BKM for Measurement

By Mike Munroe

Procedure

Preprocess and Run:

- Pick reference Image
- Window non-streets
- Smooth reference image
- Capture lane templates
- Densely resample templates
- Verify from within loop
- Run the main compute loop

Postprocess/Analysis:

- Raw data (run, die, image)
- Centered data (run, die image)
- Single Image Analysis
- Cull Intersections (before and after)
- Split by on-wafer
- On-off wafer switch
- Early statistics
- Smoothed Plot
- Smoothed Statistics

PREPROCESS AND RUN

Pick Reference Image

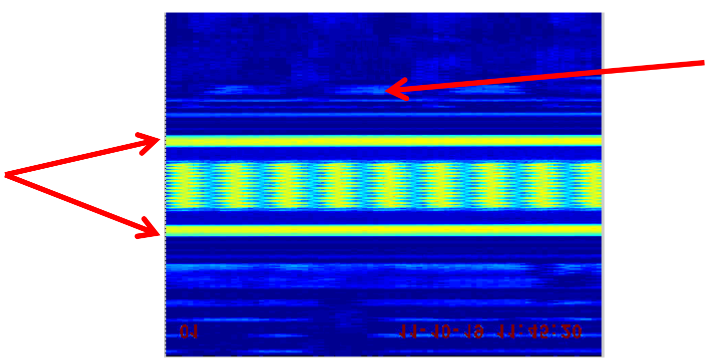
```
24  I=imread('11-10-19-10-45-19.avi107859.png','png');
25  I=double(rgb2gray(I))/255;
26
27  %is the image correct, does it meet the following criteria:
28  %   are there zero intersections
29  %   is this away from die-edge corruptions
30  % if not, pick a filename for an image that meets
31  if 1
32      surf(I)
33      axis tight; view(2); shading flat;
34      return
35  end
36
```

<u>Description:</u>

24 indicates reference image png.

25 converts it to numeric useful form: double instead of integer, scaled from 0 to 1 instead of 1 to 255.

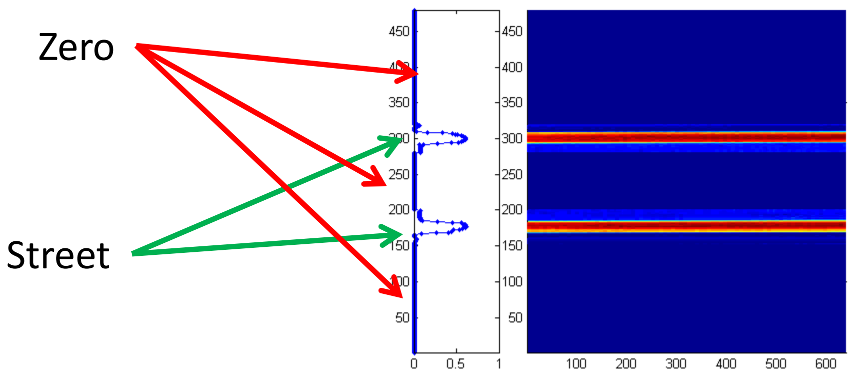
31-35 allow user to verify that a reasonable image is selected



At the end of this step an acceptable reference image has been specified. This is essential for registration.

Window non-streets

```
40
41 - 	I([1:150 200:280 320:480],:)=0;
42
43  	%Are the windows at the right location?
44  	%   centered on streets
45  	%   around 60 pixels wide
46  	% if not, adjust centers
47 - 	if 0
48 - 	    figure(1);clf
49 - 	    subplot(1,4,[2 3 4])
50 - 	    surf(I)
51 - 	    axis tight; view(2); shading flat;
52
53 - 	    subplot(1,4,1)
54 - 	    plot(mean(I,2),1:length(mean(I,2)),'.b-')
55 - 	    axis tight
56 - 	    xlim([0 1])
57 - 	    return
58 - 	end
```



Description:

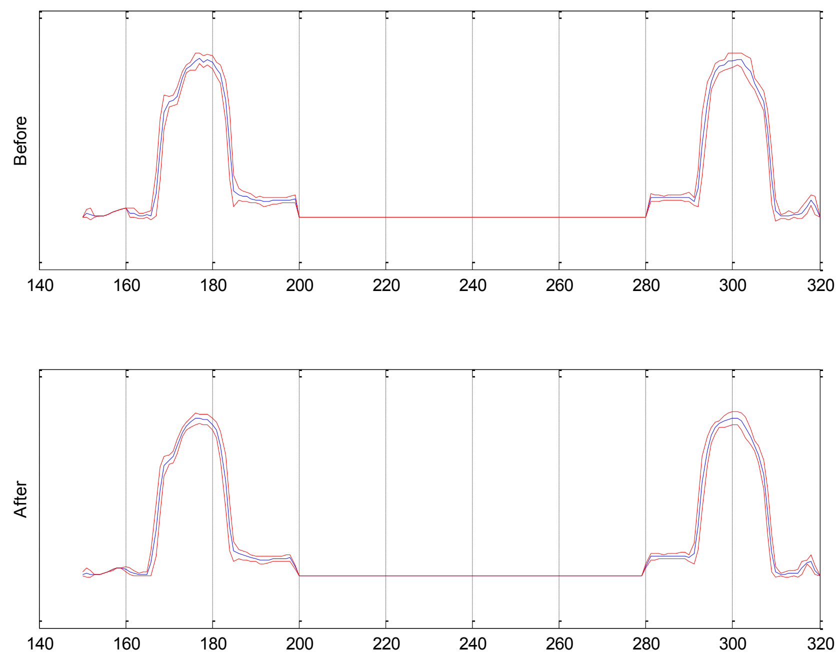
40 sets non-streets to zero. Regions retained are from 151 to 199, and from 281 to 319.

46-50 allow user to verify that a reasonable street location is selected

At the end of this step an acceptable window has been specified. This makes compute speed much faster, a requirement for processing 70k images.

Smooth Reference Image

```
69    h=fspecial('gaussian',10,15/255);
70    J=imfilter(I,h,'symmetric');
71    ind=150:320 ;
72
73    if 0
74        figure(1);clf
75        subplot(2,1,1)
76
77        plot(ind,mean(I(ind,:),2),'b')
78        hold on
79        plot(ind,mean(I(ind,:),2)+2*std(I(ind,:),[],2),'r')
80        plot
81        ylak
82        grid
83        set(
84
85
86        subp
87        plot
88        hold
89        plot
90        plot
91        ylak
92
93        grid
94        set(
95
96
97        retu
98    end
99
```



Description:

69 defines the gaussian smoothing function

70 applies it to a copy of the data

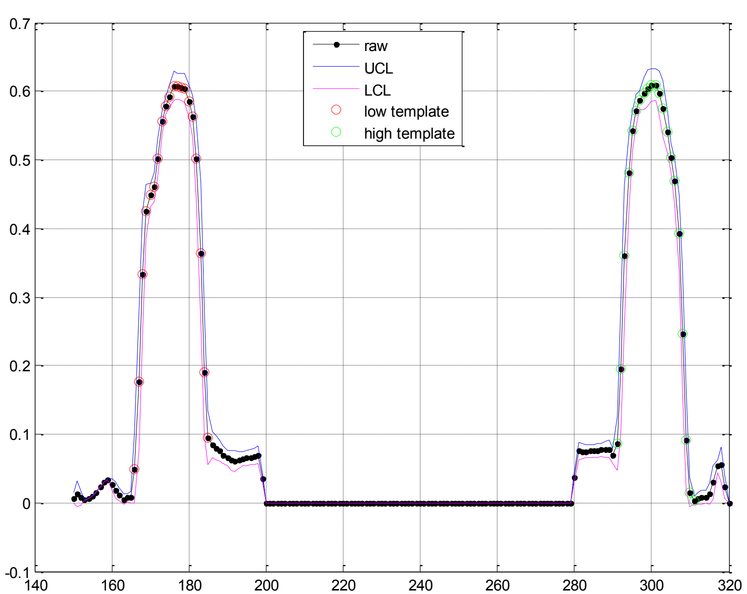
73-98 display the results of the smoothing. The goal is that the noise at the surface of the reference region is reduced (improves quality of fit). Try to make the xy-size (aka hsize) half the street width. Try to make the z-size (aka sigma) the range of z-values at the top of the street.

At this point the reference image is smoothed to improve fit. UCL/LCL (red) are made non-toothy.

As long as the reference image is consistent with the images in the "movie" then this process is effective.

