
| red | 183 | 167.5913043 |
| yellow | 161 | 144.1225383 |
| green | 138 | 84.16754202 |

Gaussian Center YUV Statistics

| Color | max_y_channel_gaus | mean_y_channel_gaus |
|--------|--------------------|---------------------|
| red | 184 | 154.6862745 |
| yellow | 183 | 138.0609319 |
| green | 212 | 149.4482343 |

| Color | max_u_channel_gaus | mean_u_channel_gaus |
|--------|--------------------|---------------------|
| red | 121 | 113.7124183 |
| yellow | 139 | 81.53225806 |
| green | 153 | 139.3928571 |

| Color | max_v_channel_gaus | mean_v_channel_gaus |
|--------|--------------------|---------------------|
| red | 180 | 171.8823529 |
| yellow | 157 | 143.0591398 |
| green | 121 | 76.00441413 |

Change from 9428

> 10

< 10

Red

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 516 | 370.8235294 |
| yellow | 12 | 2.032258065 |
| green | 0 | 0 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 56.40350877 | 10194 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 13 | 4 | | |
| 0.764706 | 0.235294 | red | 4 |
| | | green | 277 |
| | | yellow | 62 |

Threshold Values Used: [196 95 136 103 183 138]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 519 | 361.5882353 |
| yellow | 4 | 1 |
| green | 0 | 0 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 54.46491228 | 2490.27193 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 13 | 4 | | |
| 0.764706 | 0.235294 | red | 4 |
| | | green | 277 |
| | | yellow | 62 |

Threshold Values Used: [194 106 132 101 181 139]

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax,Vmean – SD]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 590 | 513.4117647 |
| yellow | 100 | 30.12903226 |
| green | 2 | 0.014440433 |

Threshold Values Used: [196 63 136 99 183 133]

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 92.98245614 | 102844.4474 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 16 | 1 | red | 1 |
| 0.941176 | 0.058824 | green | 277 |
| | | yellow | 62 |

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 571 | 453.7058824 |
| yellow | 20 | 5.903225806 |
| green | 0 | 0 |

Threshold Values Used: [194 71 132 101 181 138]

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 70.86842105 | 25881.53509 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 16 | 1 | red | 1 |
| 0.941176 | 0.058824 | green | 277 |
| | | yellow | 62 |

FN defined as a bounding box with less 25% of pixels identified

Green

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| yellow | 29 | 7.887096774 |
| green | 609 | 181.0108303 |

Threshold Values Used: [237 94 156 129 126 73]

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 444.1140351 | 7980.517544 |

| TP | FN | FN by Light Color | |
|---------|---------|-------------------|----|
| 189 | 88 | | |
| 0.68231 | 0.31769 | red | 17 |
| | | green | 88 |
| | | yellow | 62 |

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| yellow | 15 | 3.403225806 |
| green | 582 | 146.2960289 |

Threshold Values Used: [235 116 153 128 126 77]

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 357.3245614 | 5368.482456 |

| TP | FN | FN by Light Color | |
|---------|---------|-------------------|----|
| 184 | 93 | | |
| 0.66426 | 0.33574 | red | 17 |
| | | green | 93 |
| | | yellow | 62 |

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax, Vmean – SD]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| yellow | 50 | 7.032258065 |
| green | 630 | 151.8375451 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 372.7631579 | 28305.39474 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|----|
| 192 | 85 | | |
| 0.693141 | 0.306859 | red | 17 |
| | | green | 85 |
| | | yellow | 62 |

Threshold Values Used: [237 76 156 133 126 67]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| yellow | 30 | 3.709677419 |
| green | 555 | 103.5234657 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 253.5614035 | 4787.54386 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 139 | 138 | | |
| 0.501805 | 0.498195 | red | 17 |
| | | green | 138 |
| | | yellow | 62 |

Threshold Values Used: [235 85 153 134 126 70]

FN defined as a bounding box with less 25% of pixels identified

Threshold Testing on Sequence
9431 (GREEN ONLY)

Thresholds

Bounding Box YUV Statistics

| Color | max_Y | mean_Y | max_U | mean_U | max_V | mean_V |
|--------|-------|-------------|-------|-------------|-------|-------------|
| red | 196 | 102.0798274 | 136 | 113.2824507 | 183 | 148.4875641 |
| green | 237 | 104.8908334 | 156 | 139.3072033 | 126 | 83.26130015 |
| yellow | 194 | 105.7548312 | 141 | 101.4593322 | 168 | 139.5871453 |

Gaussian Max Value YUV Statistics

| Color | max_y_channel_gaus_max | mean_y_channel_gaus_max |
|--------|------------------------|-------------------------|
| red | 196 | 113.7725694 |
| green | 233 | 121.0827601 |
| yellow | 189 | 111.5158562 |

| Color | max_u_channel_gaus_max | mean_u_channel_gaus_max |
|--------|------------------------|-------------------------|
| red | 135 | 116.8185265 |
| green | 155 | 138.8132337 |
| yellow | 140 | 103.83159 |

| Color | max_v_channel_gaus_max | mean_v_channel_gaus_max |
|--------|------------------------|-------------------------|
| red | 183 | 152.1726587 |
| green | 126 | 90.18922652 |
| yellow | 159 | 140.3061889 |

Gaussian Center YUV Statistics

| Color | max_y_channel_gaus | mean_y_channel_gaus |
|--------|--------------------|---------------------|
| red | 194 | 116.6697626 |
| green | 235 | 126.3242966 |
| yellow | 193 | 123.1554192 |

| Color | max_u_channel_gaus | mean_u_channel_gaus |
|--------|--------------------|---------------------|
| red | 132 | 111.5816993 |
| green | 153 | 138.5855412 |
| yellow | 140 | 97.07293797 |

| Color | max_v_channel_gaus | mean_v_channel_gaus |
|--------|--------------------|---------------------|
| red | 181 | 149.3157895 |
| green | 126 | 87.20230027 |
| yellow | 165 | 140.0027267 |

Example with Gaussian weighting threshold of 0.05 (only pixels with a weighted value \leq are used for threshold development)

Thresholds

Bounding Box YUV Statistics

| Color | max_Y | mean_Y | max_U | mean_U | max_V | mean_V |
|-------|-------|-------------|-------|------------|-------|-------------|
| green | 237 | 155.0318239 | 152 | 135.988552 | 125 | 96.94160701 |

Gaussian Max Value YUV Statistics

| Color | max_y_channel_gaus_max | mean_y_channel_gaus_max |
|-------|------------------------|-------------------------|
| green | 237 | 161.1793917 |

| Color | max_u_channel_gaus_max | mean_u_channel_gaus_max |
|-------|------------------------|-------------------------|
| green | 148 | 136.180865 |

| Color | max_v_channel_gaus_max | mean_v_channel_gaus_max |
|-------|------------------------|-------------------------|
| green | 124 | 102.7452066 |

Gaussian Center YUV Statistics

| Color | max_y_channel_gaus | mean_y_channel_gaus |
|-------|--------------------|---------------------|
| green | 237 | 167.874612 |

| Color | max_u_channel_gaus | mean_u_channel_gaus |
|-------|--------------------|---------------------|
| green | 152 | 135.3038485 |

| Color | max_v_channel_gaus | mean_v_channel_gaus |
|-------|--------------------|---------------------|
| green | 123 | 100.1815642 |

Change from 9428

> 10

< 10

Green

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

Threshold Values Used: [237 94 156 129 126 73]

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| green | 265 | 83.41061453 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 170.6342857 | 2170.051429 |

| TP | FN | FN by Light Color | |
|-----|----|-------------------|---|
| 358 | 0 | red | 0 |
| 1 | 0 | green | 0 |
| | | yellow | 0 |

Gaussian Mean True Positives

Threshold Values Used: [235 116 153 128 126 77]

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| green | 244 | 73.37988827 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 150.1142857 | 834.0571429 |

| TP | FN | FN by Light Color | |
|-----|----|-------------------|---|
| 358 | 0 | red | 0 |
| 1 | 0 | green | 0 |
| | | yellow | 0 |

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax,Vmean – SD]

Bounding Box True Positives

Threshold Values Used: [237 76 156 133 126 67]

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| green | 386 | 76.5 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 156.4971429 | 6010.245714 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|----|
| 339 | 19 | | |
| 0.946927 | 0.053073 | red | 0 |
| | | green | 19 |
| | | yellow | 0 |

Gaussian Mean True Positives

Threshold Values Used: [235 85 153 134 126 70]

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| green | 273 | 50.64804469 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 103.6114286 | 873.5142857 |

| TP | FN | FN by Light Color | |
|---------|---------|-------------------|-----|
| 258 | 100 | | |
| 0.72067 | 0.27933 | red | 0 |
| | | green | 100 |
| | | yellow | 0 |

FN defined as a bounding box with less 25% of pixels identified

Threshold Testing on Sequence 9423

Red

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 477 | 435.2540717 |
| yellow | 20 | 11.11111111 |
| green | 0 | 0 |

Threshold Values Used: [196 95 136 103 183 138]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 440 | 405.3127036 |
| yellow | 19 | 9.507936508 |
| green | 0 | 0 |

Threshold Values Used: [194 106 132 101 181 139]

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 449.2408027 | 4769.799331 |

| TP | FN | FN by Light Color |
|----------|----------|-------------------|
| 304 | 3 | |
| 0.990228 | 0.009772 | red 3 |
| | | green 275 |
| | | yellow 63 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 418.1605351 | 3085.561873 |

| TP | FN | FN by Light Color |
|----------|----------|-------------------|
| 304 | 3 | |
| 0.990228 | 0.009772 | red 3 |
| | | green 275 |
| | | yellow 63 |

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax,Vmean – SD]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 650 | 591.3550489 |
| yellow | 255 | 194.6507937 |
| green | 0 | 0 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 648.1906355 | 48617.0602 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 304 | 3 | | |
| 0.990228 | 0.009772 | red | 3 |
| | | green | 275 |
| | | yellow | 63 |

Threshold Values Used: [196 63 136 99 183 133]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 597 | 539.6644951 |
| yellow | 94 | 61.47619048 |
| green | 0 | 0 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 567.0568562 | 14936.46823 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 304 | 3 | | |
| 0.990228 | 0.009772 | red | 3 |
| | | green | 275 |
| | | yellow | 63 |

Threshold Values Used: [194 71 132 101 181 138]

FN defined as a bounding box with less 25% of pixels identified

Green

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| yellow | 0 | 0 |
| green | 286 | 195.6909091 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 179.9832776 | 11574.68227 |

| TP | FN | FN by Light Color | |
|-----|-----|-------------------|-----|
| 165 | 110 | red | 307 |
| 0.6 | 0.4 | green | 110 |
| | | yellow | 63 |

Threshold Values Used: [237 94 156 129 126 73]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| yellow | 0 | 0 |
| green | 246 | 137.1963636 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 126.1839465 | 1422.016722 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 123 | 152 | red | 307 |
| 0.447273 | 0.552727 | green | 152 |
| | | yellow | 63 |

Threshold Values Used: [235 116 153 128 126 77]

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax,Vmean – SD]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| yellow | 0 | 0 |
| green | 1563 | 430.3963636 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 395.8494983 | 15618.10033 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 258 | 17 | | |
| 0.938182 | 0.061818 | red | 307 |
| | | green | 17 |
| | | yellow | 63 |

Threshold Values Used: [237 76 156 133 126 67]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| yellow | 0 | 0 |
| green | 653 | 269.2654545 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 247.6521739 | 10491.7291 |

| TP | FN | FN by Light Color | |
|----------|----------|-------------------|-----|
| 204 | 71 | | |
| 0.741818 | 0.258182 | red | 307 |
| | | green | 71 |
| | | yellow | 63 |

Threshold Values Used: [235 85 153 134 126 70]

FN defined as a bounding box with less 25% of pixels identified

Threshold Testing on Sequence 9407 (RED ONLY)

Red

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 474 | 95.82878151 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 267.5337243 | 1270.316716 |

| TP | FN | FN by Light Color |
|----------|----------|-------------------|
| 838 | 114 | |
| 0.880252 | 0.119748 | red 114 |
| | | green 0 |
| | | yellow 0 |

Threshold Values Used: [196 95 136 103 183 138]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 432 | 80.92542017 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 225.9266862 | 812.1964809 |

| TP | FN | FN by Light Color |
|----------|----------|-------------------|
| 718 | 234 | |
| 0.754202 | 0.245798 | red 234 |
| | | green 0 |
| | | yellow 0 |

Threshold Values Used: [194 106 132 101 181 139]

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax,Vmean – SD]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 643 | 140.9390756 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 393.4721408 | 16892.62463 |

| TP | FN | FN by Light Color |
|-----|----|-------------------|
| 952 | 0 | |
| 1 | 0 | red 0 |
| | | green 0 |
| | | yellow 0 |

Threshold Values Used: [196 63 136 99 183 133]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 571 | 118.467437 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 330.7360704 | 4253.472141 |

| TP | FN | FN by Light Color |
|---------|---------|-------------------|
| 881 | 71 | |
| 0.92542 | 0.07458 | red 71 |
| | | green 0 |
| | | yellow 0 |

Threshold Values Used: [194 71 132 101 181 138]

FN defined as a bounding box with less 25% of pixels identified

Threshold Testing on Sequence 9433

Red

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 47 | 32.27631579 |
| yellow | 24 | 11.11290323 |
| green | 0 | 0 |

Threshold Values Used: [196 95 136 103 183 138]

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 39.275 | 649.3375 |

| TP | FN | FN by Light Color |
|----------|----------|-------------------|
| 75 | 1 | |
| 0.986842 | 0.013158 | |
| | | red |
| | | green |
| | | yellow |

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 45 | 29.07894737 |
| yellow | 24 | 7.419354839 |
| green | 0 | 0 |

Threshold Values Used: [194 106 132 101 181 139]

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 33.375 | 300.2 |

| TP | FN | FN by Light Color |
|----------|----------|-------------------|
| 75 | 1 | |
| 0.986842 | 0.013158 | |
| | | red |
| | | green |
| | | yellow |

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax, Vmean – SD]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 53 | 39.44736842 |
| yellow | 63 | 33.29032258 |
| green | 0 | 0 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 63.275 | 21818.1625 |

| TP | FN | FN by Light Color |
|----|----|-------------------|
| 76 | 0 | |
| 1 | 0 | red 0 |
| | | green 86 |
| | | yellow 1 |

Threshold Values Used: [196 63 136 99 183 133]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 47 | 34.65789474 |
| yellow | 31 | 12.82258065 |
| green | 0 | 0 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 42.8625 | 4554.05 |

| TP | FN | FN by Light Color |
|----------|----------|-------------------|
| 75 | 1 | |
| 0.986842 | 0.013158 | red 1 |
| | | green 86 |
| | | yellow 26 |

Threshold Values Used: [194 71 132 101 181 138]

FN defined as a bounding box with less 25% of pixels identified

Green

Findings

[Ymax, Ymean – 10, Umax, Umean – 10, Vmax,Vmean – 10]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| yellow | 4 | 0.064516129 |
| green | 132 | 71.30232558 |

Threshold Values Used: [237 94 156 129 126 73]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| yellow | 6 | 0.096774194 |
| green | 127 | 63.79069767 |

Threshold Values Used: [235 116 153 128 126 77]

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 76.7 | 2599.8 |

| TP | FN | FN by Light Color |
|----|----|-------------------|
| 86 | 0 | |
| 1 | 0 | red 76 |
| | | green 0 |
| | | yellow 62 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 68.65 | 79.2875 |

| TP | FN | FN by Light Color |
|----|----|-------------------|
| 86 | 0 | |
| 1 | 0 | red 76 |
| | | green 0 |
| | | yellow 62 |

FN defined as a bounding box with less 25% of pixels identified

Findings

[Ymax, Ymean – SD, Umax, Umean – SD, Vmax,Vmean – SD]

Bounding Box True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| yellow | 2 | 0.032258065 |
| green | 152 | 76.30232558 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 82.05 | 470.1625 |

| TP | FN | FN by Light Color |
|----|----|-------------------|
| 86 | 0 | |
| 1 | 0 | red 76 |
| | | green 0 |
| | | yellow 62 |

Threshold Values Used: [237 76 156 133 126 67]

Gaussian Mean True Positives

| T_result | max_tp_box_pixels | mean_tp_box_pixels |
|----------|-------------------|--------------------|
| red | 0 | 0 |
| yellow | 2 | 0.032258065 |
| green | 137 | 60.81395349 |

| true_pos_pixels_average_per_frame | false_positive_pixels_average_per_frame |
|-----------------------------------|---|
| 65.4 | 173.2875 |

| TP | FN | FN by Light Color |
|----------|----------|-------------------|
| 82 | 4 | |
| 0.953488 | 0.046512 | red 76 |
| | | green 4 |
| | | yellow 62 |

Threshold Values Used: [235 85 153 134 126 70]

