Title: Method for Measuring Centroid Algorithm Accuracy

Topic: Engineering

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Coauthor(s):

Time: 3:40 PM

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Abstract:

The precision with which a centroid position is measured on the X,Y axis using a CCD detector is extremely important to interferometric feedback control processes that acquire and track fringes. So it would be helpful to have a simple method for determining the accuracy of the centroid algorithm being used. This paper will describe such a method for measuring the accuracy of centroid algorithms using a relatively inexpensive setup consisting of a white light source, lenses, a CCD camera, an electro-strictive actuator, and a DAC (Digital-to-Analog Converter), and employing embedded PowerPC, VxWorks, and Solaris based software. The paper will also present some illustrative experimental results and conclusions based upon the examination of an algorithm.

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Close

Method for Measuring Centroid Algorithm Accuracy
Introduction

What's Covered in this Presentation

- Centroids and Their Importance
- Candidate Centroid Algorithms?
- Accuracy Criteria Used to Select a Centroid Algorithm

Theoretical Model

- The Selection of Weighted Averaging
  - Estimation of Algorithm Accuracy Using A Gaussian Beam Profile
  - Estimated Center of Light Centroid Error Vs True Centroid
- Initial Conclusions About Accuracy of Algorithm Selection

Experimental Verification

- Testing Centroid Accuracy : A General Description
  - The Hardware Setup
  - The Software Setup
  - The Test Procedure

Method for Measuring Centroid Algorithm Accuracy
Introduction

What's Covered in this Presentation

- Determining the Expected X,Y Centroid Position
  - Based upon Actuator Performance Graphs
  - Based Upon Caliper Measurements
  - From Derived 4th degree Polynomial Equations
- The Actual Centroid Measurements Taken
- Expected Vs.Actual Centroid Position Readings
- Findings: An Analysis
  - View of Centroid Movement in X & Y Directions
  - Some Unexpected Results
  - Centroid Accuracy Graphs : Expected Vs Actual Position
- The Limitations Of and Constraints On Methodology
- Future Improvements of the Experiment Being Considered
- Summary

Method for Measuring Centroid Algorithm Accuracy – Centroids & Their Importance –