Capture Lanes

```
101
102     %% capture means of streets as y-templates
103     % indL and indH should be selected so that at template ends wh
104     % street ends.
105 -   mu=mean(I,2);
106
107     %lower lane
108 -   indL=166:185; yL=mu(indL);
109
110     %higher lane
111 -   indH=291:311;yH=mu(indH);
112
113 -
114 -
115 -
116 -
117 -
118 -
119 -
120 -                                                        ce','L
121 -
122 -
123 -
124
```



Description:

105 computes the row means for the reference image

108 and 111 take those means (and their indices) to use for "template" profiles

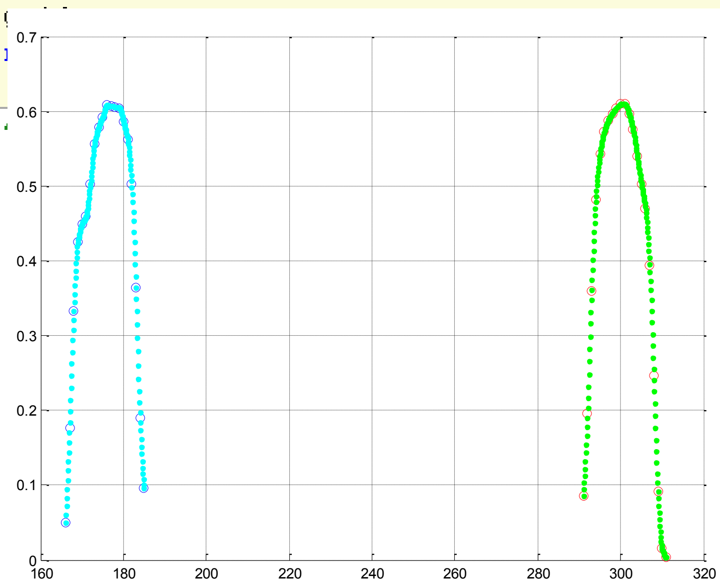
113-123 plot the templates against the raw data. Templates end at "valley" or transition to valley. This occurs where stdev has a jump in values.

At this point we have the templates used in the fitting process, and we have validated that we do not have index error.

Human judgment is used (at this point) to determine what constitutes a "feature of interest" for the template.

Densely resample the templates

```
128     %    improves accuracy of registration
129 -   indLb=linspace(min(indL),max(indL),length(indL)*10);
130 -   yLr=interp1(indL,yL,indLb,'pchip');
131 -   indHb=linspace(min(indH),max(indH),length(indH)*10);
132 -   yHr=interp1(indH,yH,indHb,'pchip');
133
134 -   if 1
135 -       figure(1); clf
136 -       hold on
137 -       plot(indL,yL,'ob');plot(indH,yH,'or')
138 -       plot(indLb,yLr,'.c');plot(indHb,yHr,'.g')
139
140 -
141 -
142 -   end
143     %% I
```



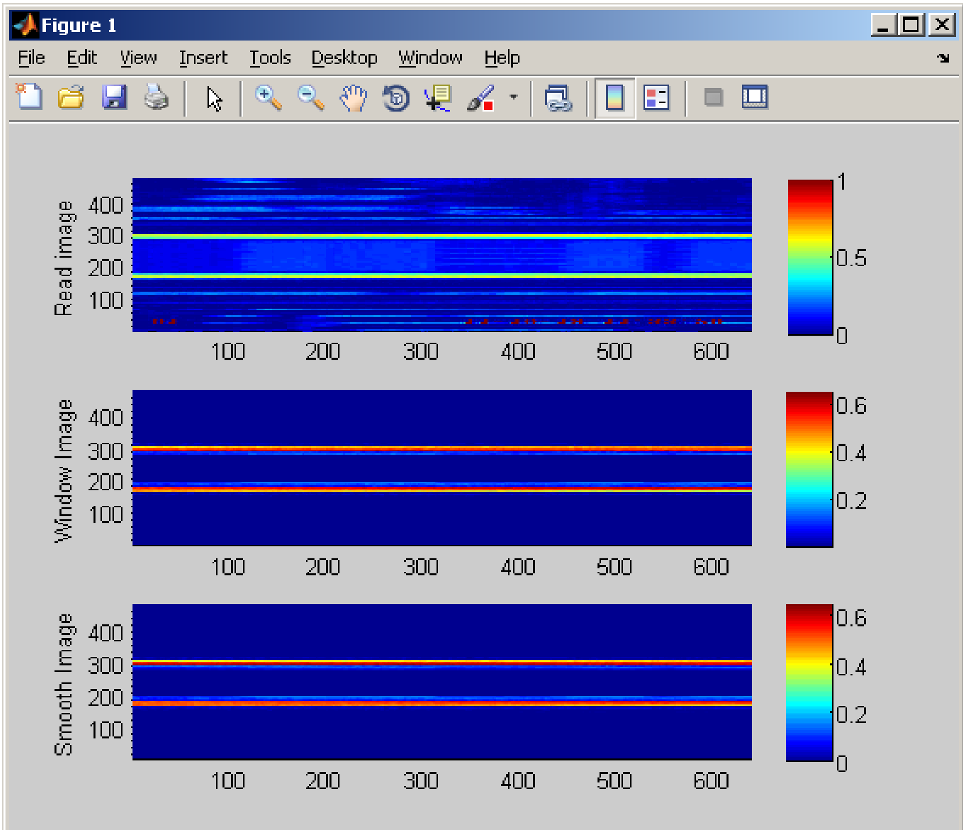
Description:

129 and 131 create resampled indices for the templates

130 and 132 use “pchip” interpolation to map to the denser indices.

134 through 142 display the results. The template and resample should line up properly. If they do not then there is an index problem.

Test Image from inside loop



Description:

To get this requires the variable "testframe" on line 182 to be set to 1.

This is from a different run, I did not have the actual image for the earlier reference.

MatLab is failing in copying the figure because of memory issues, so this is a screen-capture.

Ready to Run

- Make sure that the in-loop truncation, filter, etc and the same as your reference image pre-processing.
- At this point the hard-working script can start working on your directory full of images.
- If you significantly change the y-location of the streets or the illumination of the die then these settings will not function properly.

POSTPROCESS RESULTS

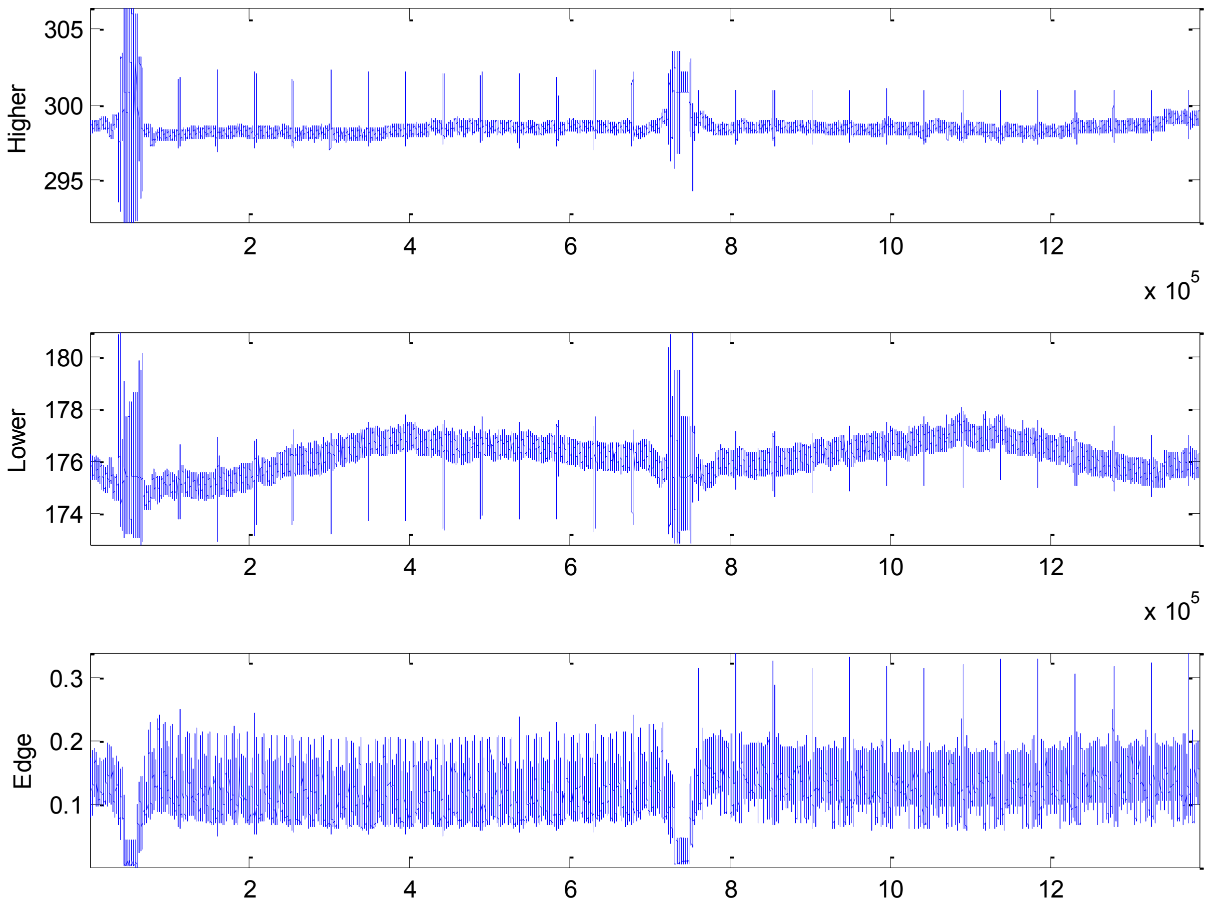
Starting the Run

```
9   format short g
10  format compact
11  close all
12  warning off all
13
14  if 1    %whether to process images (1), or results (0)
15
16      %read directory for files of interest
17      % make sure this is proper indicator of name
18      d=dir('*.png');
19
20      %% get reference images
```