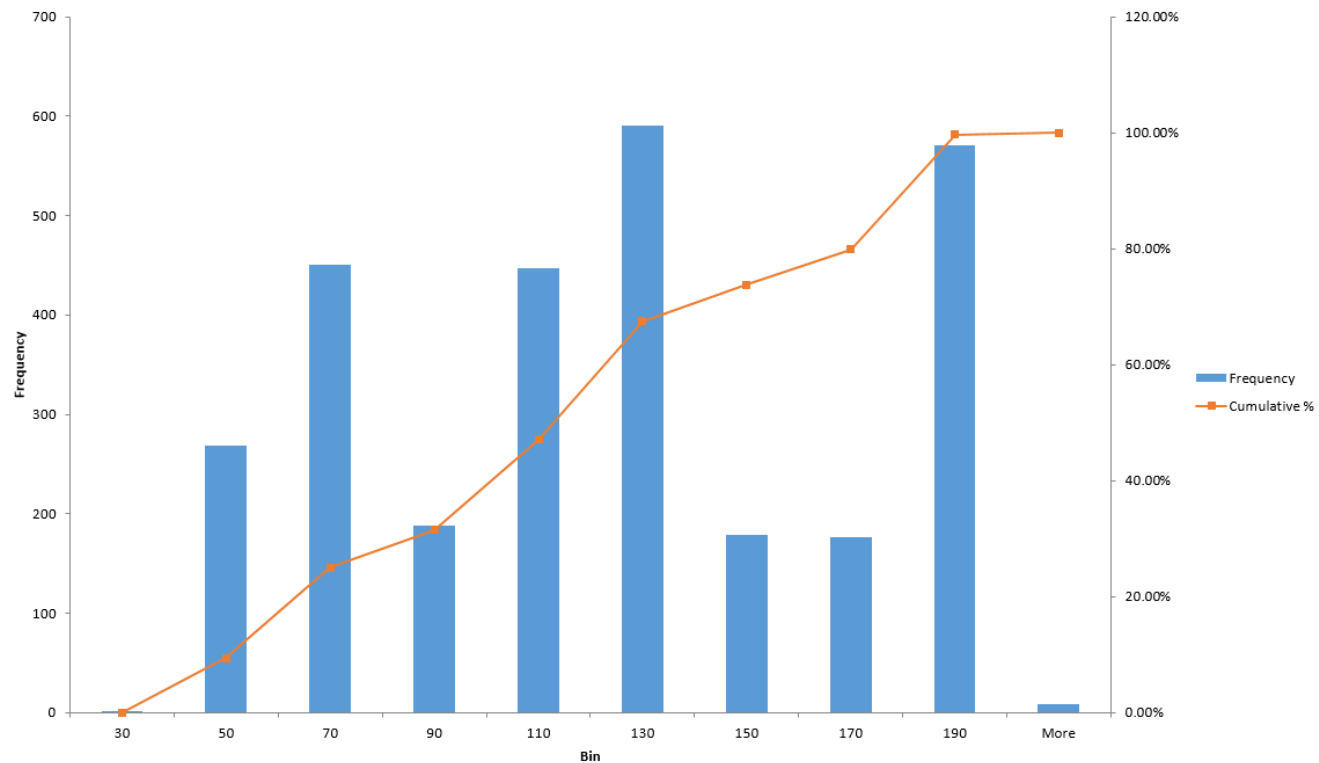
FN defined as a bounding box with less 25% of pixels identified