Centroids and Pointing Spots

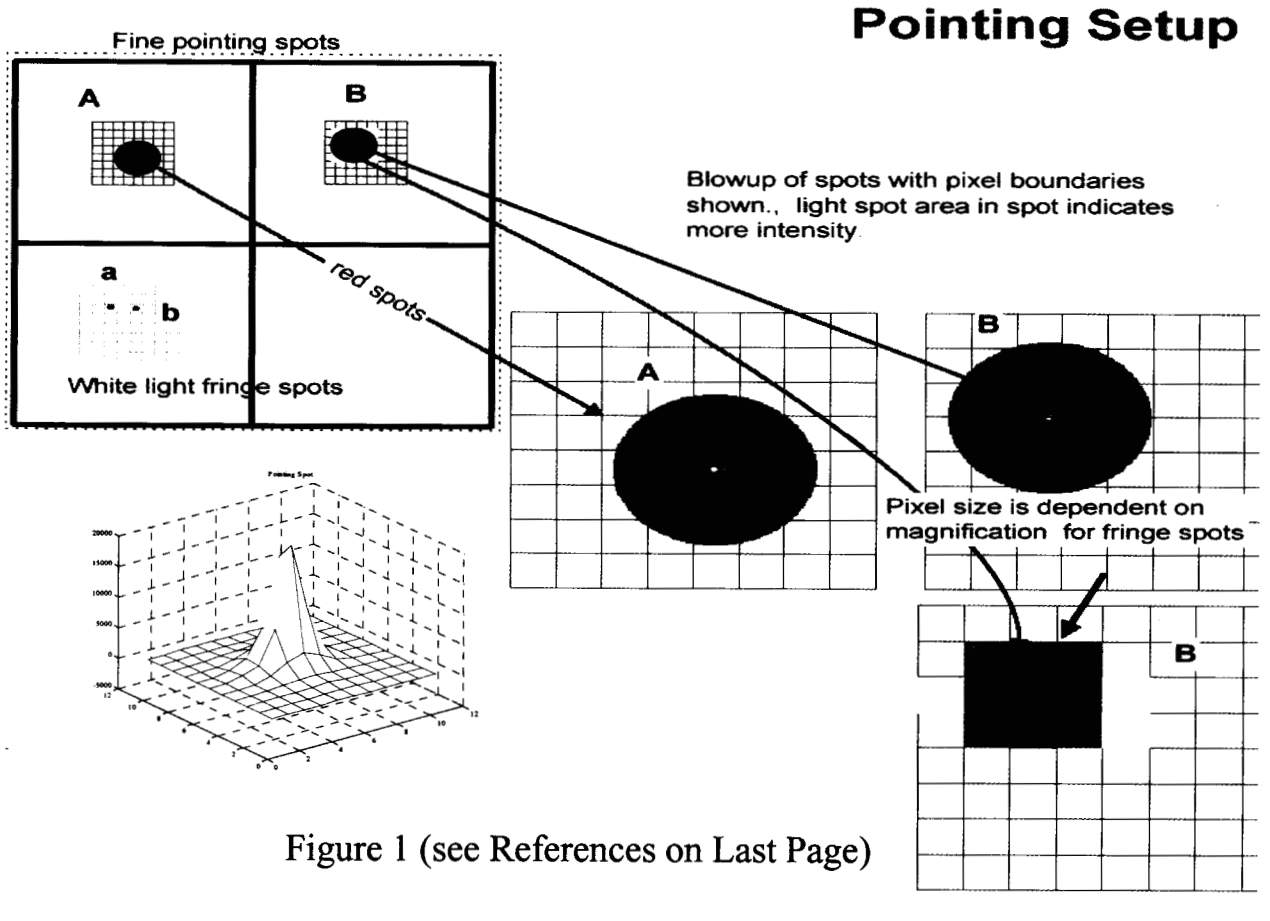


Figure 1 (see References on Last Page)

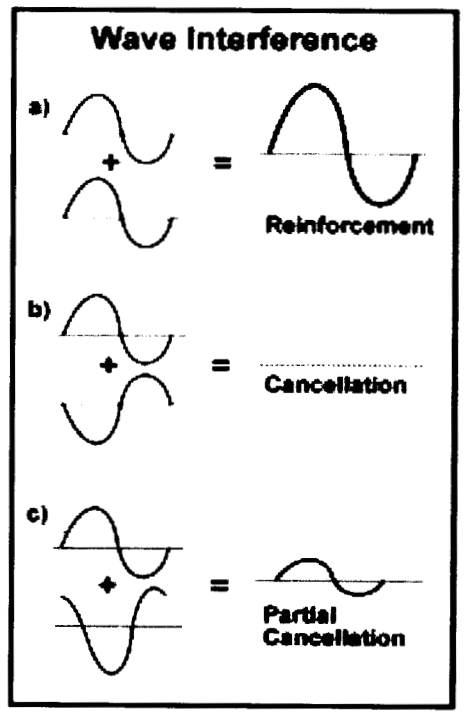
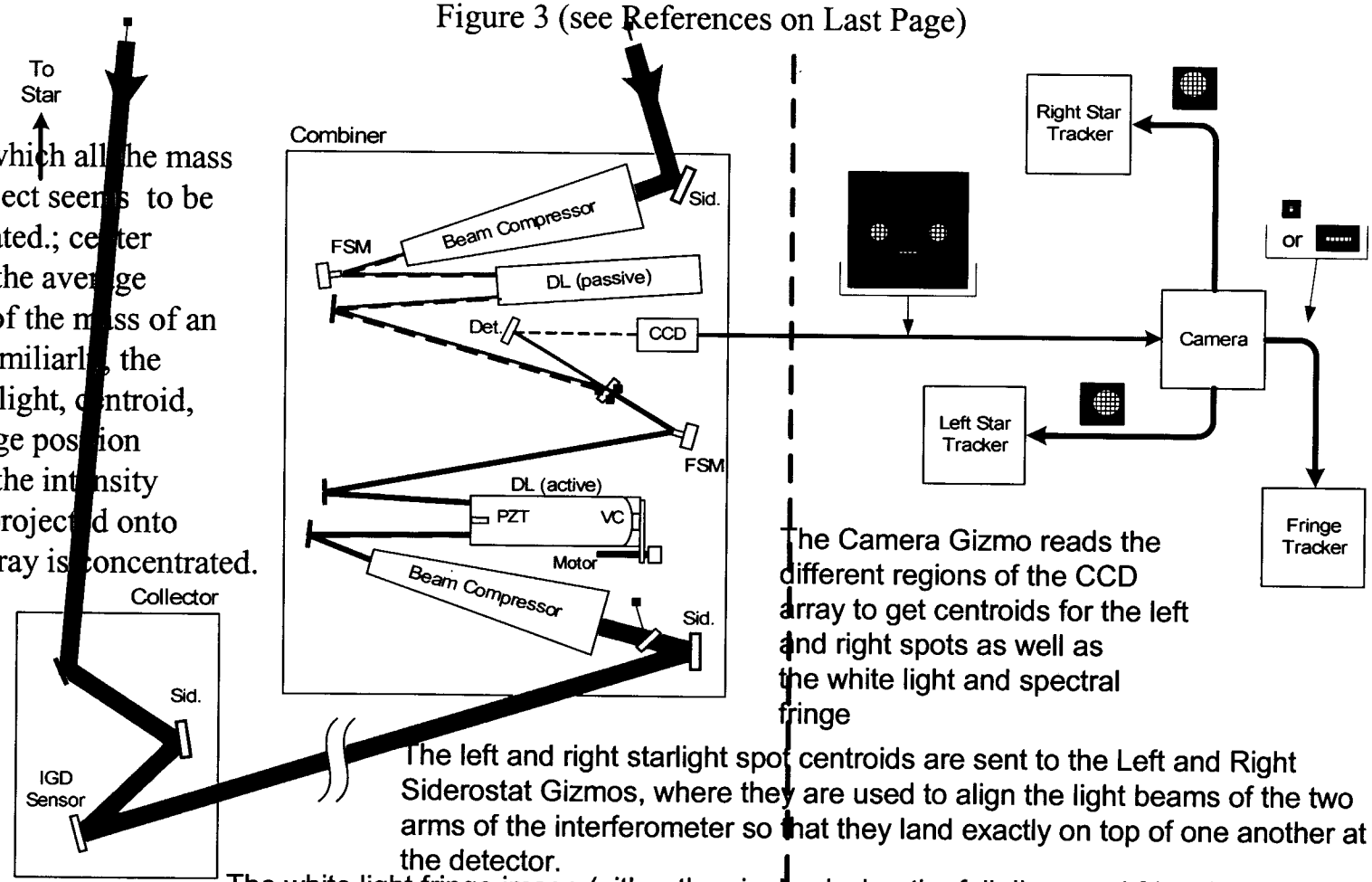