Notes:

- Set “testframe to zero and rerun”
- After the run, set the if in line 14 to zero. This switches from the process the images mode into the process results mode.

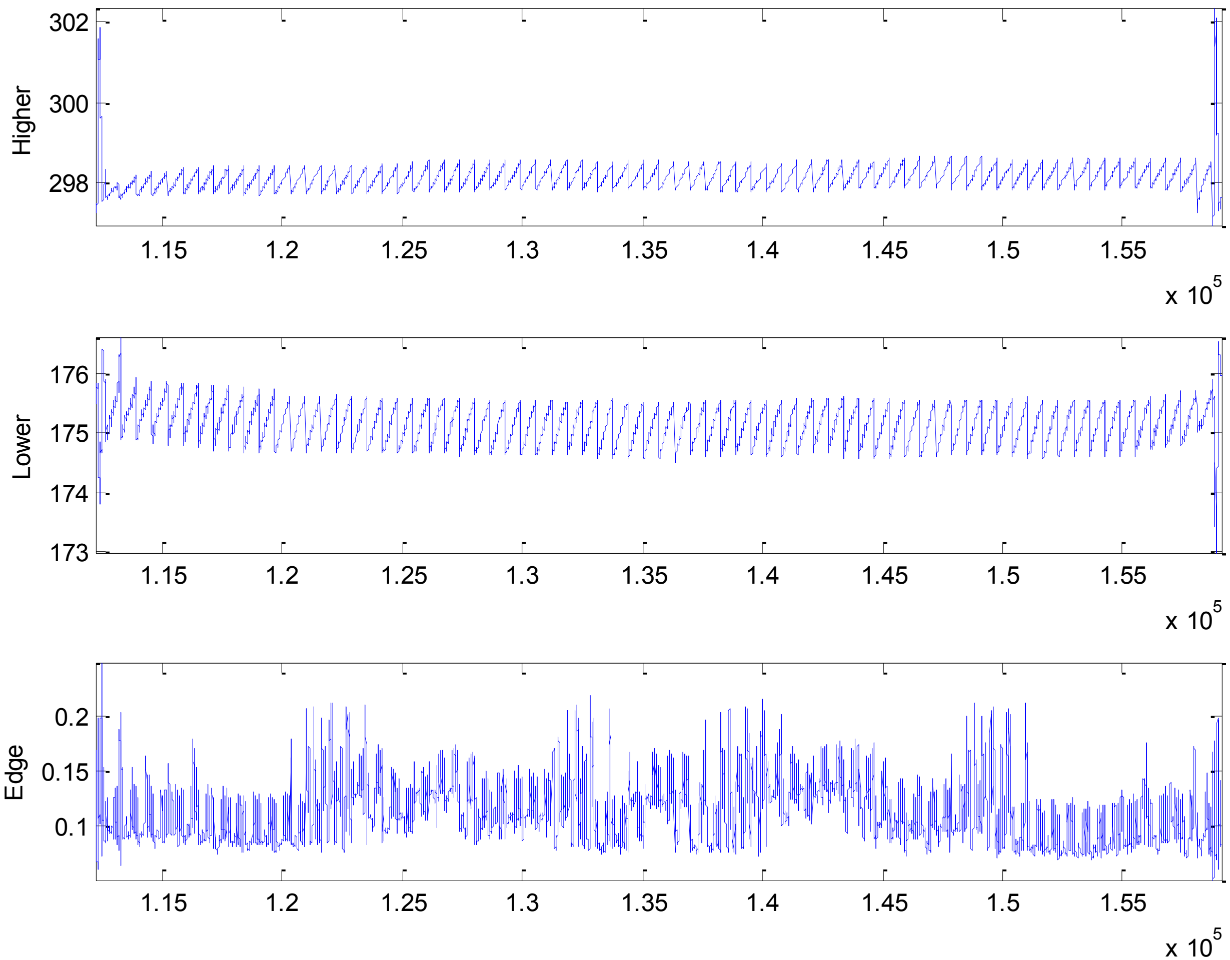
Display raw data



Notes:

- The code for this starts at line 302.
- Subplots
  - The upper subplot is the estimate for the upper street.
  - The middle subplot is for the middle street
  - The lower subplot is for the off-die indicator.
- Features
  - The thick vertical lines are off-die transitions.
  - The thin vertical lines are the streets for the individual dies.
- There are ~1.4 million data points for each subplot.

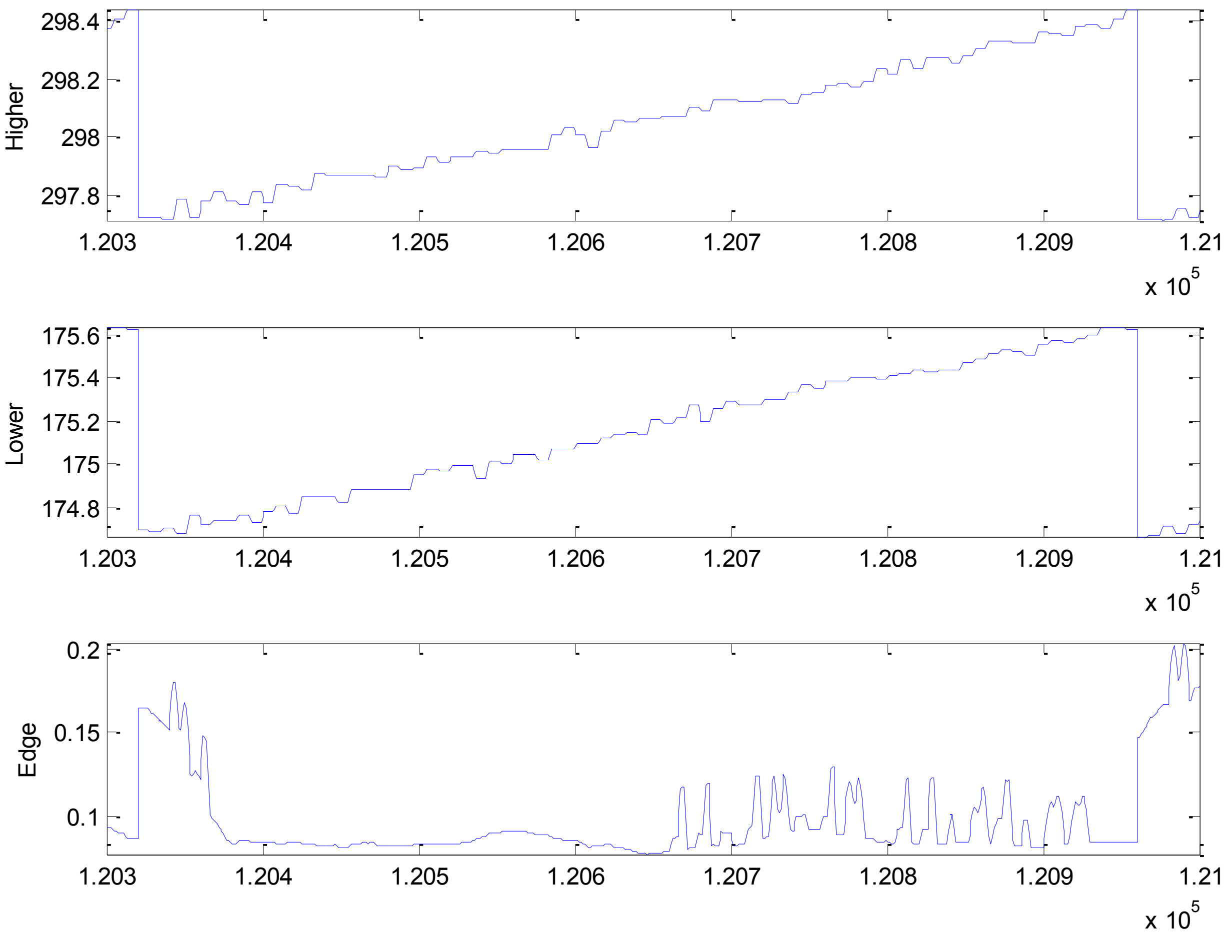
Display single Die



Notes:

- The edge vertical lines are intersections.
- There are about 73 images analyzed per die.
  - From earlier (Nyquist) this implies that there are about 36 frame-widths between dies.
  - At 700 nm per pixel this gives about 16.35 mm per die.
- The off-wafer indicates we are on-wafer.