Appendix 2

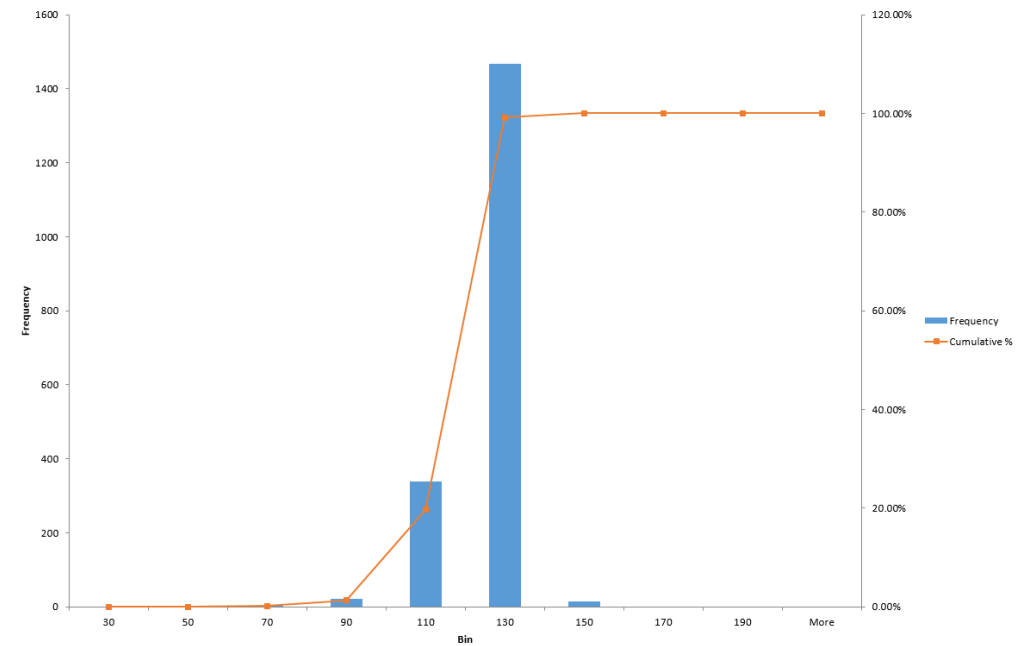
Gaussian Max Threshold

Sequence 9428

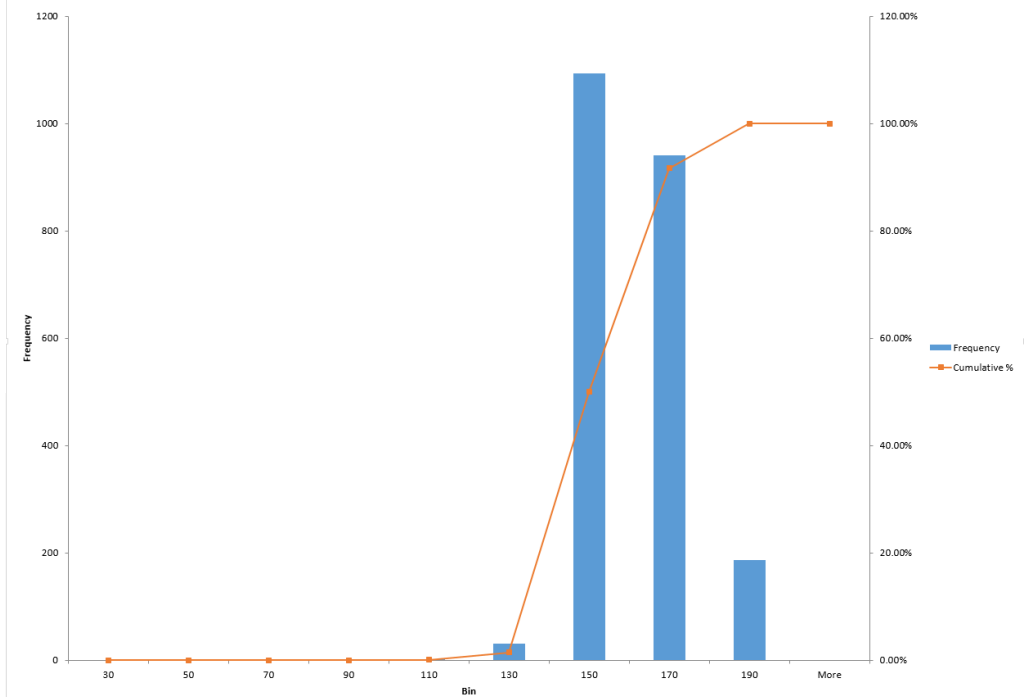
Red Values Y Channel



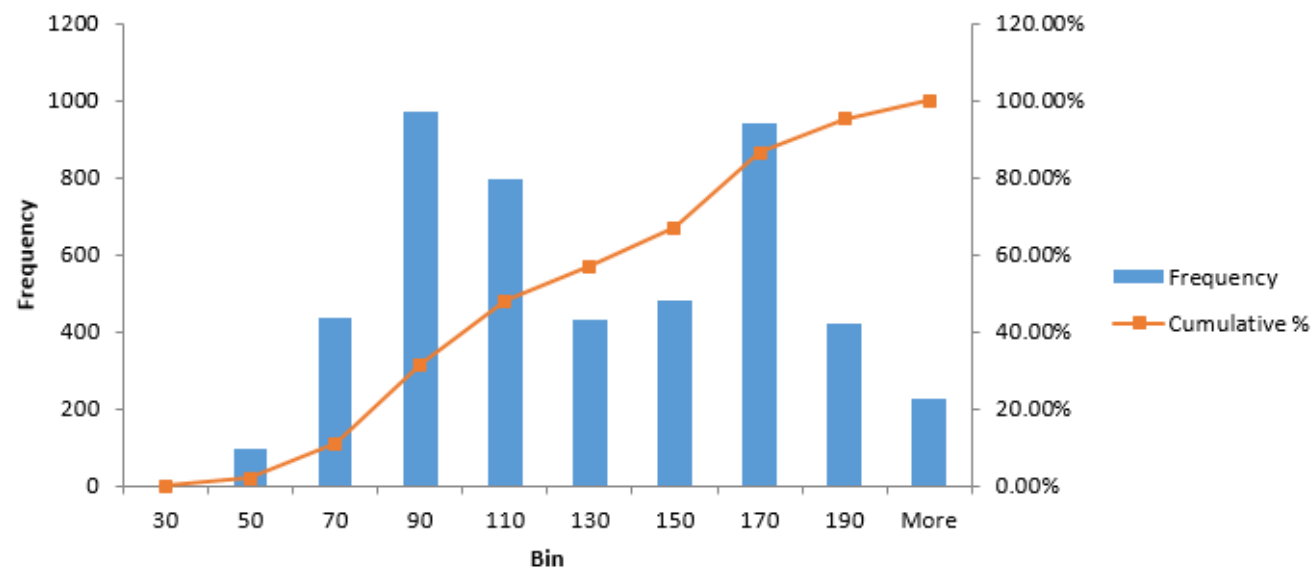
Red U Channel



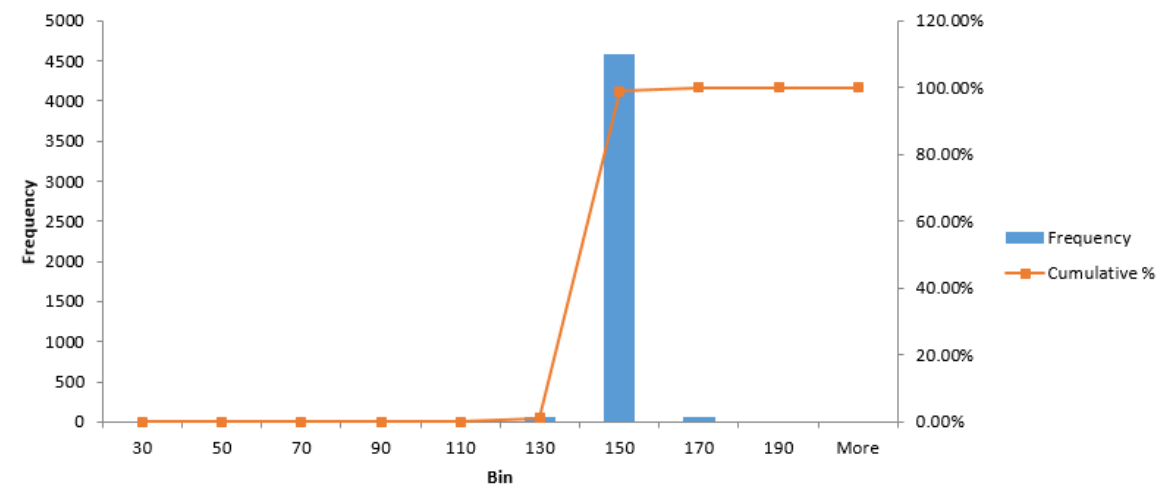
Red V Values



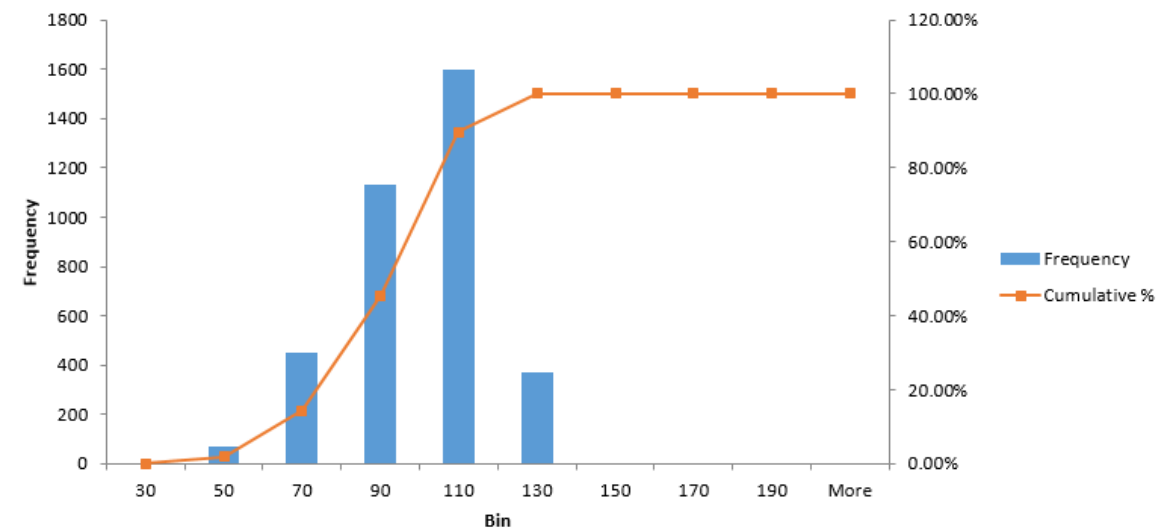
Green Values Y Channel



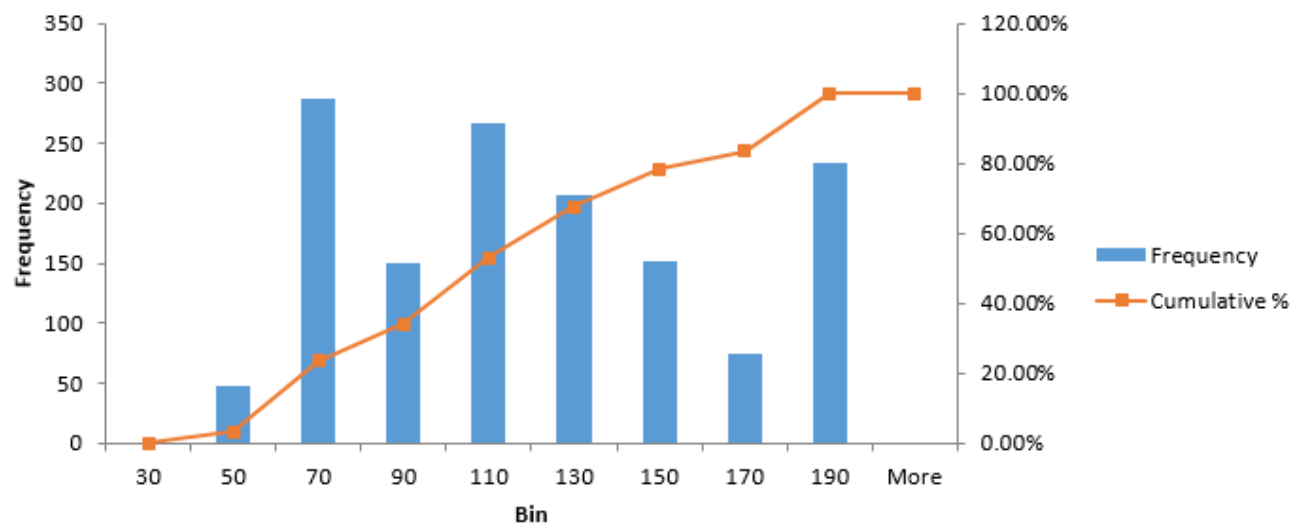
Green U Channel



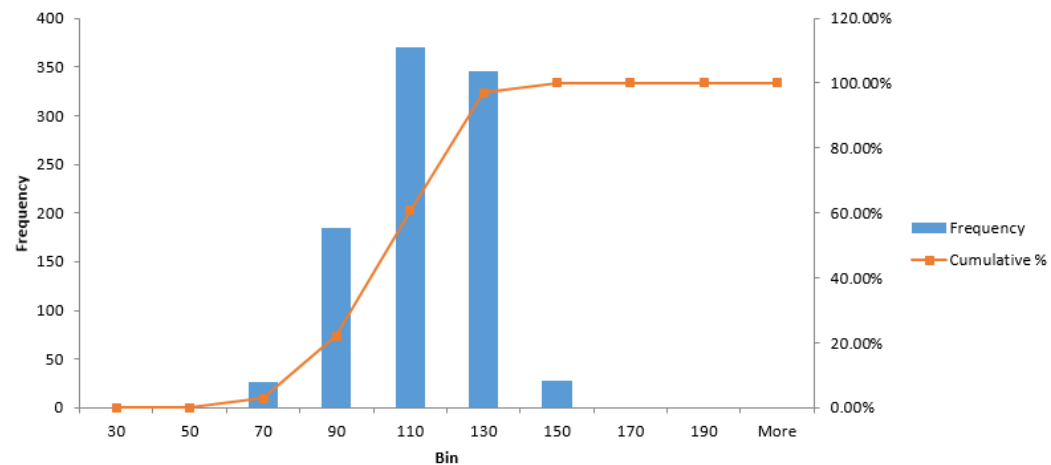
Green V Values



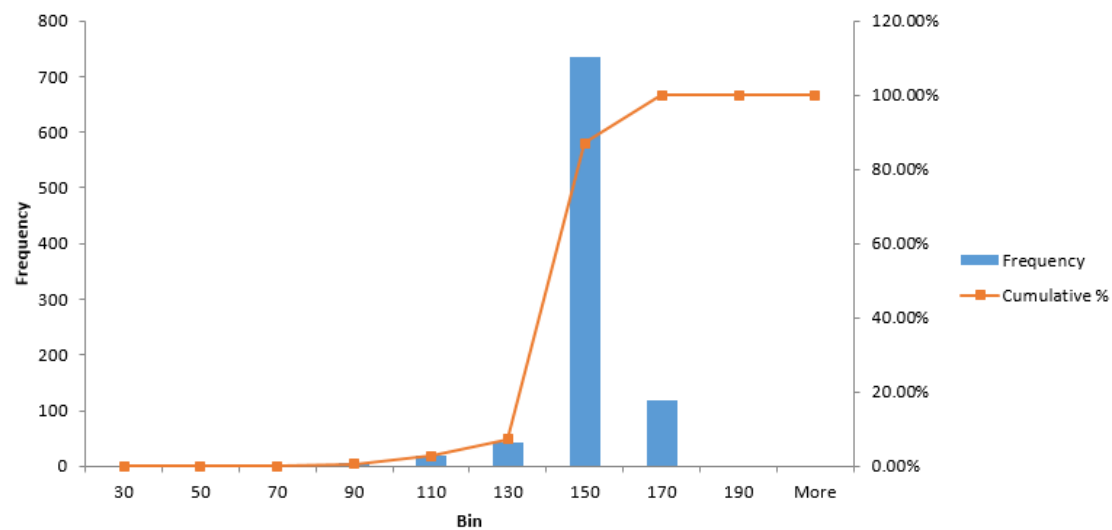
Yellow Values Y Channel



Yellow U Channel

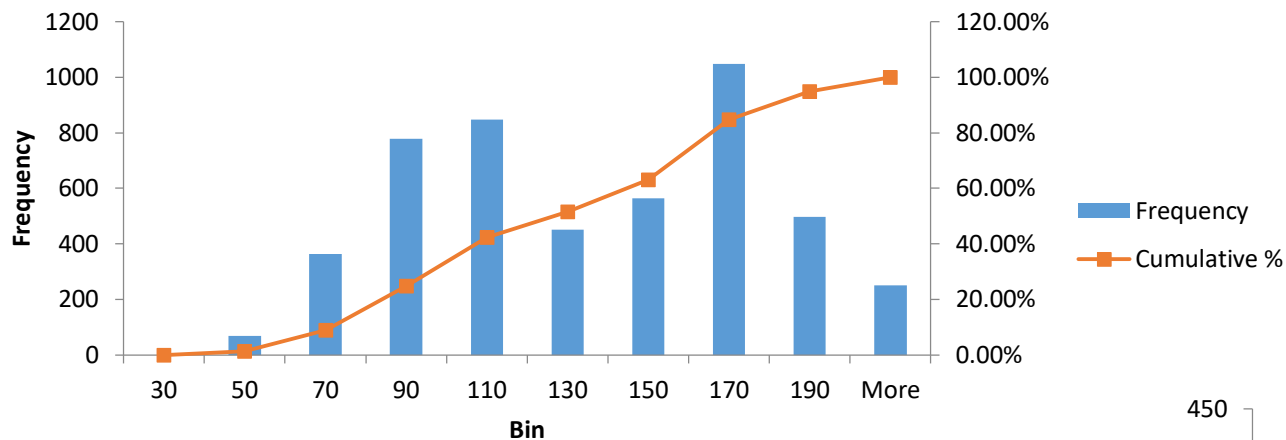


Yellow V Values

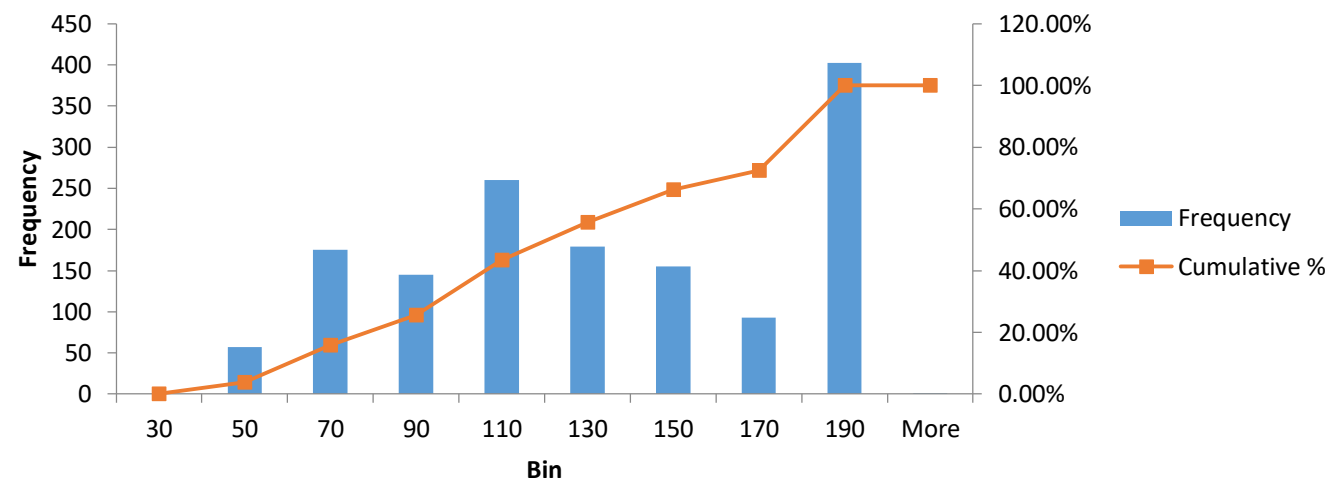


Gaussian Mean Threshold

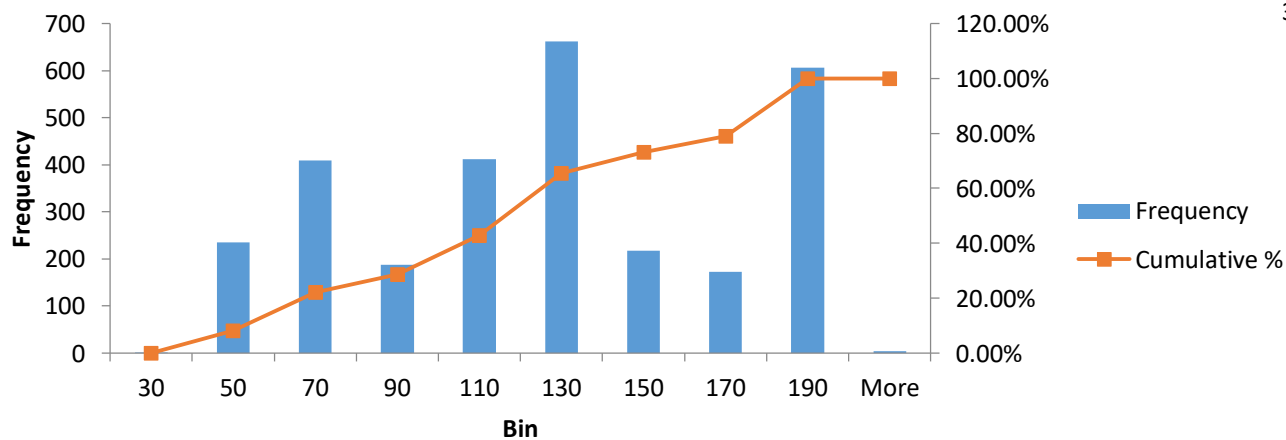
Green Y Channel



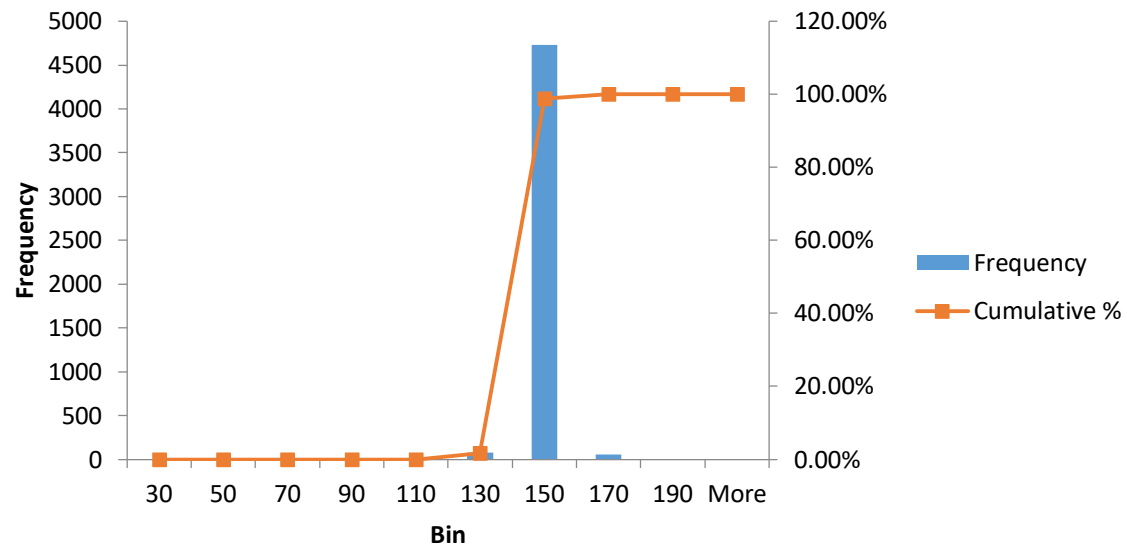
Yellow Y Channel



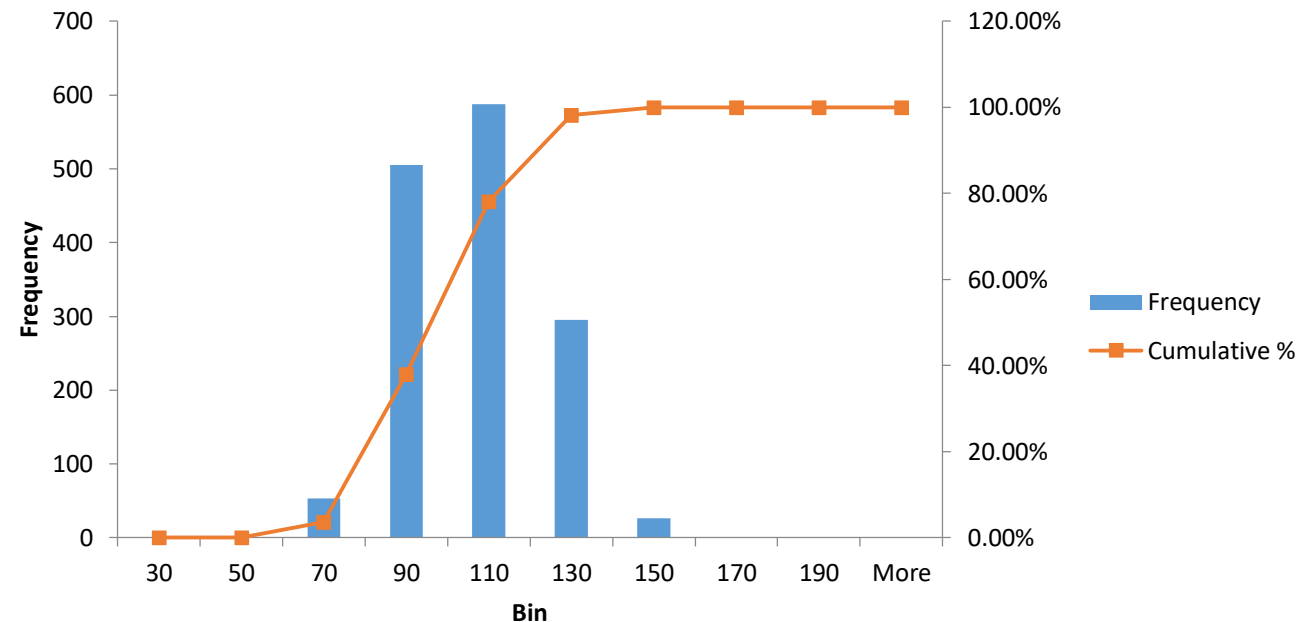
Red Y Channel



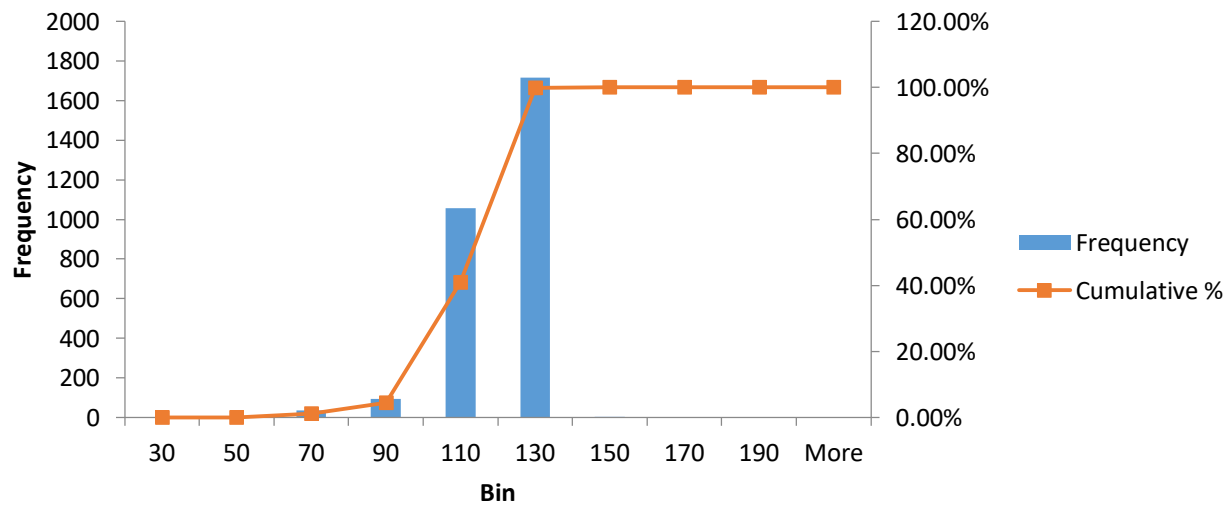
Green U Values



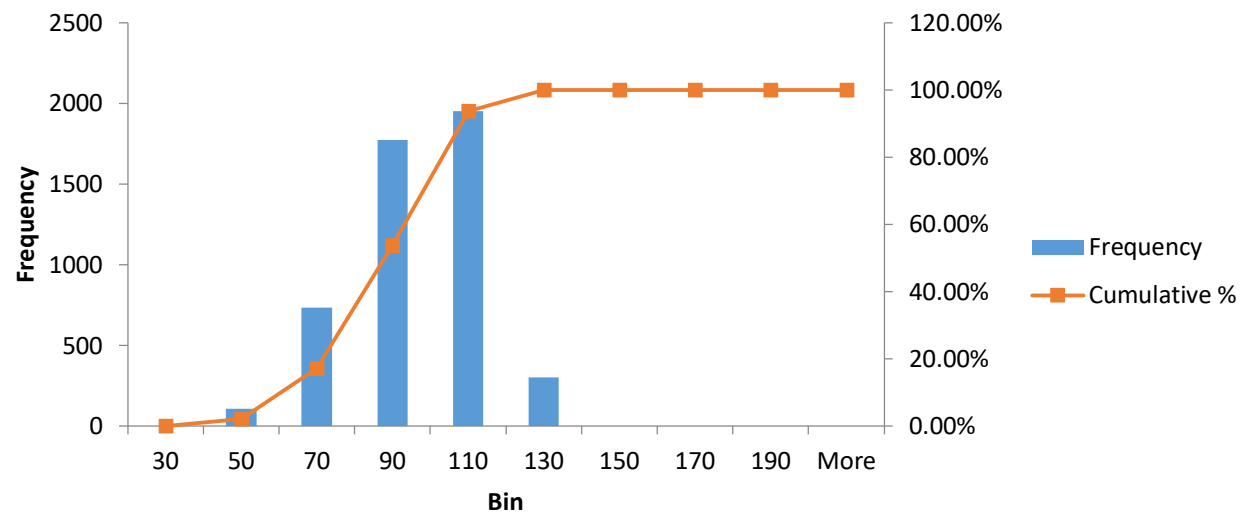
Yellow U Values



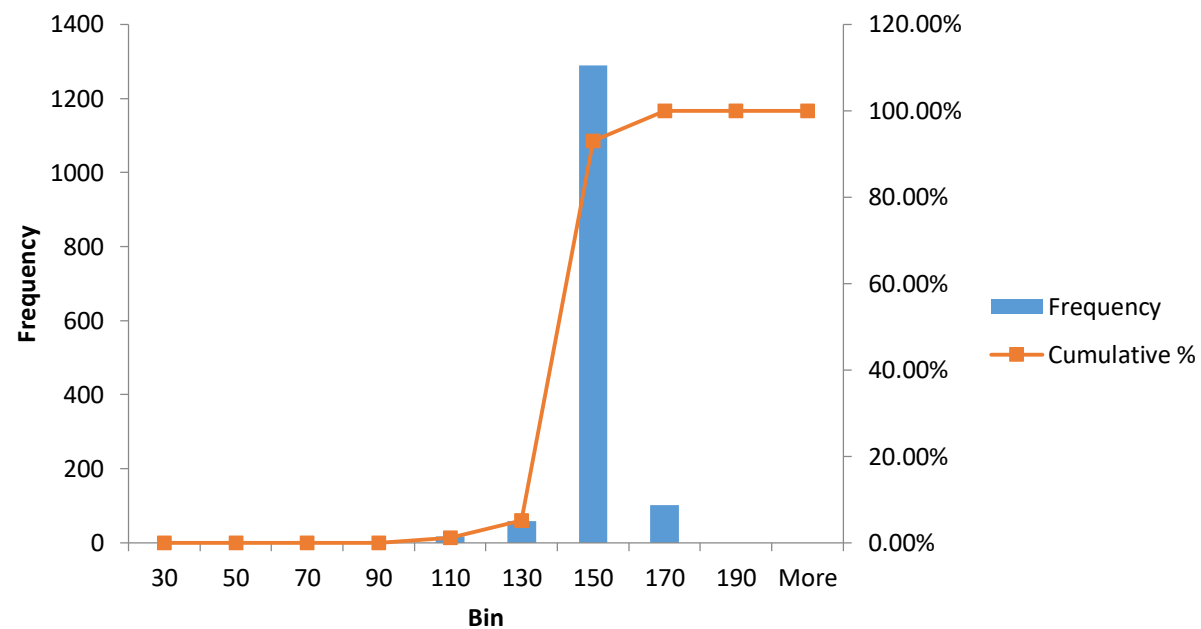
Red U Values



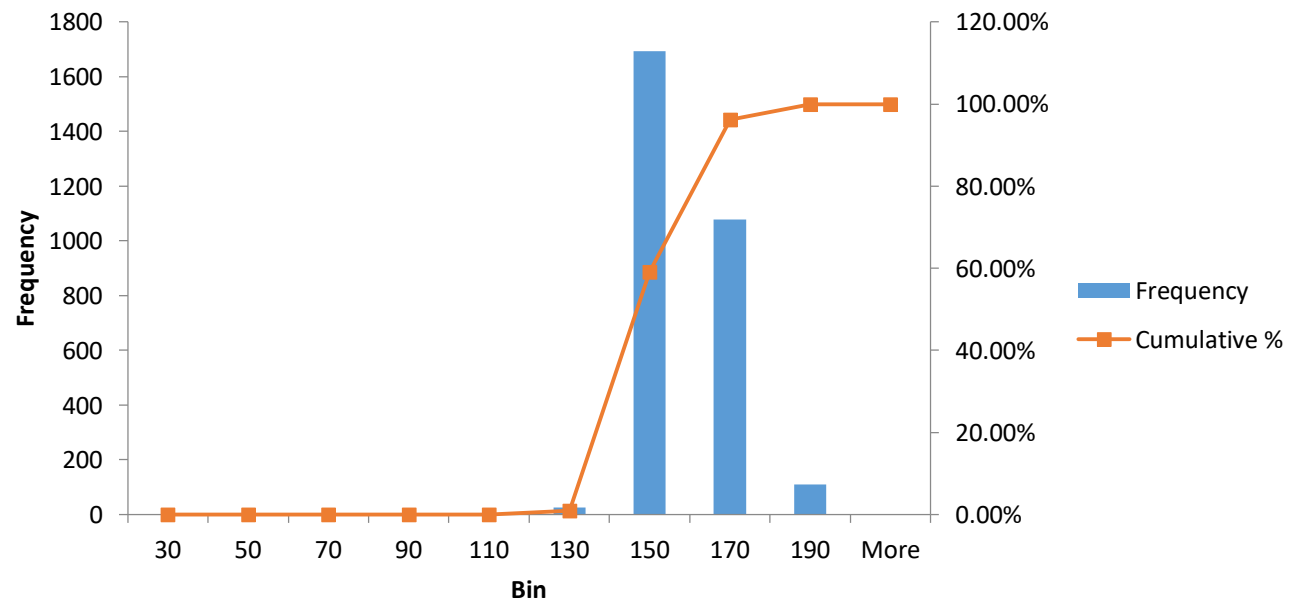
Green V Values



Yellow V Values



Red V Values



Gaussian Center YUV Statistics

| Color | GroupCount | min_y_channel_gaus | max_y_channel_gaus | mean_y_channel_gaus | std_y_channel_gaus |
|--------|------------|--------------------|--------------------|---------------------|--------------------|
| red | 2907 | 30 | 194 | 116.6697626 | 45.32965197 |
| green | 4869 | 33 | 235 | 126.3242966 | 41.68370192 |
| yellow | 1467 | 36 | 193 | 123.1554192 | 44.14437868 |

| Color | GroupCount | min_u_channel_gaus | max_u_channel_gaus | mean_u_channel_gaus | std_u_channel_gaus |
|--------|------------|--------------------|--------------------|---------------------|--------------------|
| red | 2907 | 62 | 132 | 111.5816993 | 10.67639088 |
| green | 4869 | 124 | 153 | 138.5855412 | 4.442770898 |
| yellow | 1467 | 56 | 140 | 97.07293797 | 15.6289076 |