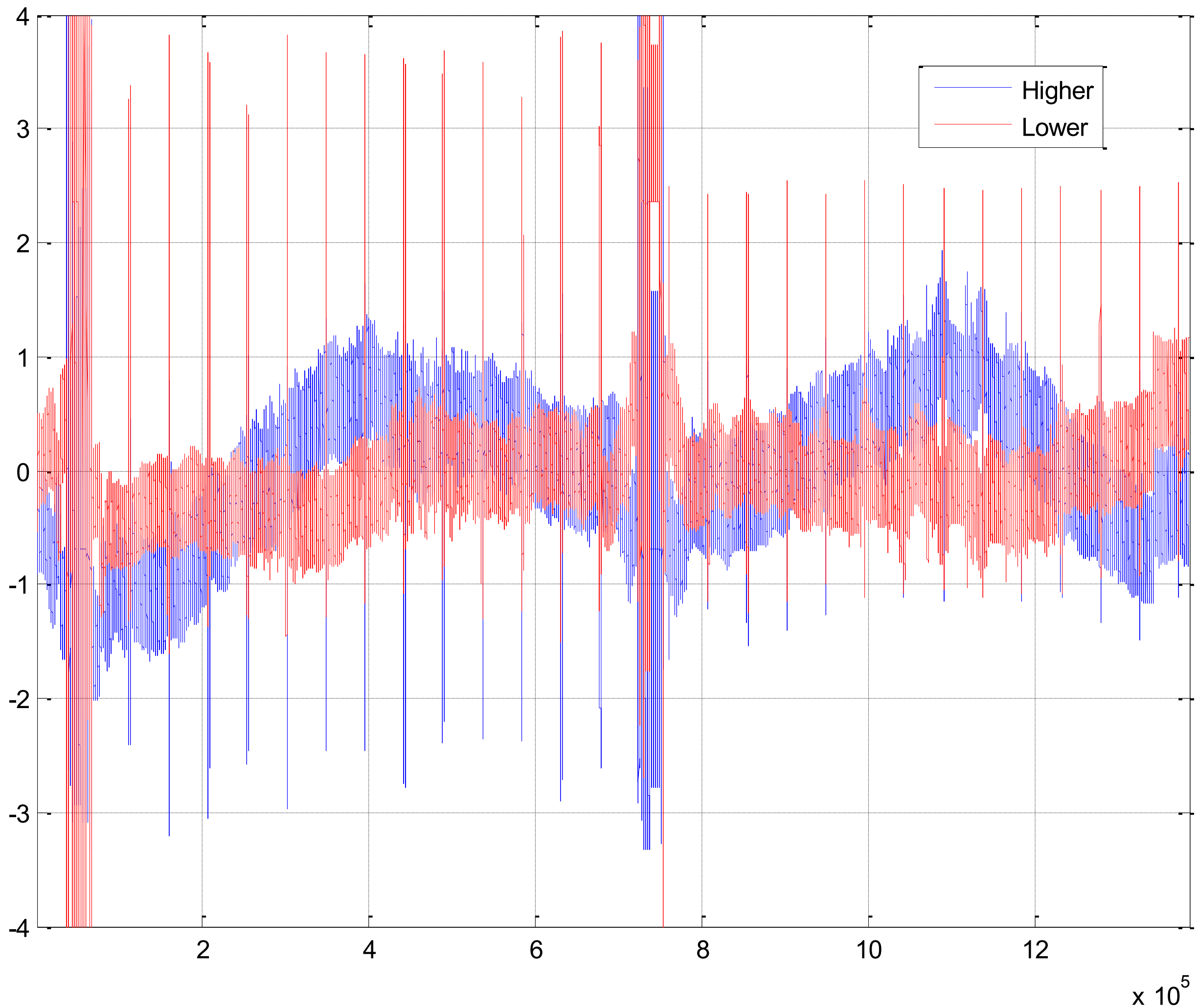
Display Single Image



Notes:

- The measurements across a single image are reasonably linear
- There are 640 measurements per image traverse

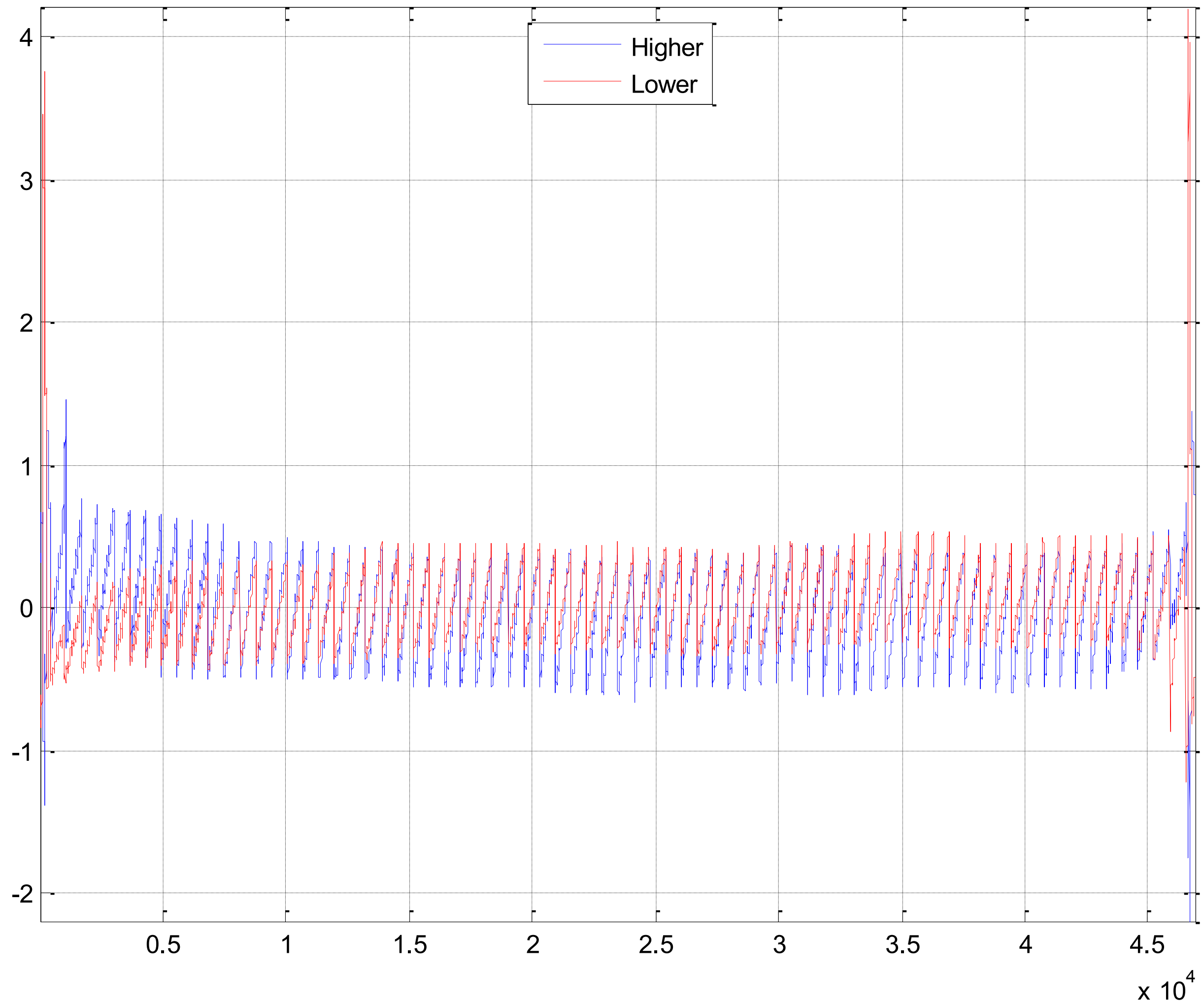
Display Centered data



Notes:

- There is significant drift of the higher lane toward the center of the wafer (around x=400k, 1100k)
- The y-position of the lower lane is relatively constant.
- Toward wafer edge there is higher divergence.
- Off-wafer data can provide bias in mean so median is used and following centering is local, not global.

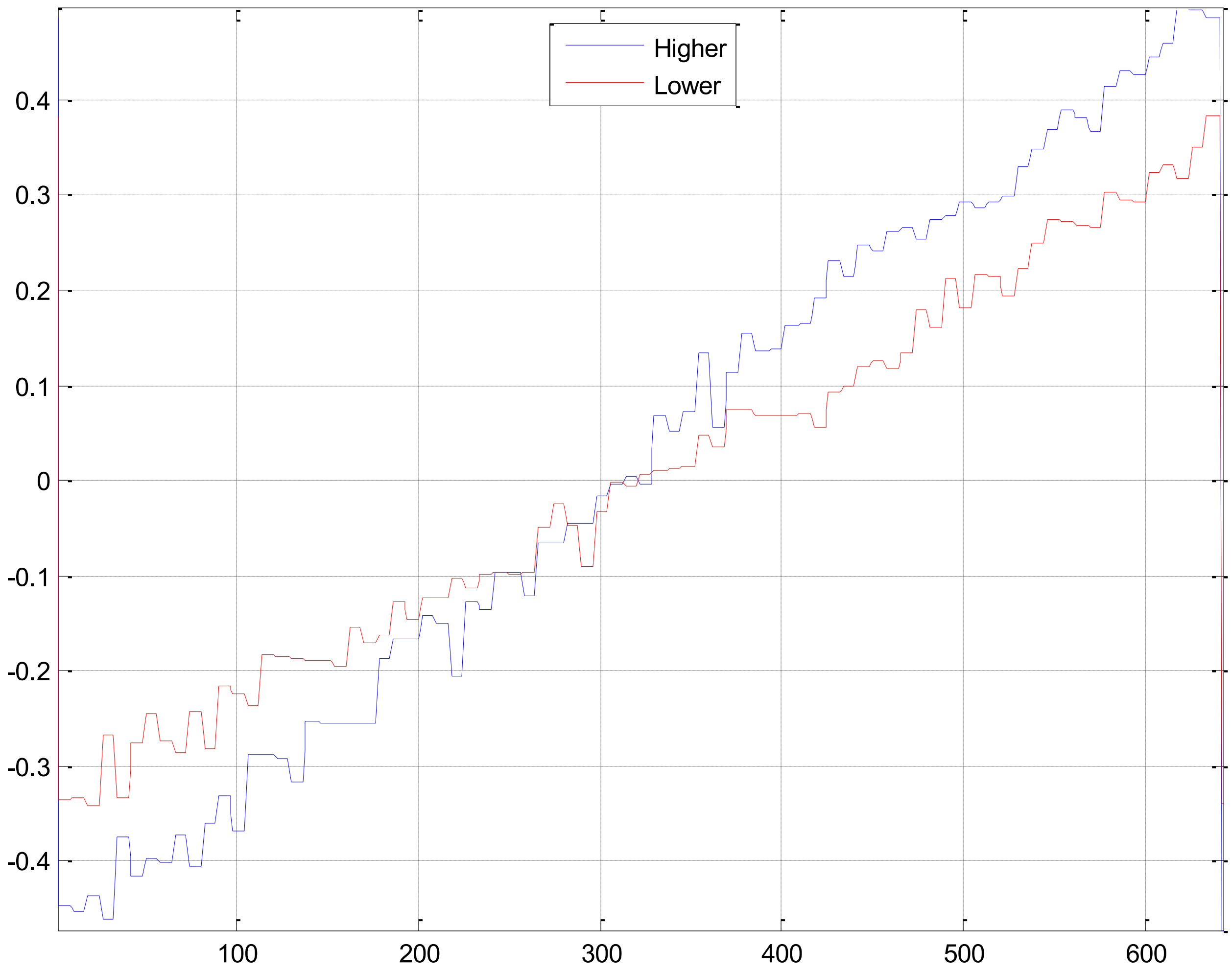
Display centered single die



Notes:

- The drift between indices is evident around 2500 when compared to 25000. It is thought to be due to a coating on the top of the lanes.
- This is compensated for by treating lane center position as the average between these two values.

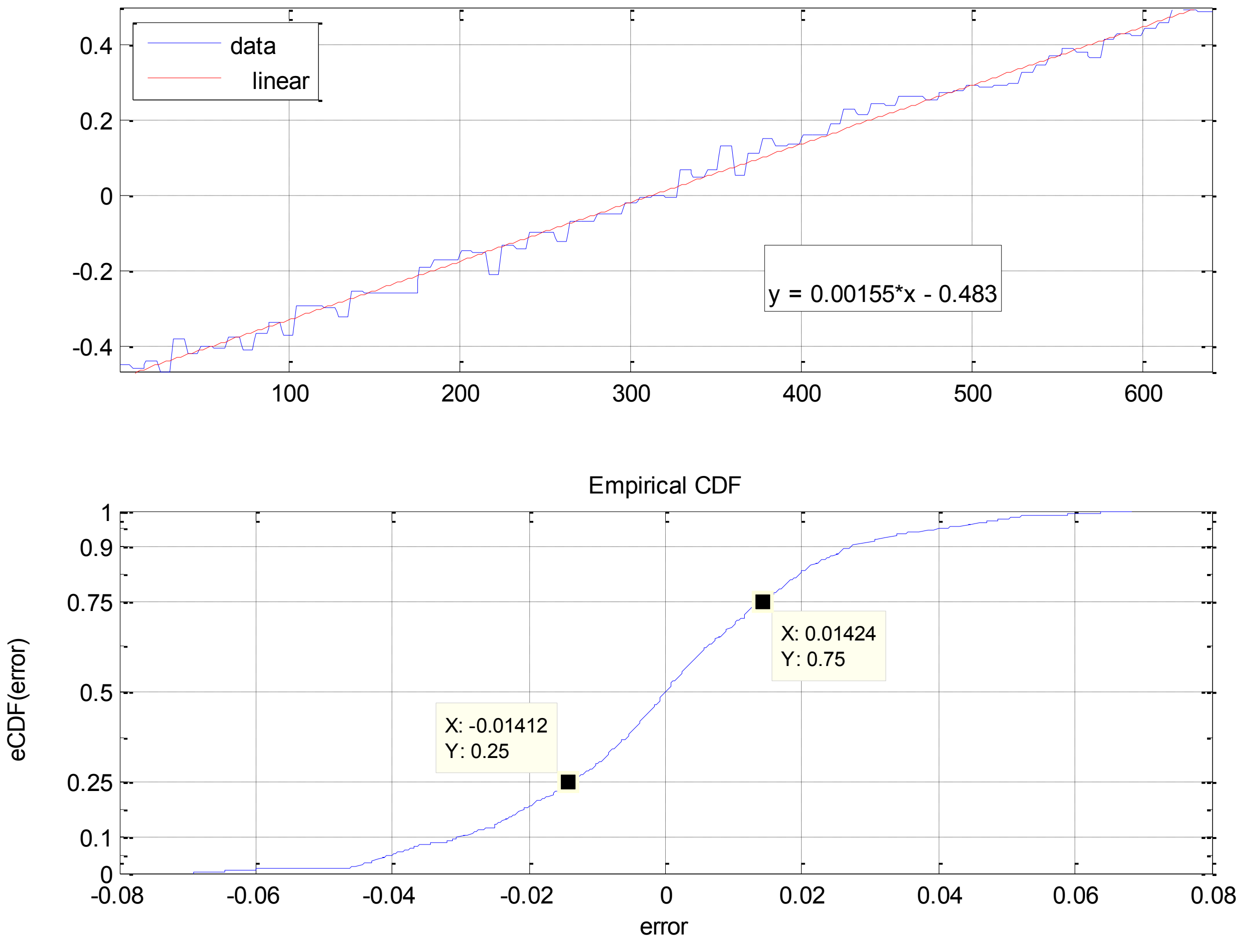
Display centered single image



Notes:

- The lines are reasonably linear
- Intersection detection is identical and perfect.
-