| Color | GroupCount | min_v_channel_gaus | max_v_channel_gaus | mean_v_channel_gaus | std_v_channel_gaus |
|--------|------------|--------------------|--------------------|---------------------|--------------------|
| red | 2907 | 111 | 181 | 149.3157895 | 10.7965944 |
| green | 4869 | 40 | 126 | 87.20230027 | 16.49792531 |
| yellow | 1467 | 96 | 165 | 140.0027267 | 7.784967722 |

Gaussian Max Value YUV Statistics

| Color | GroupCount | min_y_channel_gaus_max | max_y_channel_gaus_max | mean_y_channel_gaus_max | std_y_channel_gaus_max |
|--------|------------|------------------------|------------------------|-------------------------|------------------------|
| red | 2880 | 30 | 196 | 113.7725694 | 46.2030195 |
| green | 4797 | 37 | 233 | 121.0827601 | 42.72301089 |
| yellow | 1419 | 43 | 189 | 111.5158562 | 42.18632183 |

| Color | GroupCount | min_u_channel_gaus_max | max_u_channel_gaus_max | mean_u_channel_gaus_max | std_u_channel_gaus_max |
|--------|------------|------------------------|------------------------|-------------------------|------------------------|
| red | 1846 | 61 | 135 | 116.8185265 | 8.684291222 |
| green | 4685 | 124 | 155 | 138.8132337 | 4.272366162 |
| yellow | 956 | 59 | 140 | 103.83159 | 16.17379064 |

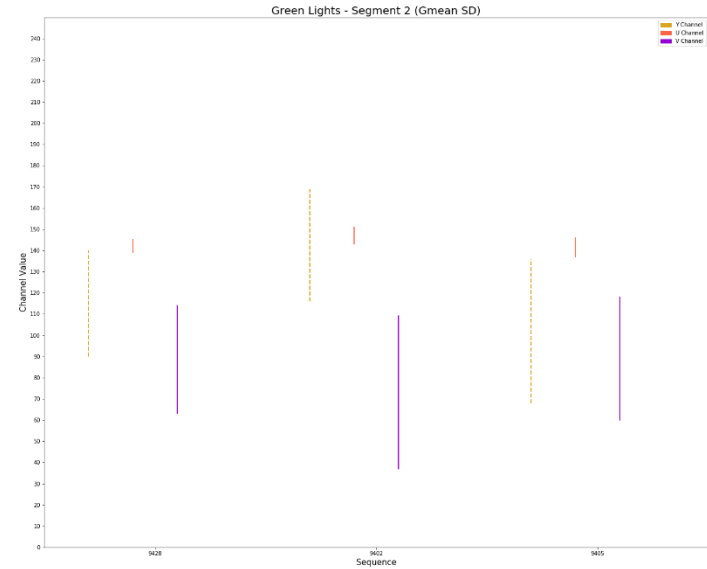
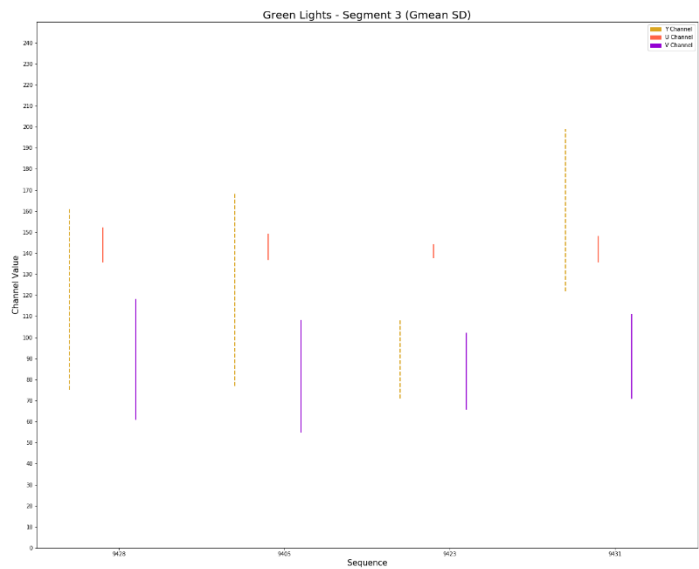
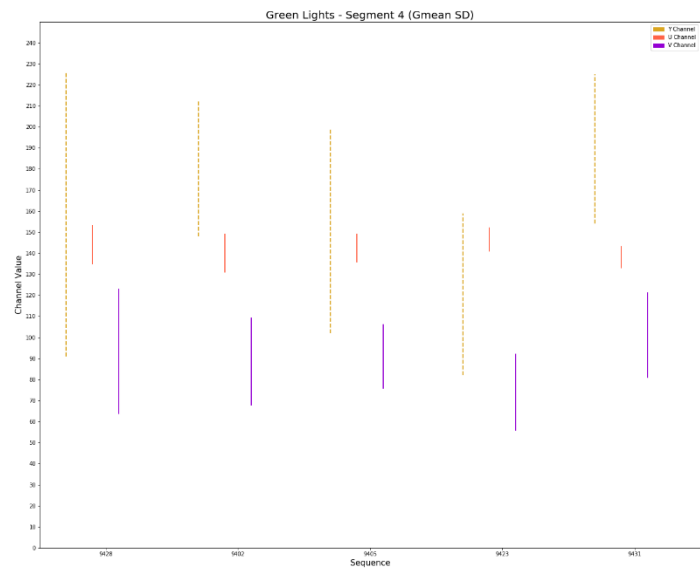
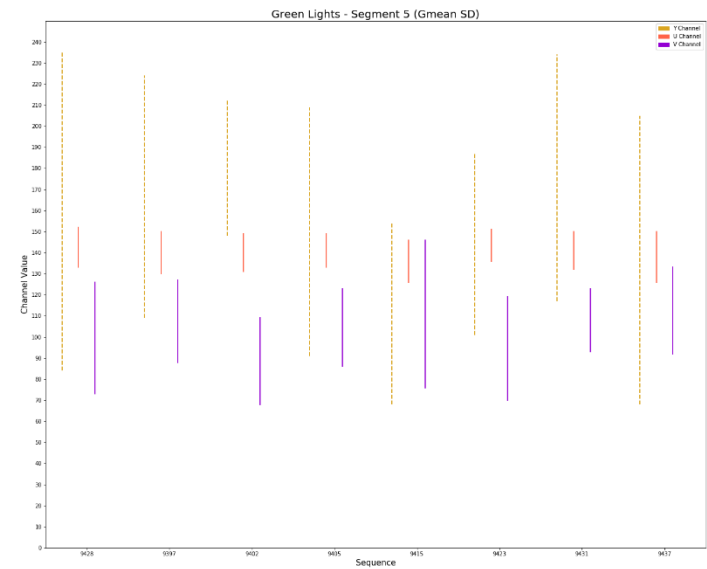
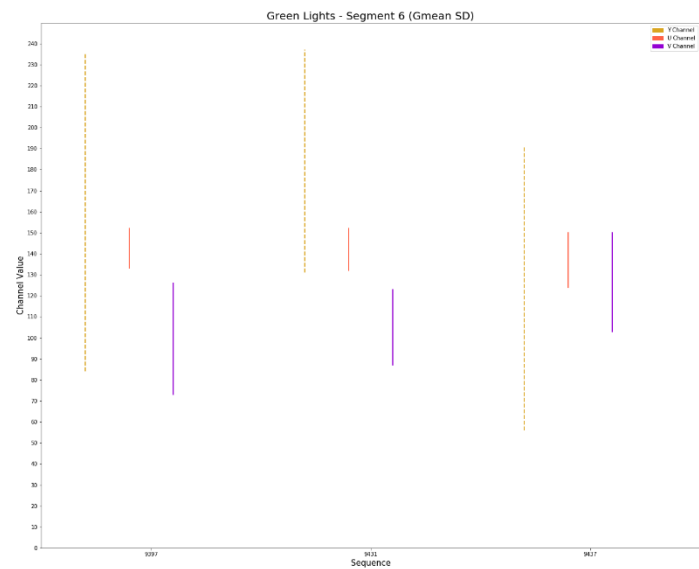
| Color | GroupCount | min_v_channel_gaus_max | max_v_channel_gaus_max | mean_v_channel_gaus_max | std_v_channel_gaus_max |
|--------|------------|------------------------|------------------------|-------------------------|------------------------|
| red | 2253 | 102 | 183 | 152.1726587 | 11.96913281 |
| green | 3620 | 42 | 126 | 90.18922652 | 16.90113459 |
| yellow | 921 | 86 | 159 | 140.3061889 | 10.39197301 |

Example with Gaussian weighting threshold of 0.05 (only pixels with a weighted value \leq are used for threshold development)