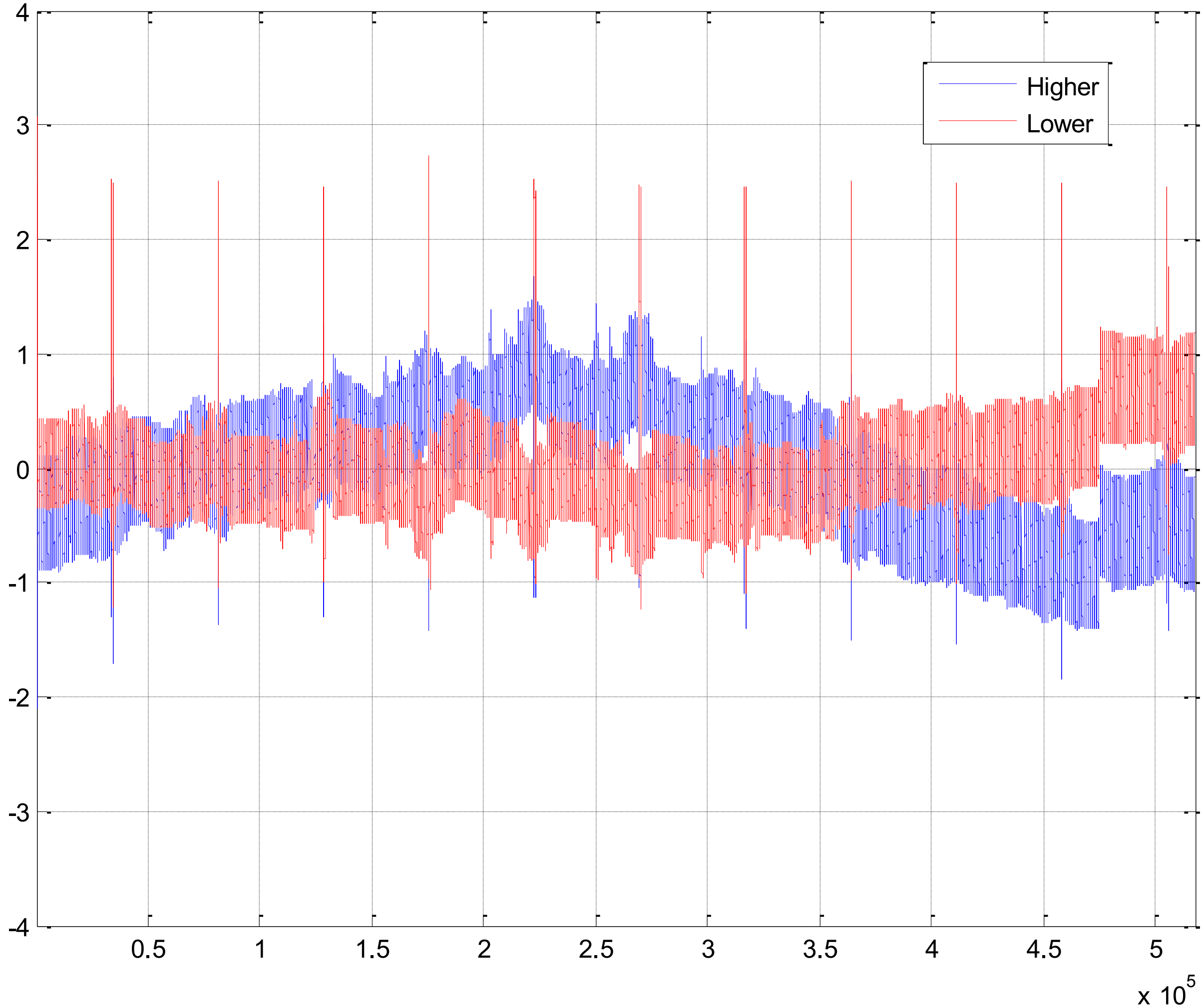
Single Image Analysis



Notes:

- The lane should be effectively perfectly linear over the space of a single image.
- A least squares fit of a line over a single lane in a single image should allow characterization of variation in position estimate for single column of data
- Stats
  - IQR = 0.028522
  - IRQ/1.35 = 0.021127

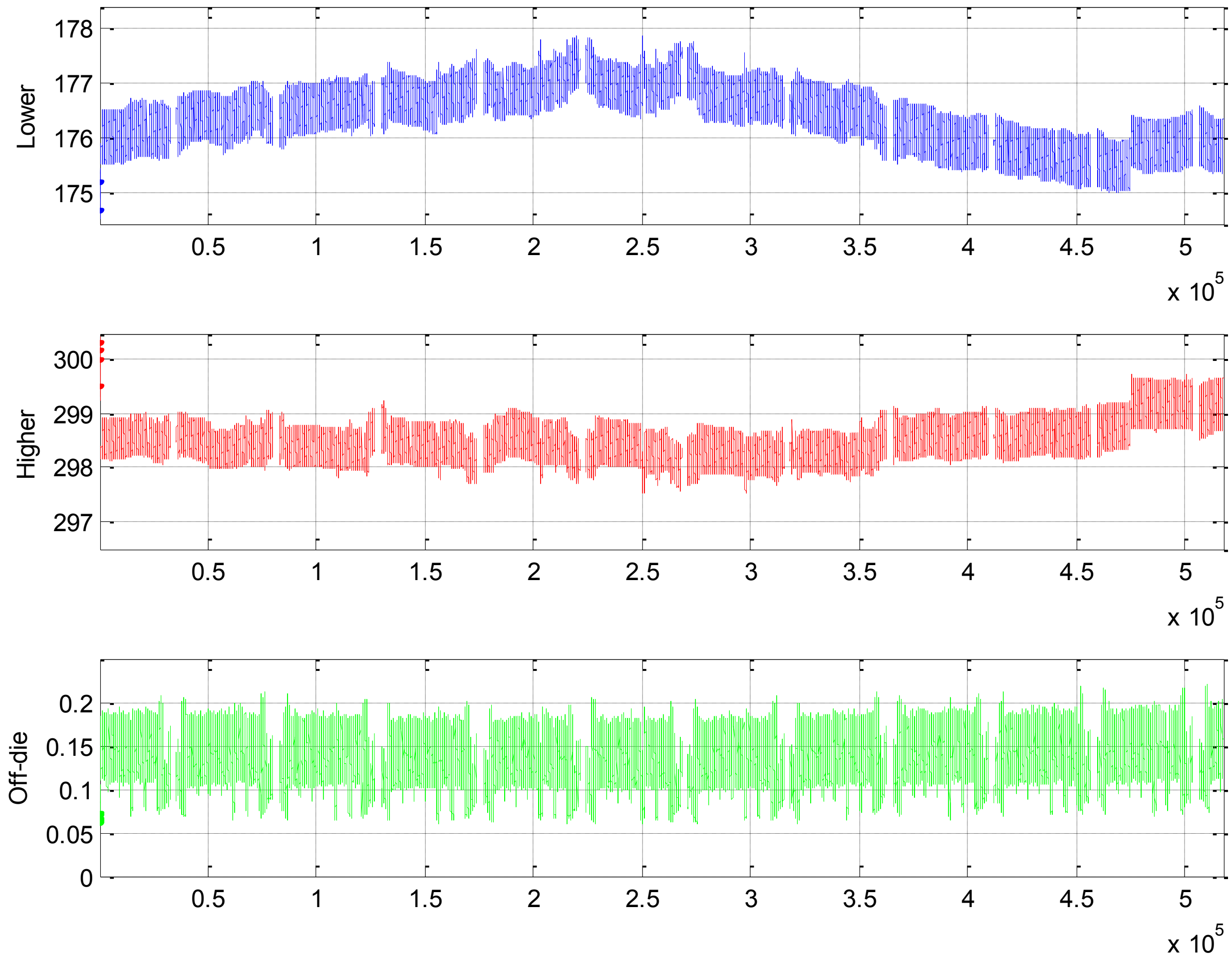
Cull intersections (before)



Notes:

- From code lines 347-412
- This is just to show intersections and culling.
- Note the (very) clean alignment of intersections.
- This is 500k columns to traverse ~11 dies along a single street
- Lane drift is ±1.5 pixels from mean, but the intersections peak above 2 pixels above mean. This informs intersection culling.