Appendix 3

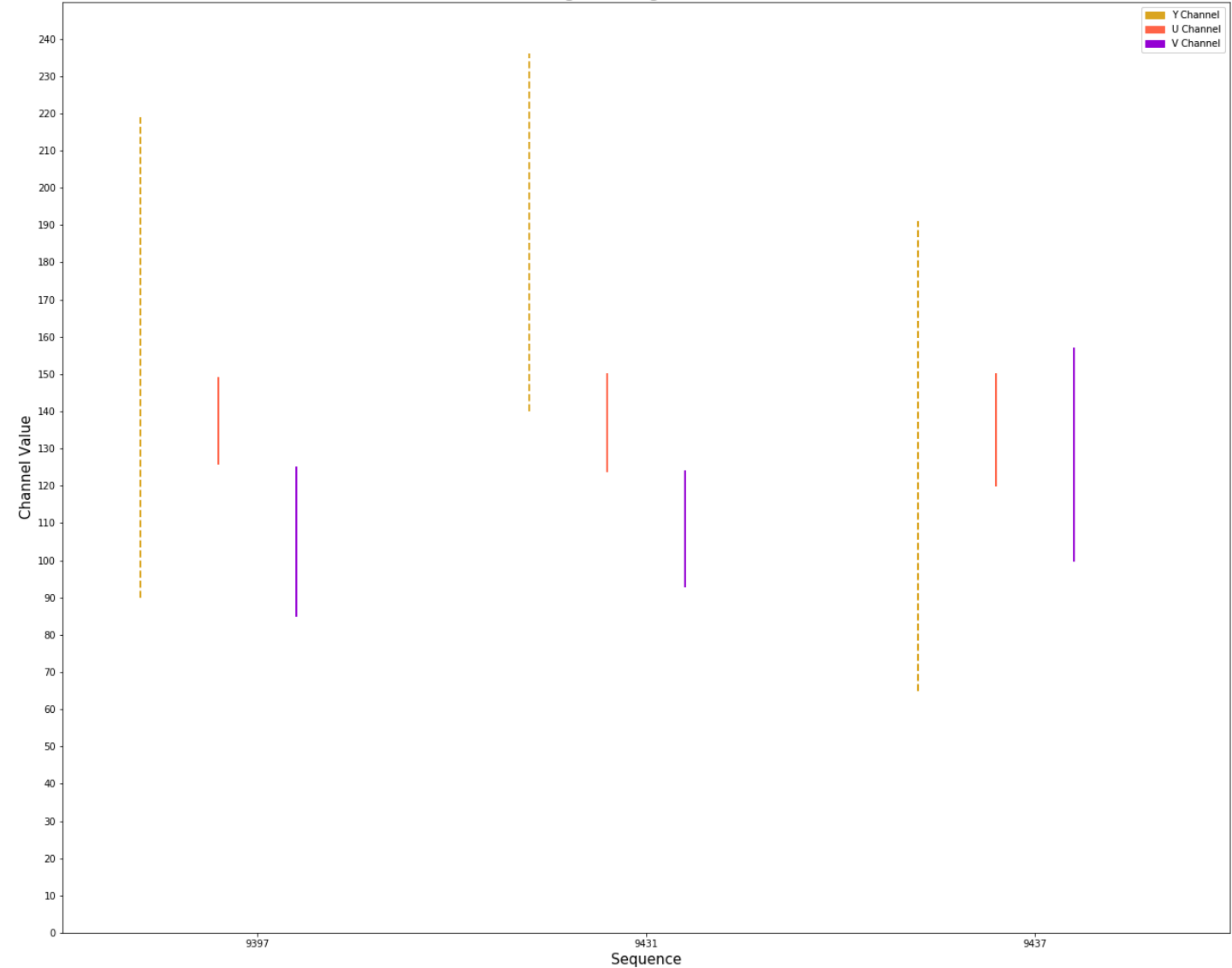
Nighttime

Cross-segment comparison of YUV channel thresholds

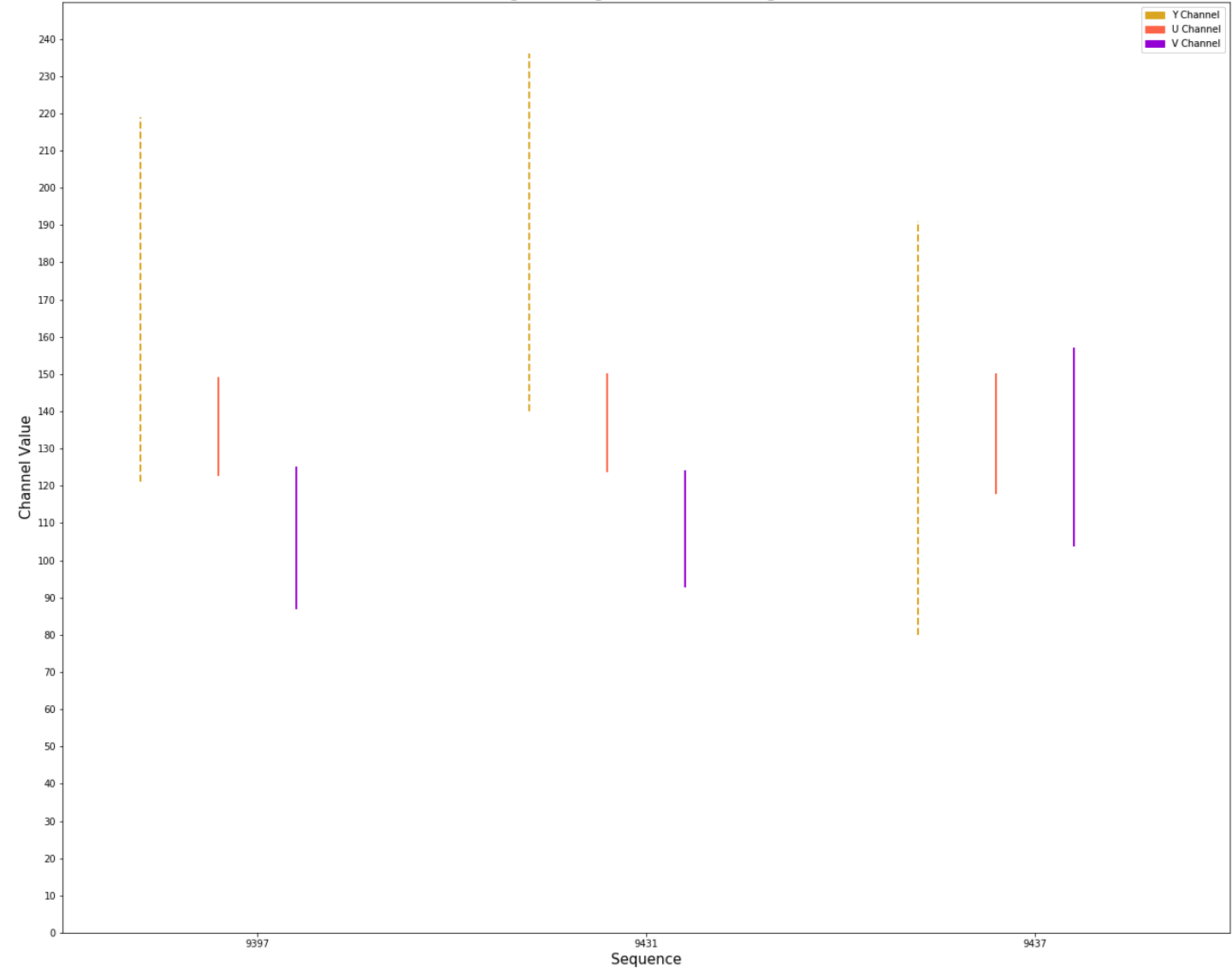


Segment 6 Statistics

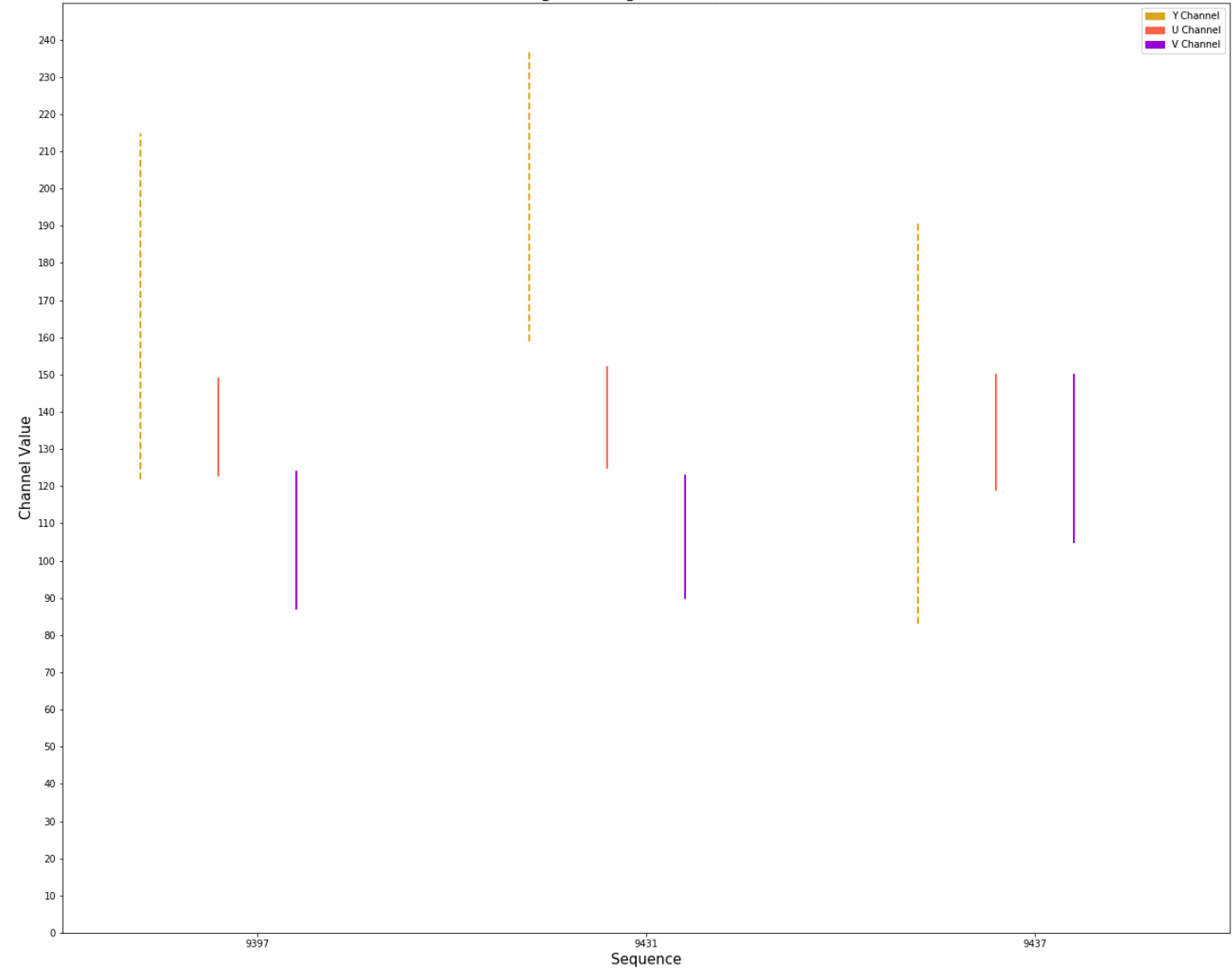
Green Lights - Segment 6 (BB SD)



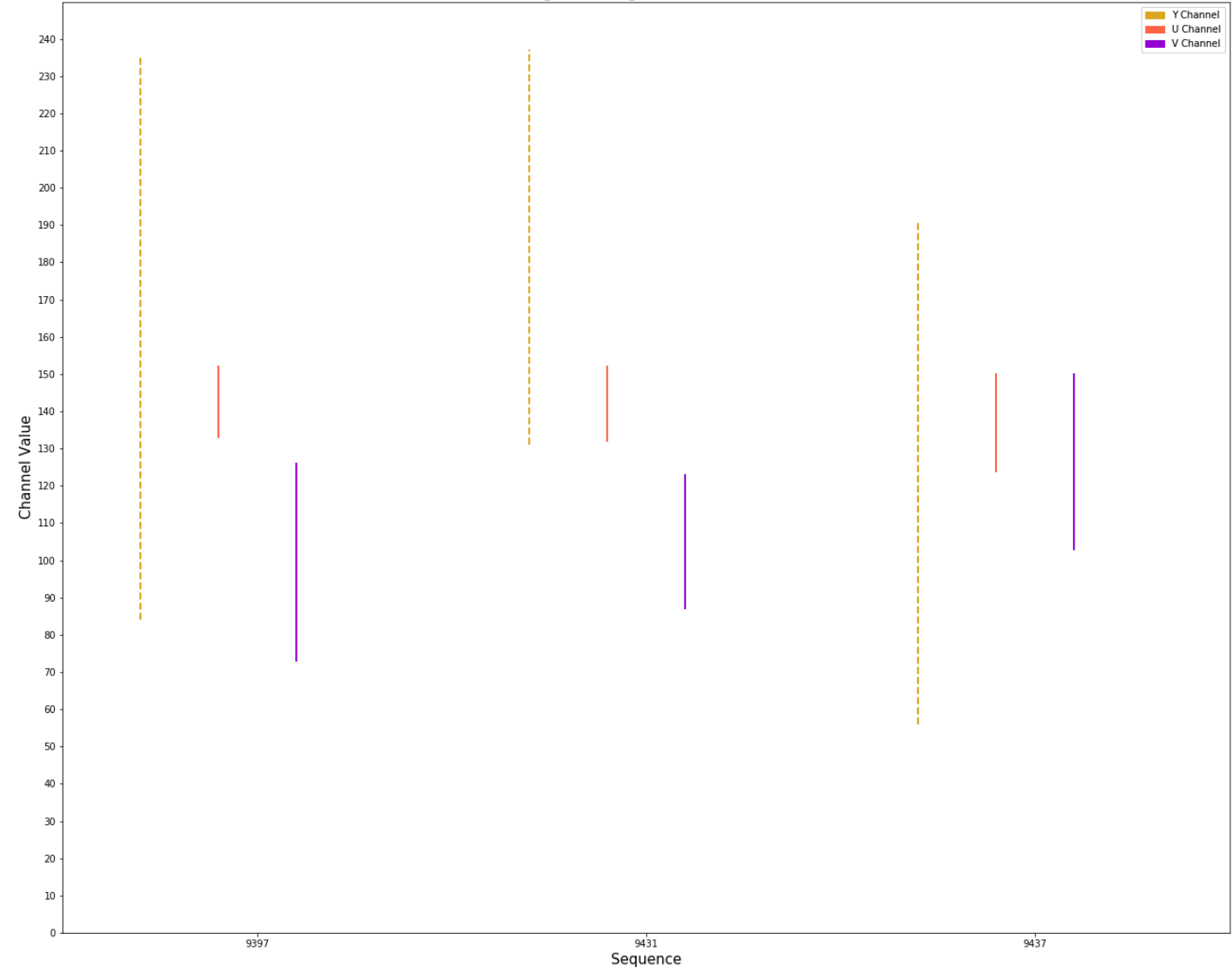
Green Lights - Segment 6 (Bounding Box -10)



Green Lights - Segment 6 (Gmean -10)

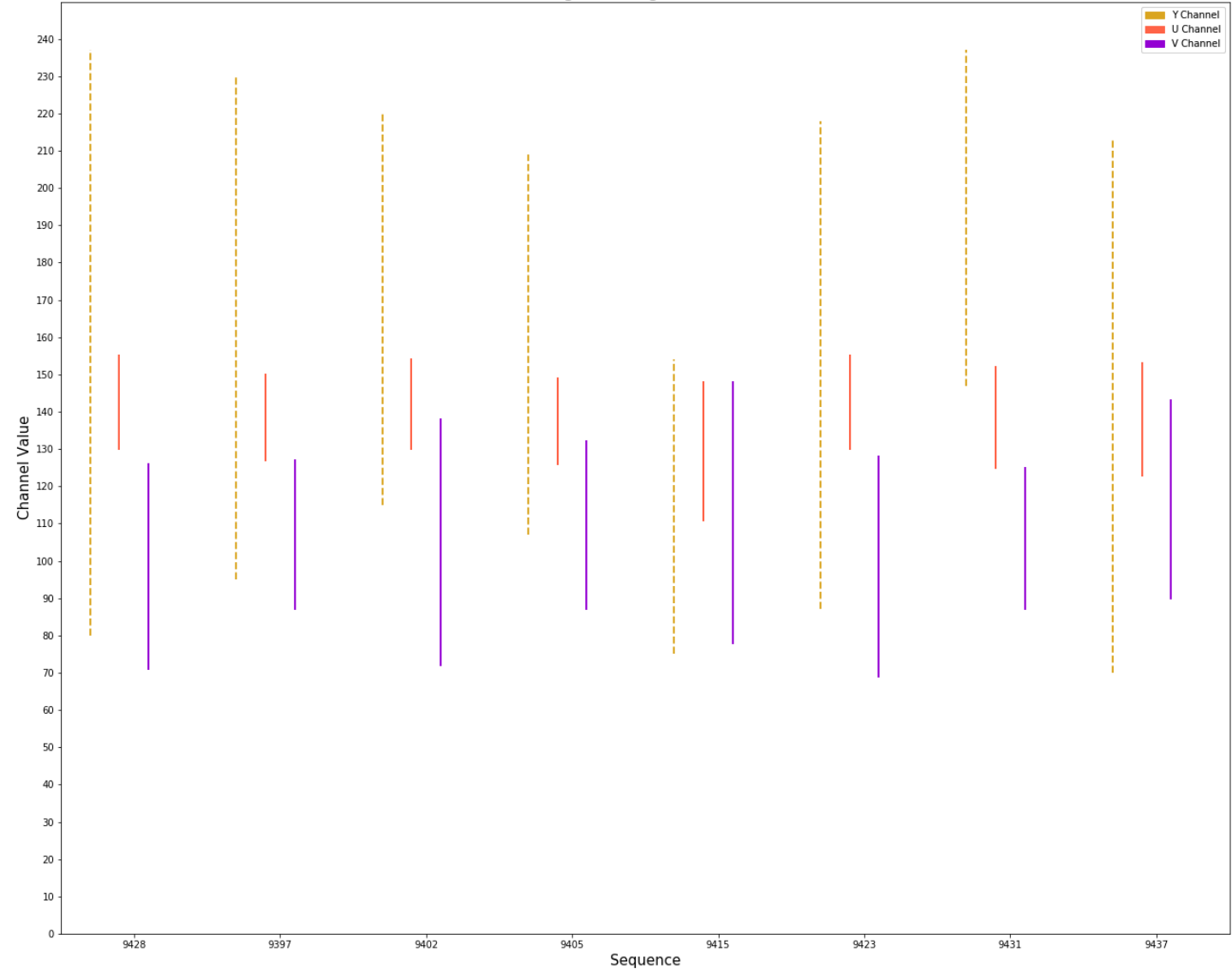


Green Lights - Segment 6 (Gmean SD)