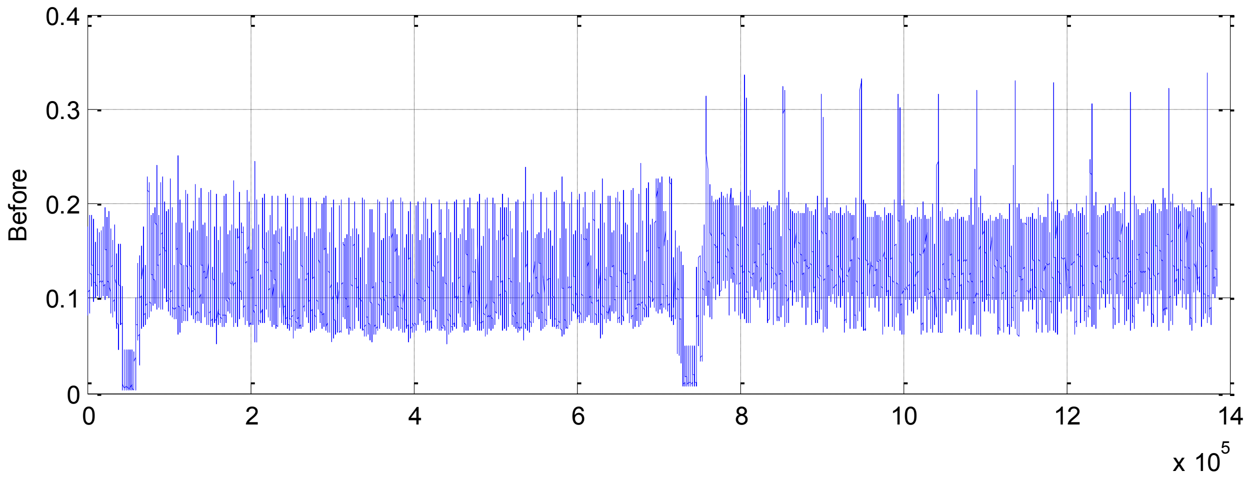
Cull Intersections (after)

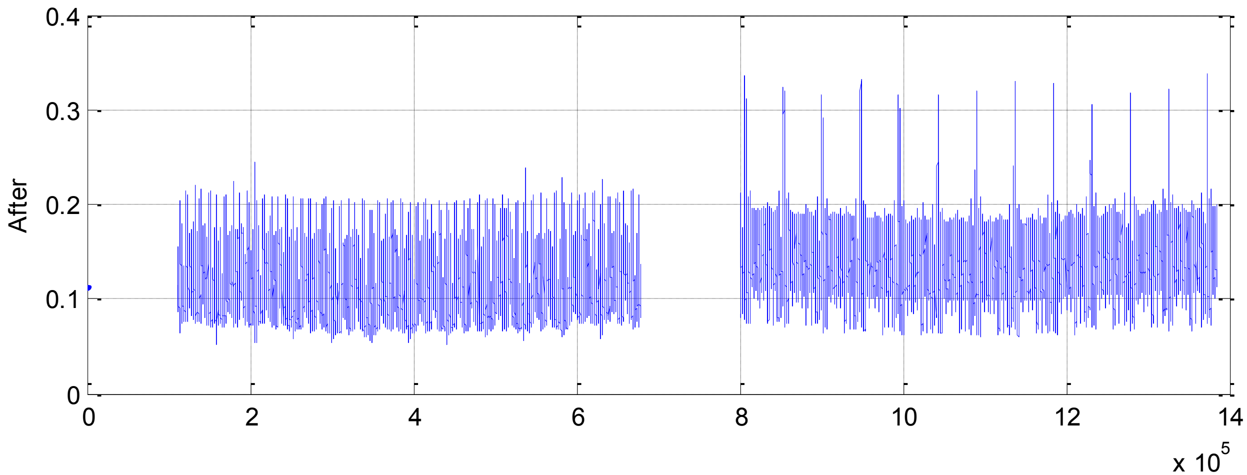


Notes:

- There are still ~500k lines of data.
- This is not at die-edge so the off-die indicator is flat.
- Lower lane has some drift.

Parse by off-wafer indicator

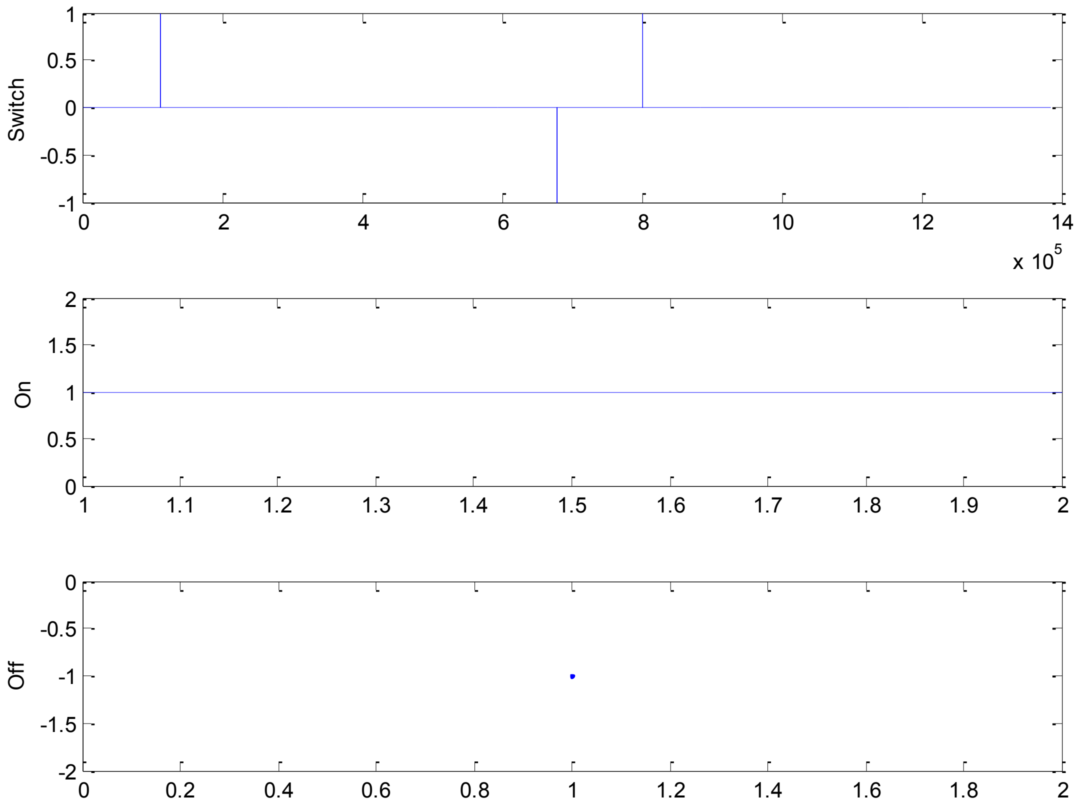




Notes:

- Off-die indicator shows off-die is when y is less than about 0.05.
- Per instruction the “cull-width” will be one die, or about 72*640 data rows either side of found “off-die” loci.
- Proper cull width can be seen around x=8e5 where the die nearest the edge is removed.

Off-wafer switch, statistics



Notes:

- This is switch engineering, tedius but required to get data.
- Subsets
  - At each “1” the data subset starts.
  - At each “-1” the data subset stops.
  - Statistics are evaluated over the subsets
- Regions
  - First is from 112518 to 678056
  - Second is from 800223 on.
- “On” and “Off”
  - These show that there are 2 on-points and 1 off point from the 1.4 million data points. This is clean parsing.
  - The first non-zero should be positive.
  - If there isn’t a clean off-die (trailing -1) then that row is culled.

Statistics

statistic	value (px)
mean	237.28
sigma	0.40606
range	1.9352
count	520477
offset	0.496
range2	0.9432
atan2(rad)	0.0014737
atan2(deg)	0.0844396

Notes

- This can be compared with the smoothed plots.
- These are computed from the average of upper and lower lanes in the street.
- Analysis
  - From slide above (Single Image Analysis) the range of the image is about 0.496.
  - The range less twice that is the range of mean locations.
  - The angle of the street over the camera image is therefore on the order of 0.1% of a radian, or 8.4% of a degree.