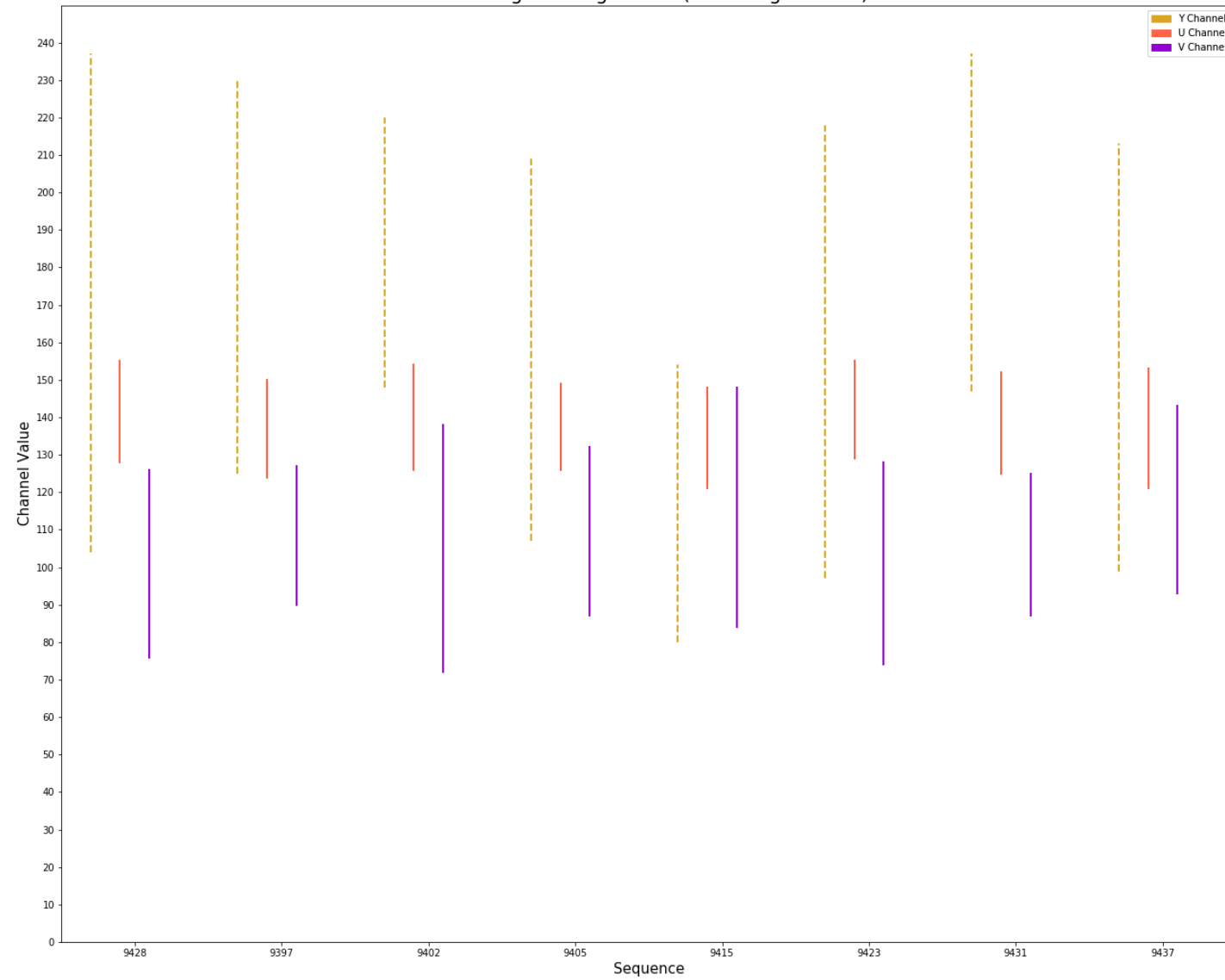


Segment 5 Statistics

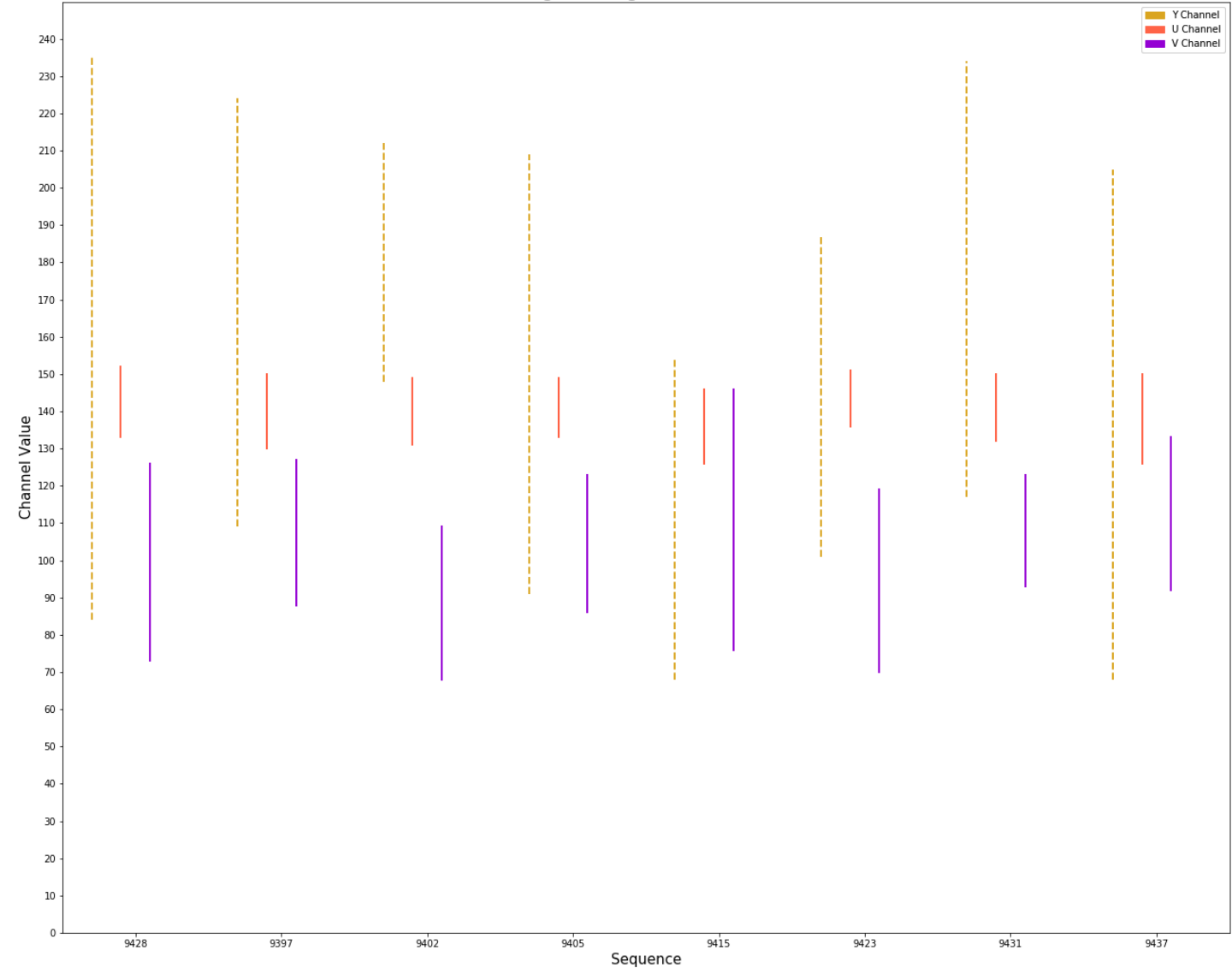
Green Lights - Segment 5 (BB SD)



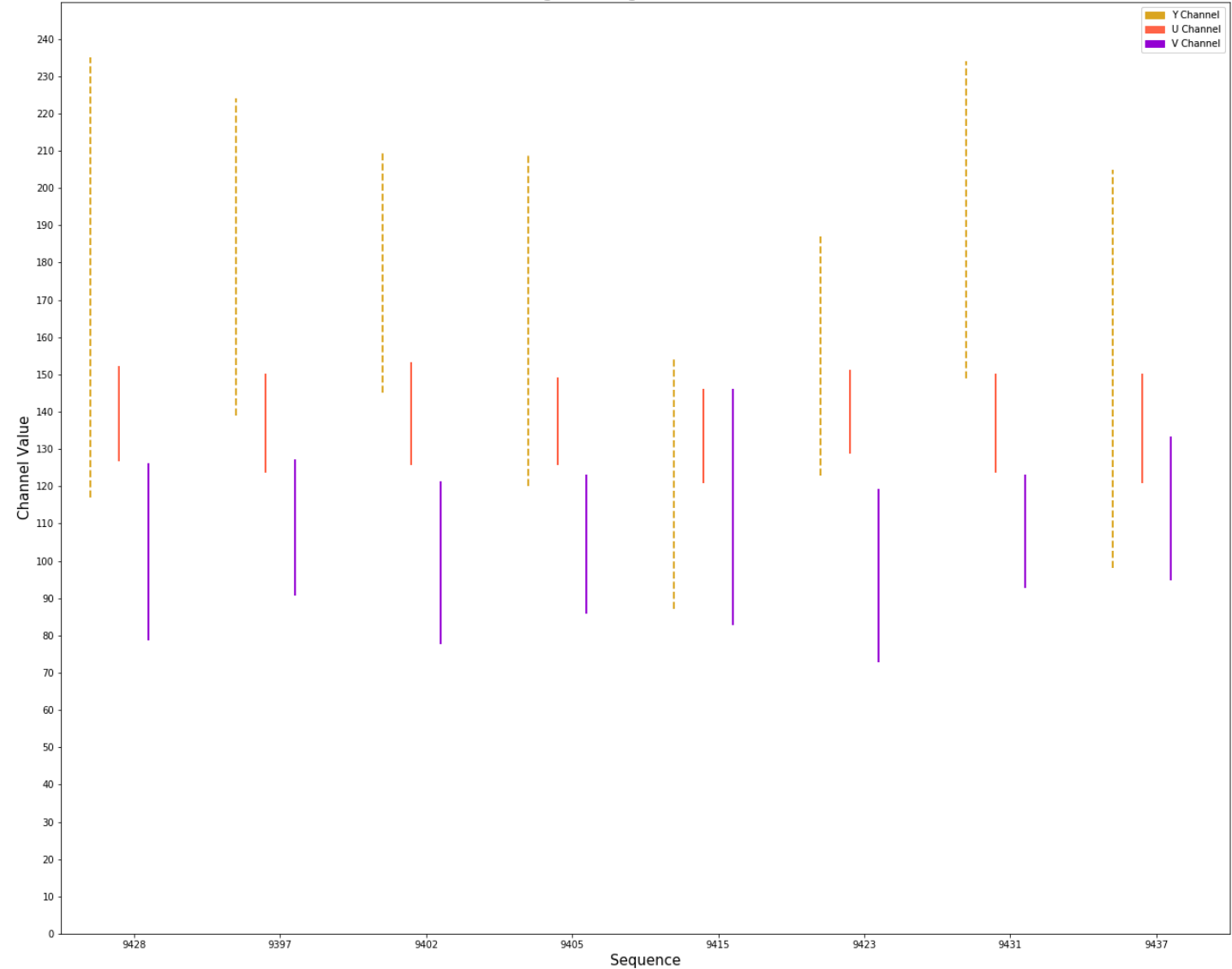
Green Lights - Segment 5 (Bounding Box -10)



Green Lights - Segment 5 (Gmean SD)

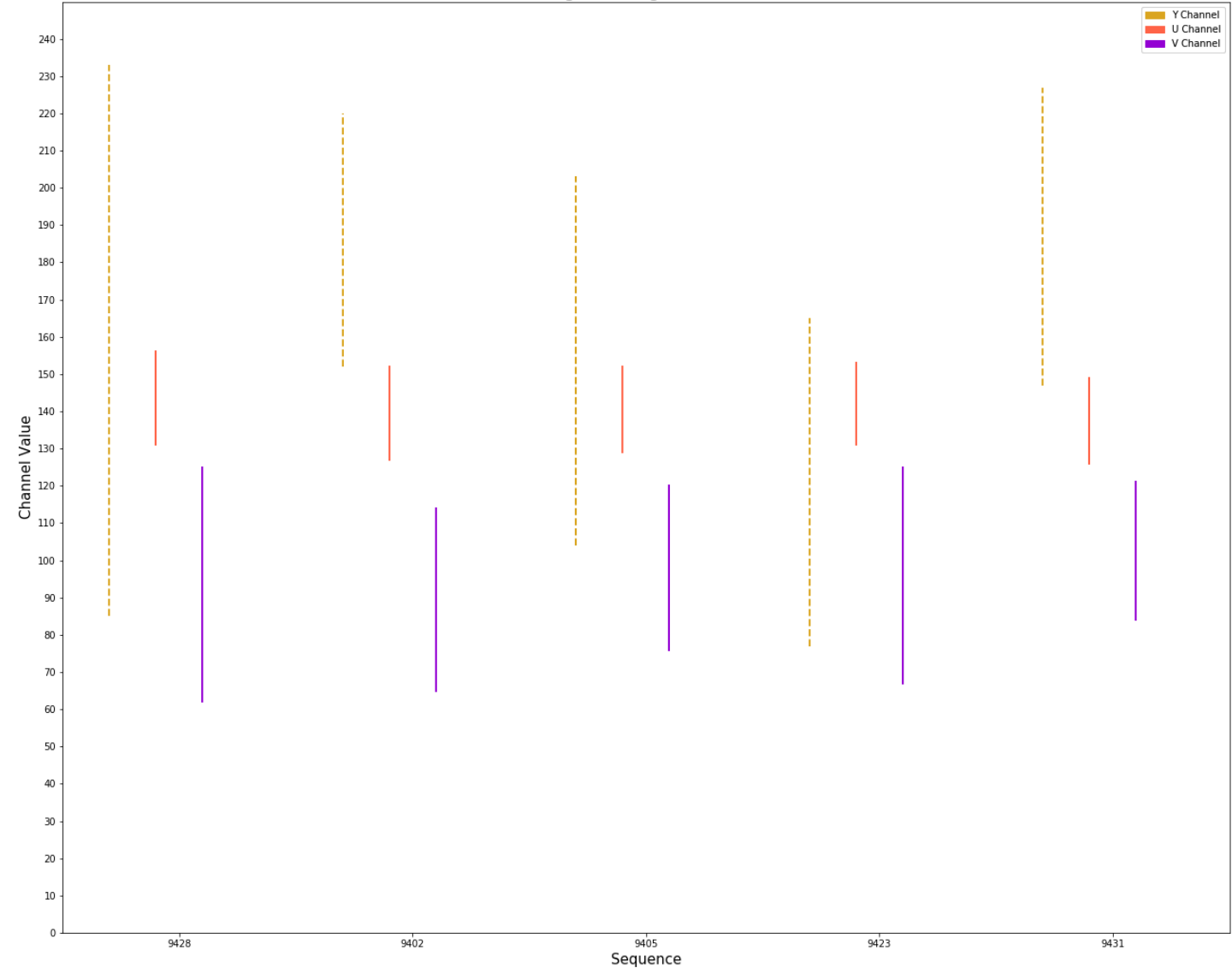


Green Lights - Segment 5 (Gmean-10)