Smoothed Plot (theory)

Process:

- For each lane
  - Compute cumulative sum
  - Fit with smoothing spline (informed by optimal model criteria)
  - Take analytic derivative of spline
  - Sample analytic derivative at column locations
- Average the smoothed lanes
- Plot smoothed value

Rationale:

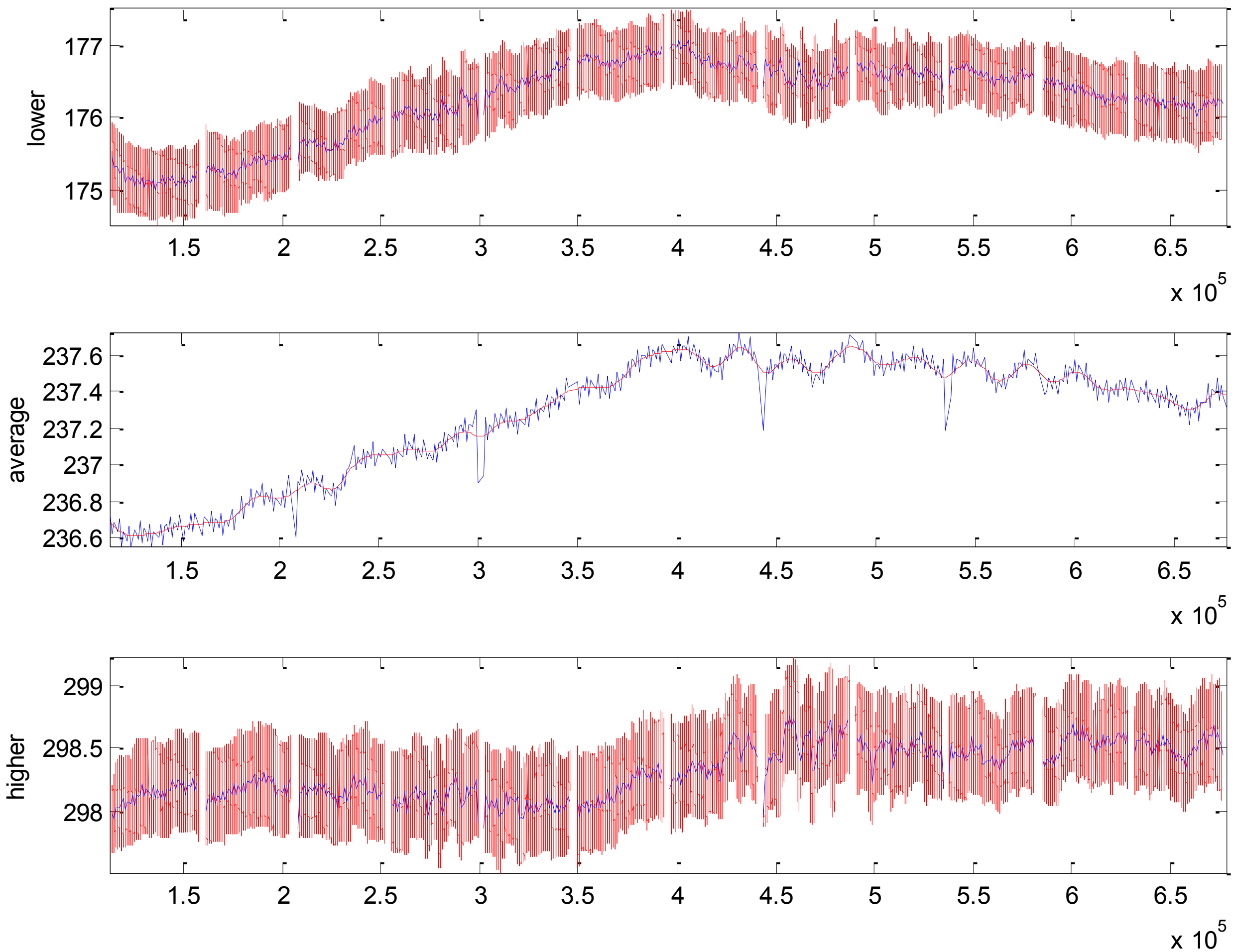
- Compute smooth first, then average means that less error is communicated to the final result. Remove errors as far upstream as possible.

Problem

- Let it run for 2 hrs on this 1.4 million point dataset and did not get the first smoothed data. It is computationally intensive.

The difference between theory and practice is that in theory they are the same and in practice they are different. -Dadi Perlmutter

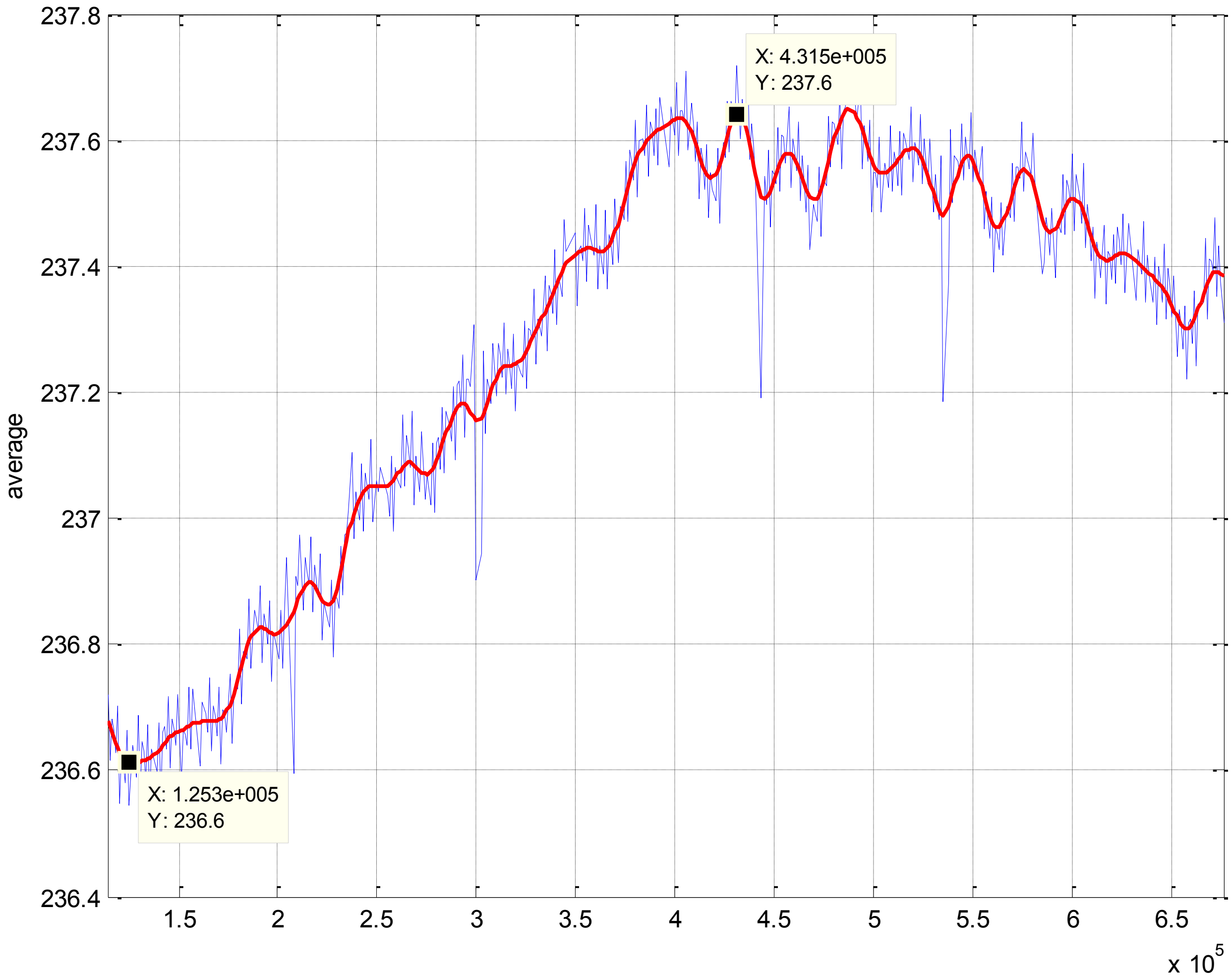
Smoothed Plot (practice)



Notes:

- Pay attention how the centerlines (local averages) track the upper and lower phenomenology of the measurements.
- Method:
  - Computed simple windowed mean, not as fancy or clean as the one that worked with (much) smaller sample sizes.
  - Smooth that sampled mean

Analysis of Smooth



Notes:

- The spline captures the signal and does not follow the noise.
- Statistics:
  - Mean = 237.27
  - Median = 237.41
  - Stdev = 0.32311
  - IQR = 0.49243
  - Range = 1.0387
  - Max = 237.65
  - Min = 236.61
- Range difference
  - From 24 = 0.9432
  - This = 1.0387
  - Relative error = 9.194%

RESULTS

- The M-file creates 2 excel spreadsheets now, one for gross/preliminary stats and one for smoothed ones. If compute time gets prohibitive then use the first one.
- The spline smoothing seriously choked with a million data-points and had to be re-engineered.
- Questions?