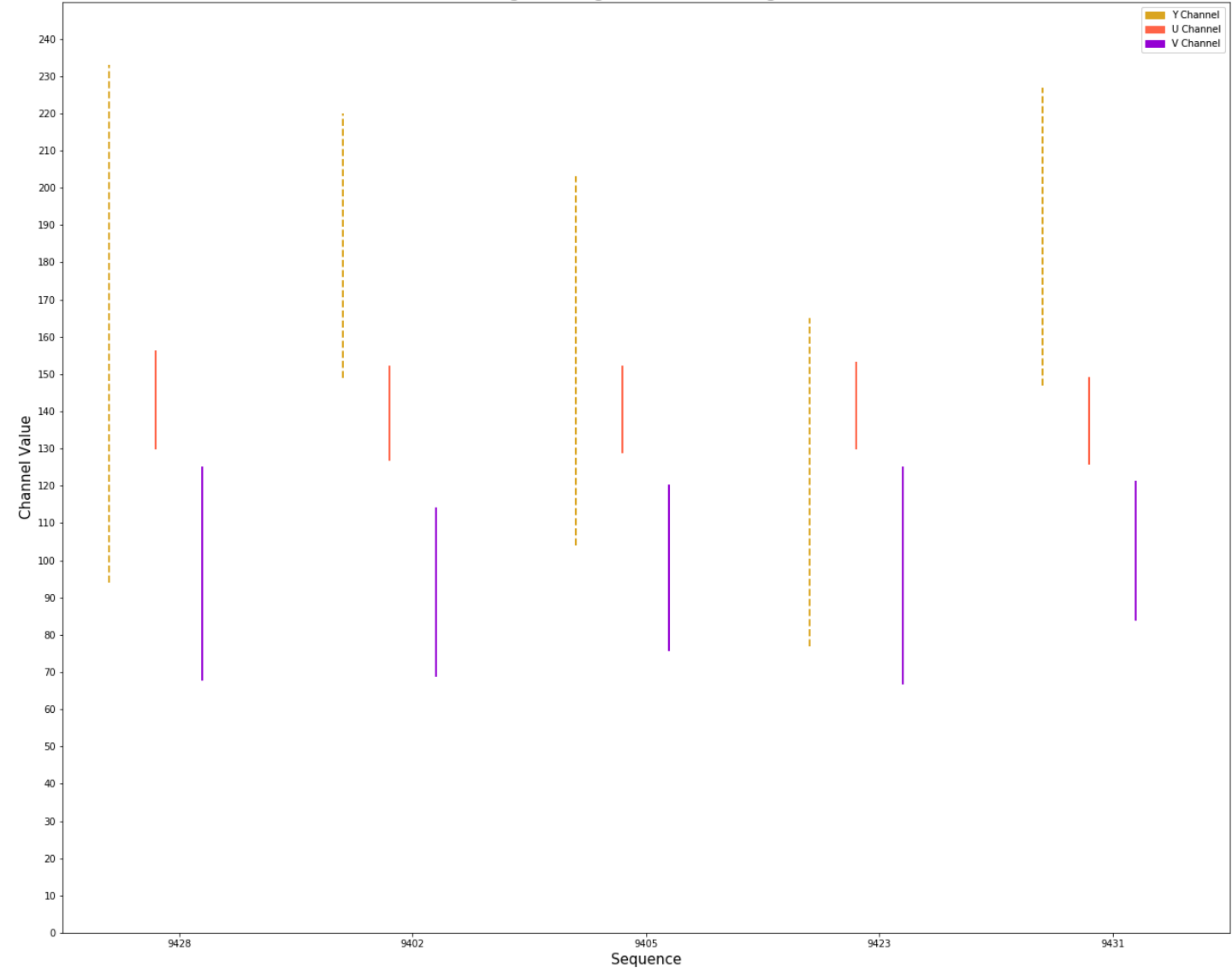


Segment 4 Statistics

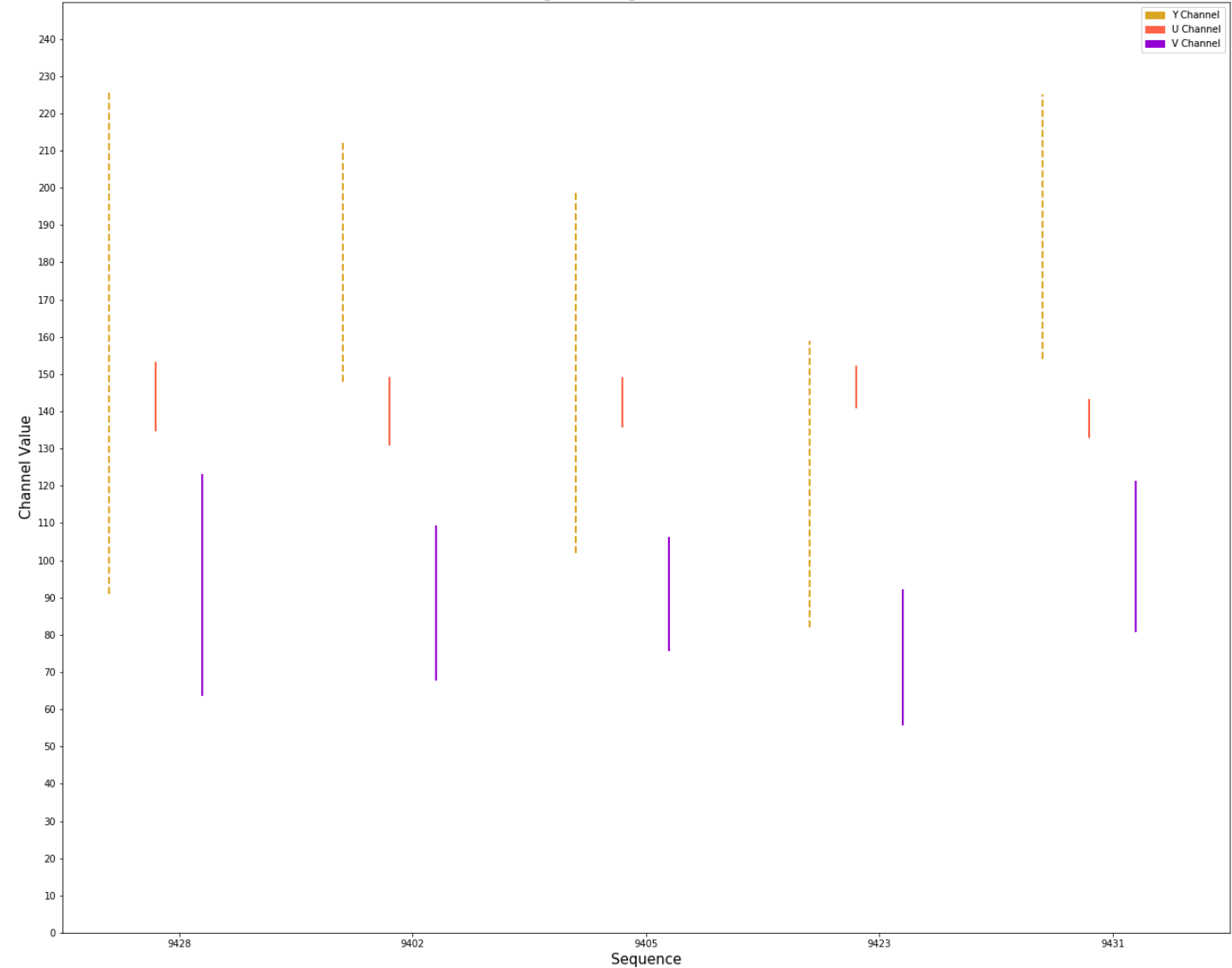
Green Lights - Segment 4 (BB SD)



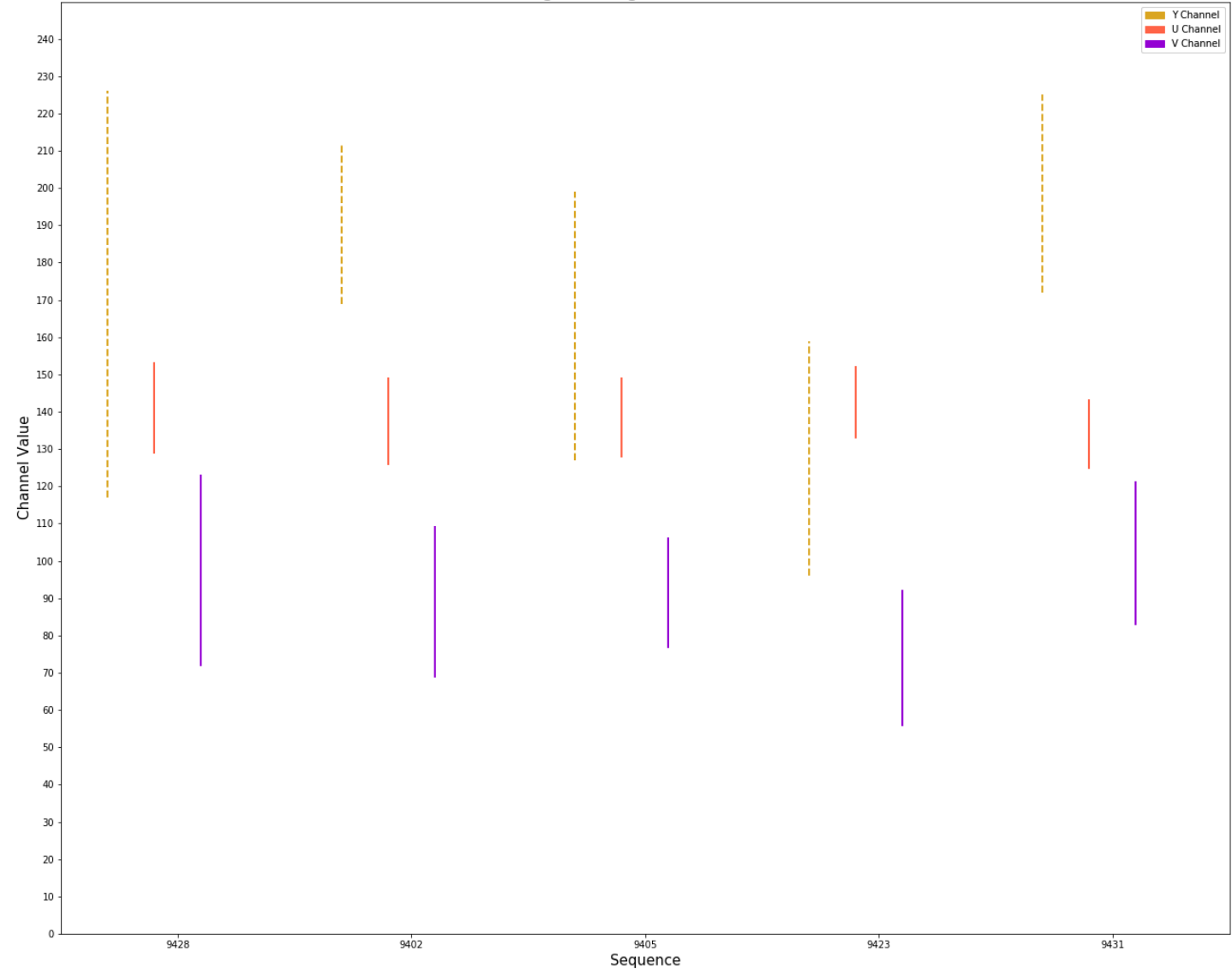
Green Lights - Segment 4 (Bounding Box -10)



Green Lights - Segment 4 (Gmean SD)

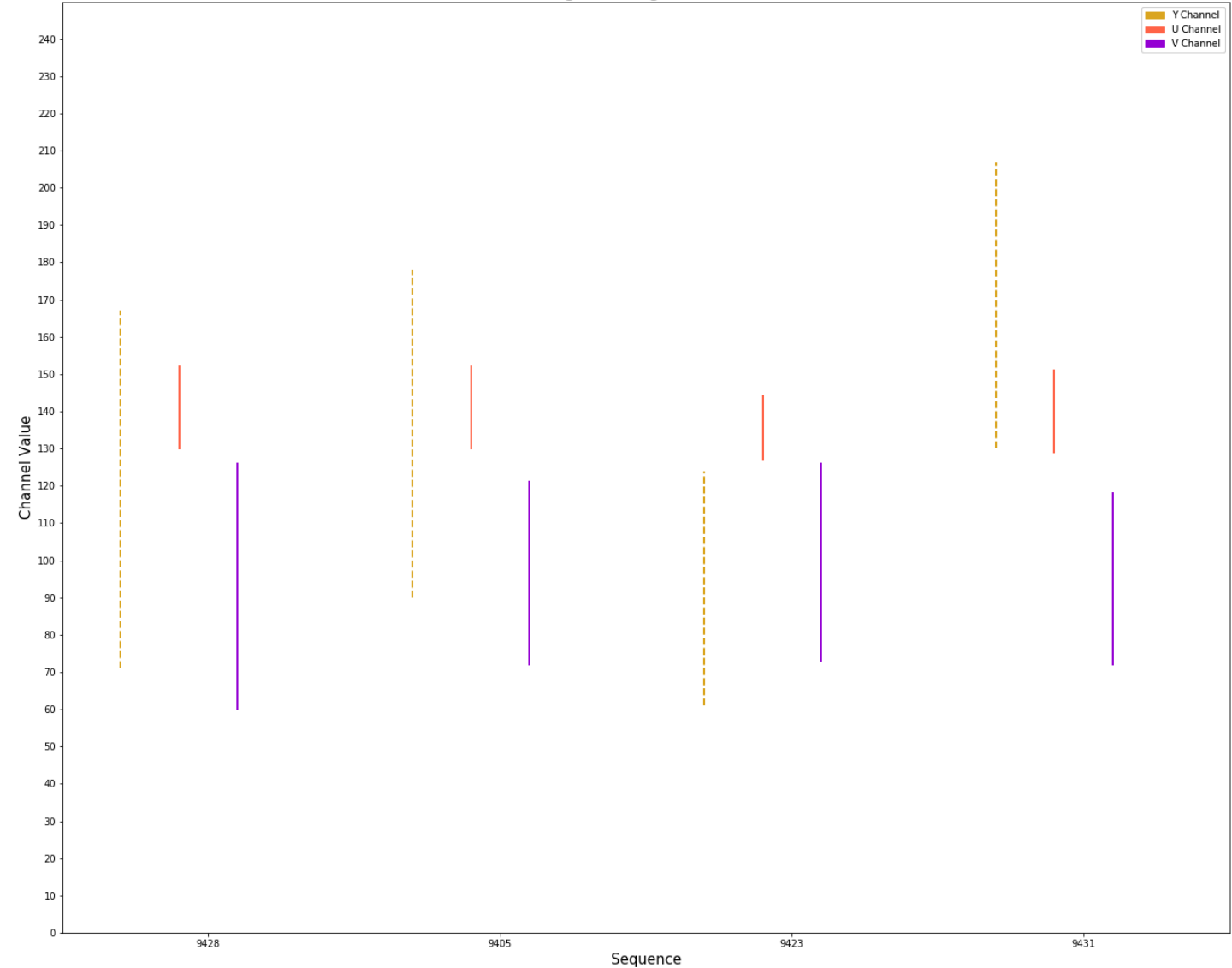


Green Lights - Segment 4 (Gmean-10)

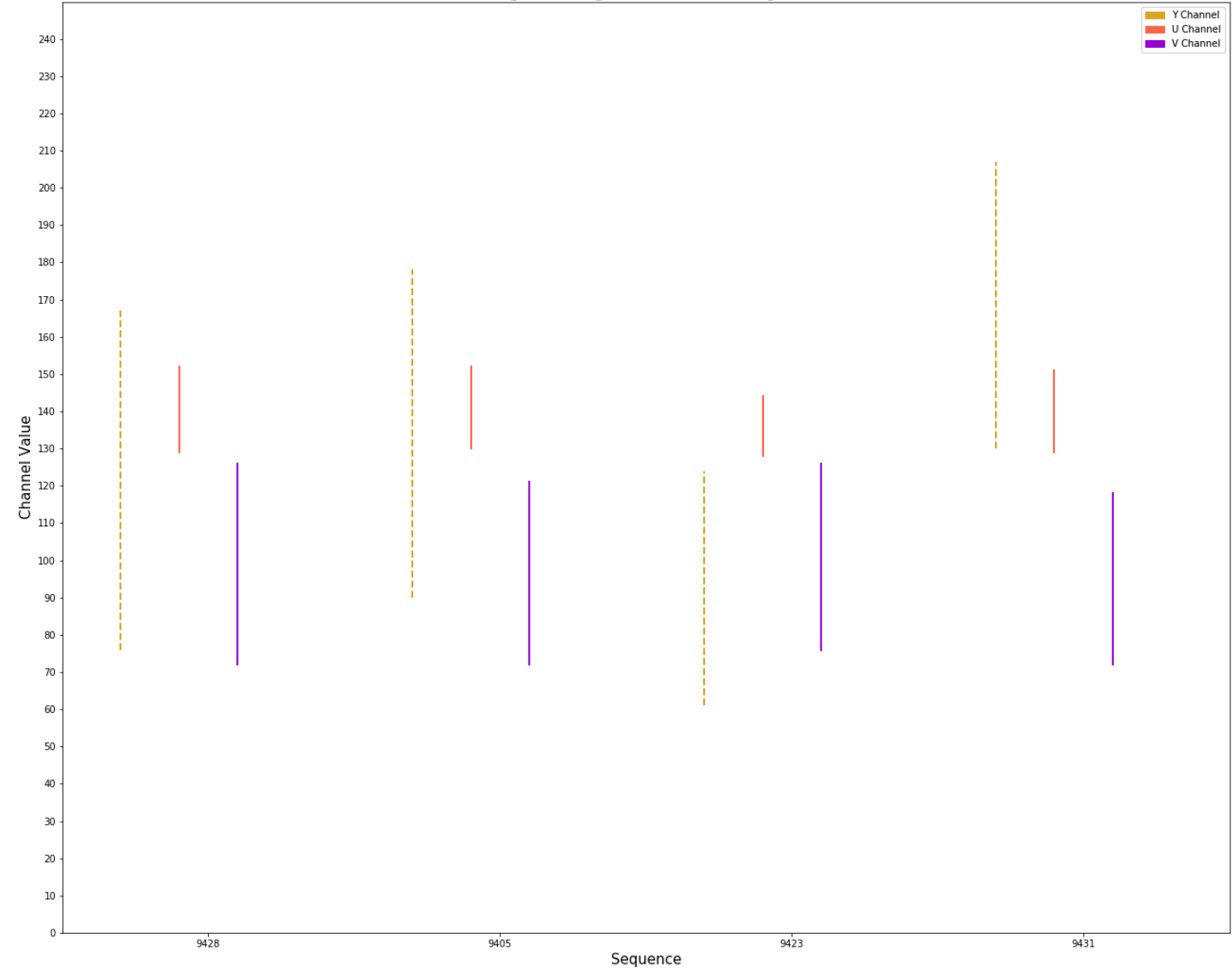


Segment 3 Statistics

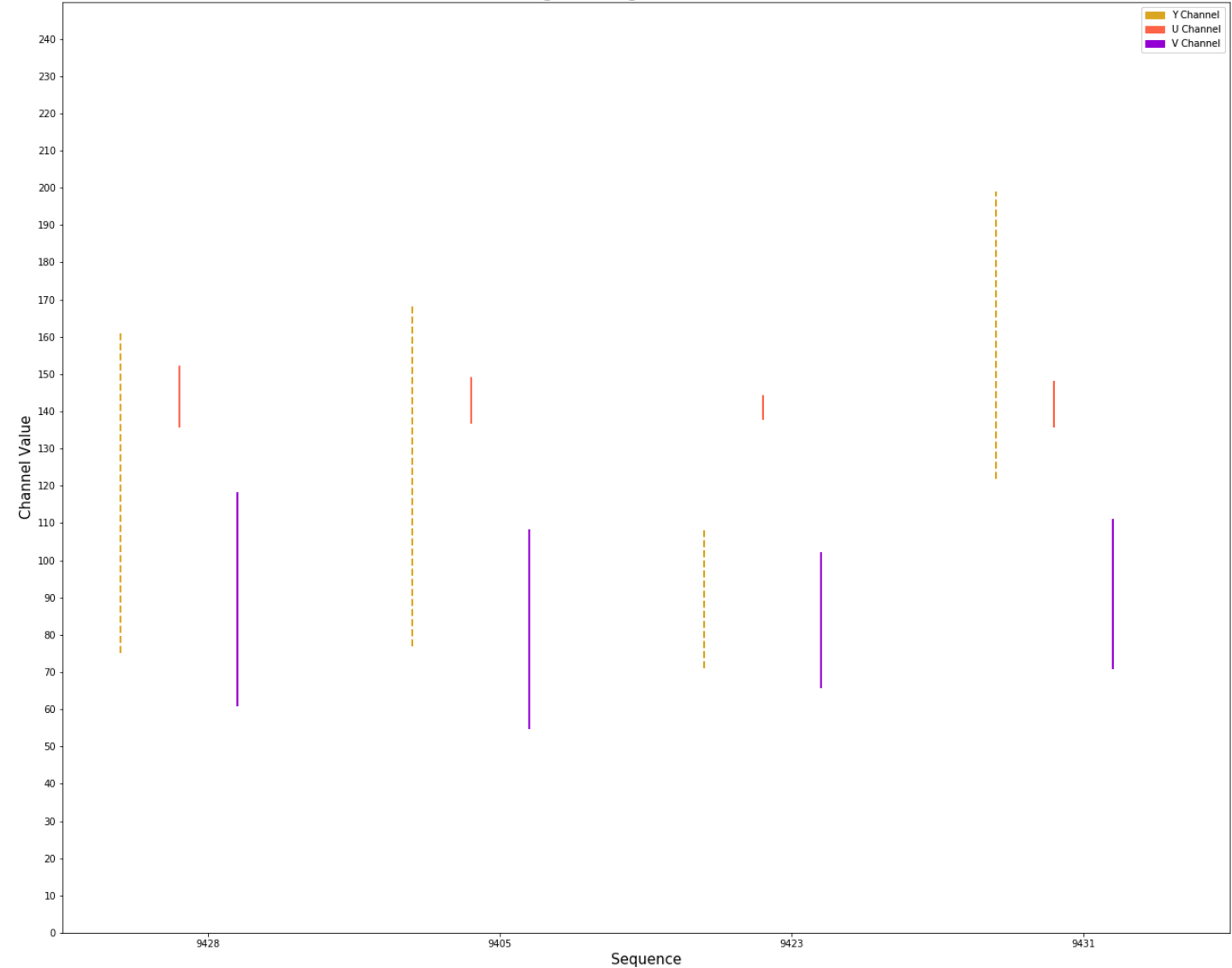
Green Lights - Segment 3 (BB SD)



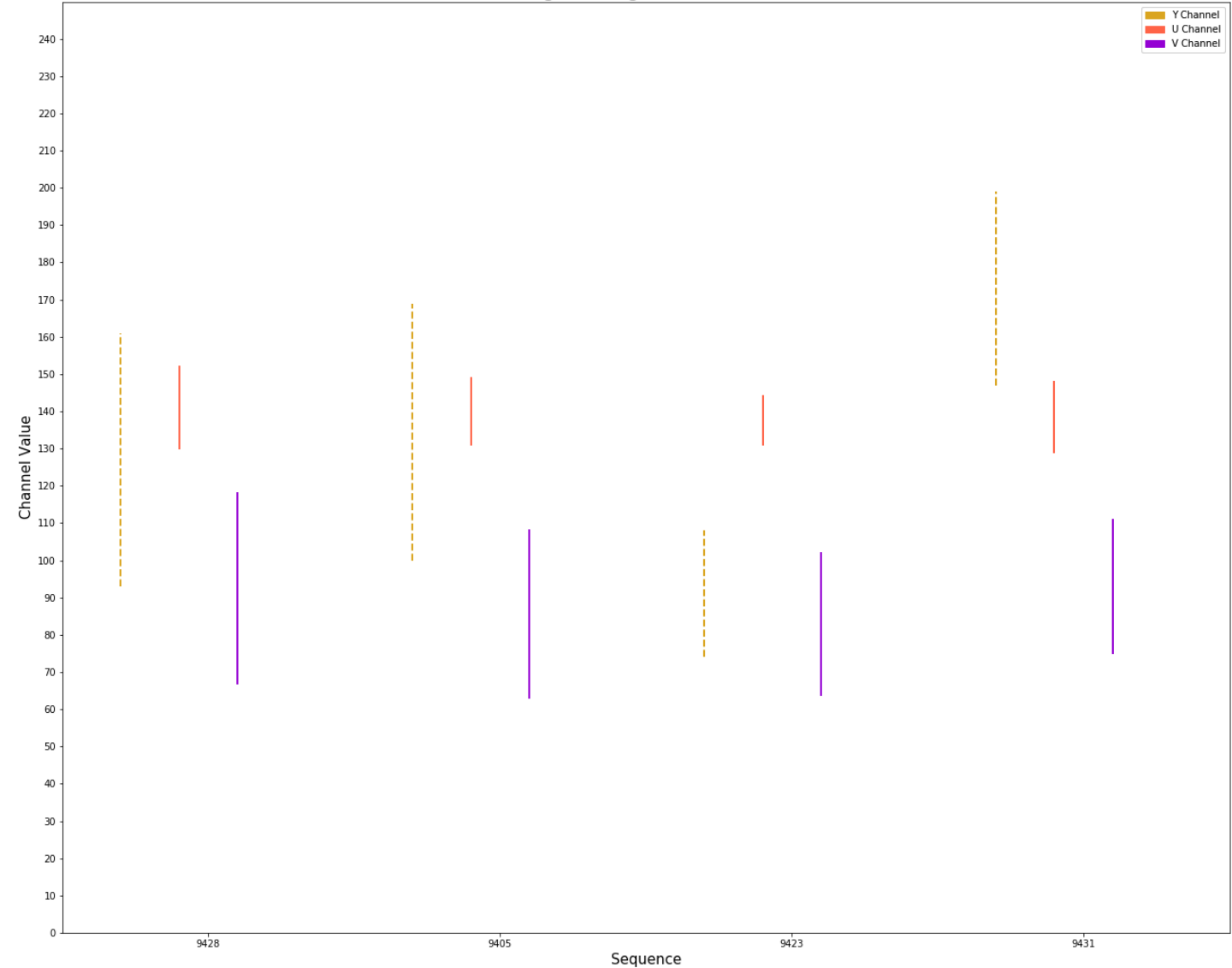
Green Lights - Segment 3 (Bounding Box -10)



Green Lights - Segment 3 (Gmean SD)

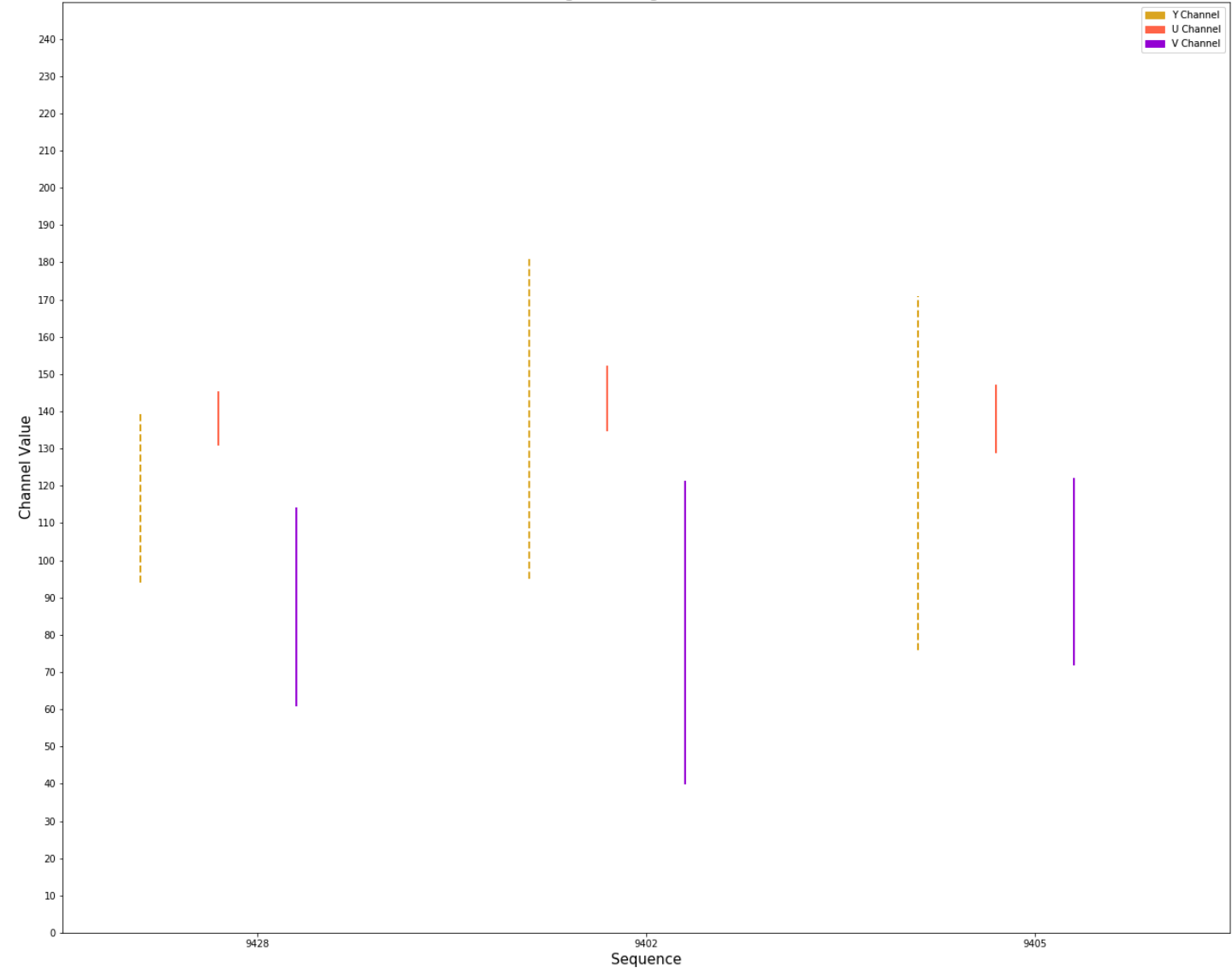


Green Lights - Segment 3 (Gmean-10)

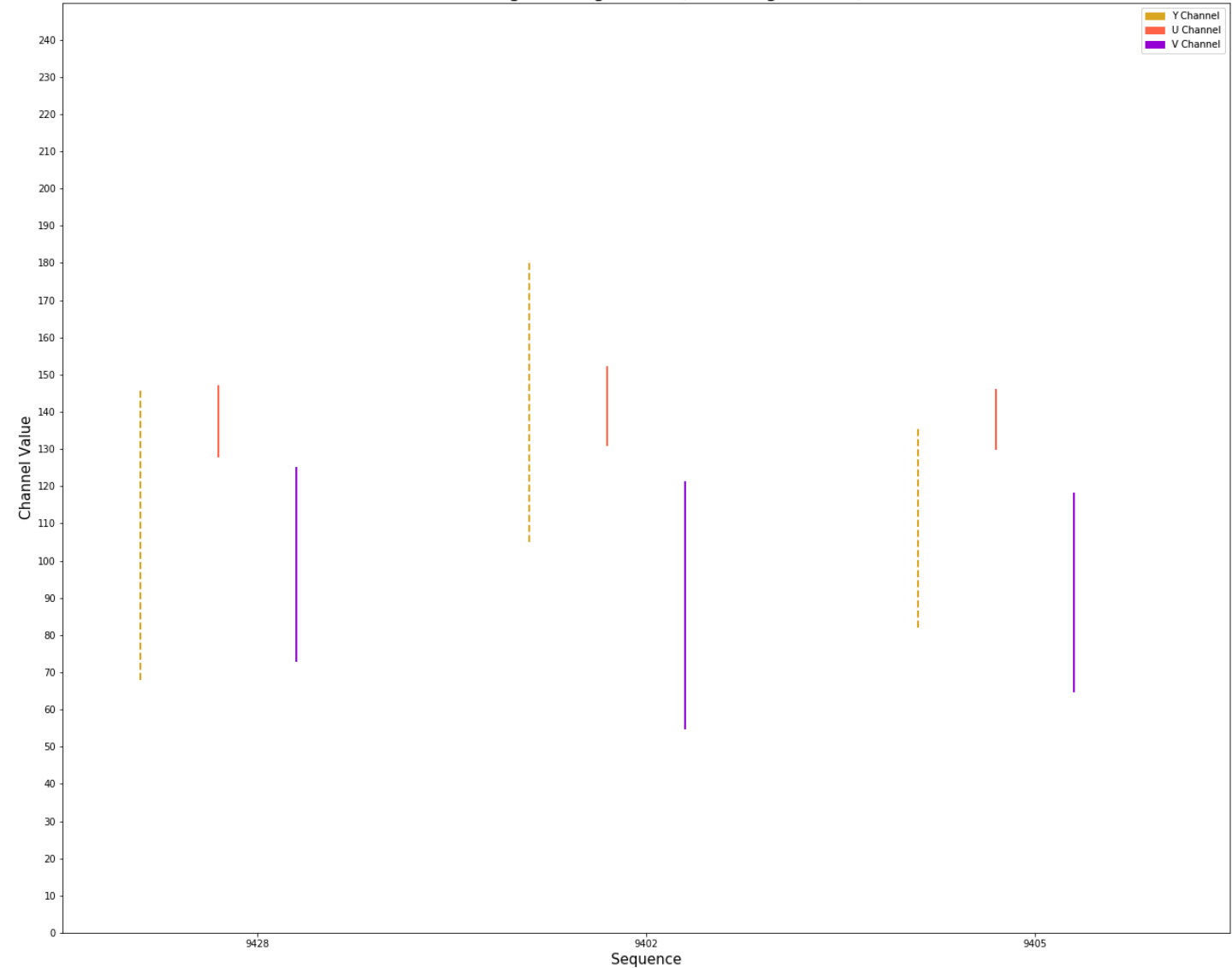


Segment 2 Statistics

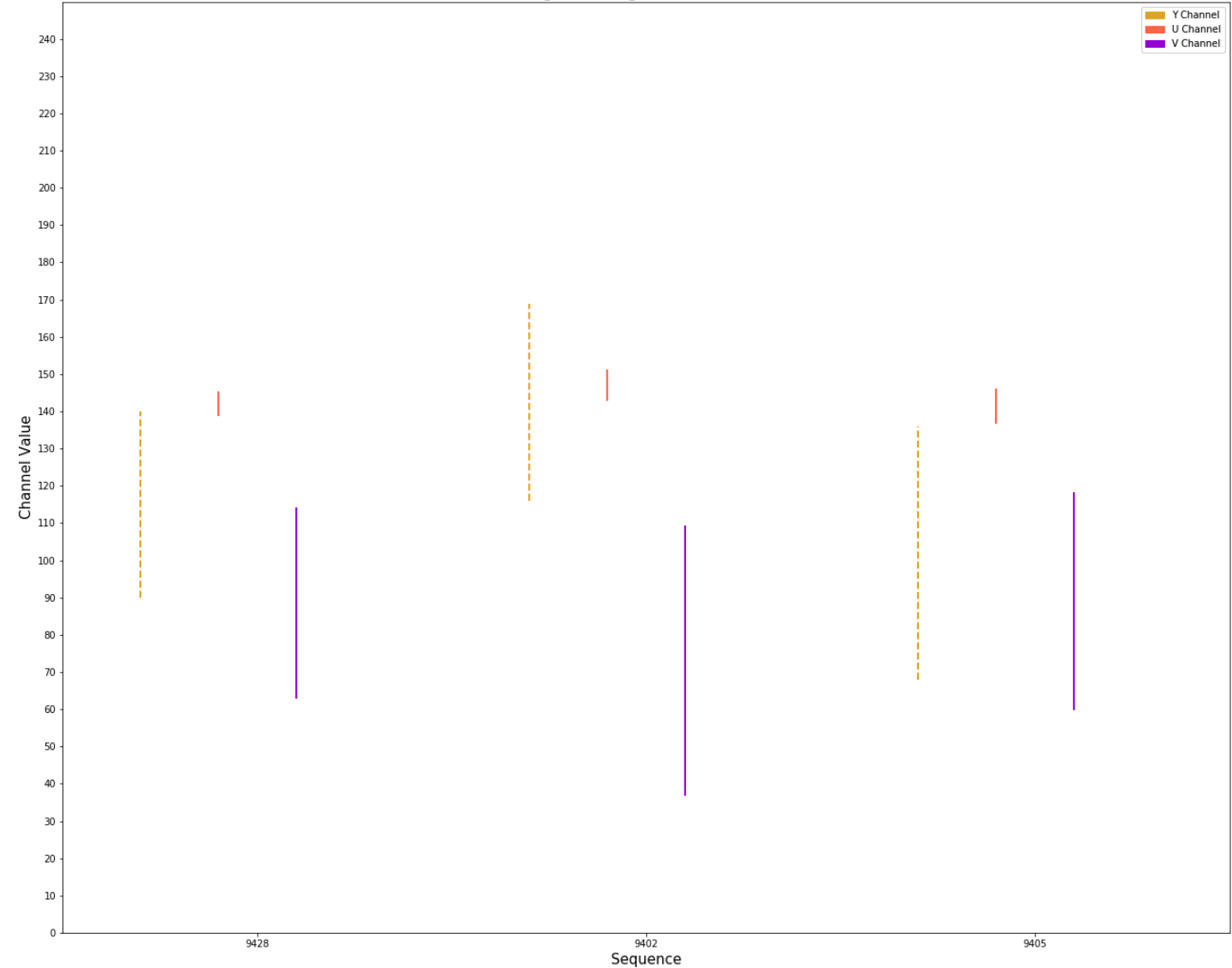
Green Lights - Segment 2 (BB SD)



Green Lights - Segment 2 (Bounding Box -10)



Green Lights - Segment 2 (Gmean SD)



Green Lights - Segment 2 (Gmean-10)