Figure 2 (see References on Last Page)

Method for Measuring Centroid Algorithm Accuracy
Centroids & Their Importance – For Interferometry

Figure 3 (see References on Last Page)



Point at which all the mass of the object seems to be concentrated.; center of mass; the average position of the mass of an object. Similiarly, the center of light, centroid, the average position at which the intensity of light projected onto a CCD array is concentrated.

The Camera Gizmo reads the different regions of the CCD array to get centroids for the left and right spots as well as the white light and spectral fringe

The left and right starlight spot centroids are sent to the Left and Right Siderostat Gizmos, where they are used to align the light beams of the two arms of the interferometer so that they land exactly on top of one another at the detector.

The white light fringe image (either the single pixel or the full dispersed fringe) is sent to the Fringe Tracker Gizmo, where it is used to determine the optical pathlength adjustment necessary in order to find the best fringe contrast.

Method for Measuring Centroid Algorithm Accuracy
Candidate Centroid Algorithms – Peak Intensity

Algorithm	Description	Strengths	Drawbacks
Peak Intensity	Find the pixel with the greatest intensity and determine it's position in the X,Y Plane	Simple to program; quick execution	Doesn't account for multiple pixels with the same peak intensity; isn't necessarily the centroid; may provide a false centroid when there is no starlight.

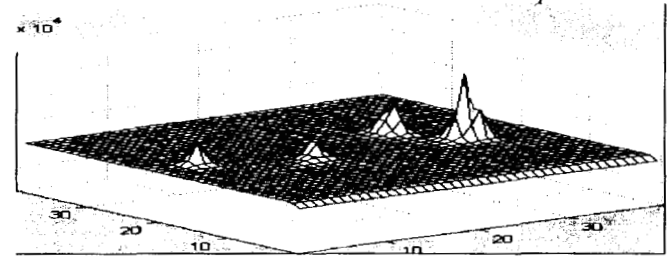


Figure 4 (see References on Last Page)

Method for Measuring Centroid Algorithm Accuracy
Candidate Centroid Algorithms – Weighted Average

Algorithm	Description	Main Strengths	Main Drawbacks
Weighted Average	Is calculated by summing the light intensity (minus average dark and read noise) in either the rows or columns, depending on which axis the centroid is being calculated for, and then forming the sum of those intensities in the remaining direction, weighted by the pixel position.	Relatively simple to program; $C_x = \frac{\sum_n x(n) \sum_m I(n,m)}{\sum_n \sum_m I(n,m)}$ $C_y = \frac{\sum_m y(m) \sum_n I(n,m)}{\sum_n \sum_m I(n,m)}$ Should be more accurate than simply finding greatest intensity (Peak Intensity Algorithm).	May be thrown off by stray light or noise; can find a false centroid when starlight not present;

Method for Measuring Centroid Algorithm Accuracy
Candidate Centroid Algorithms – QuadCells

Algorithm	Description	Main Strengths	Main Drawbacks
QuadCells	Divides subwindow where light is present into four quadrants with position (0,0) at the intersection of the quadrants; finds the sum of light intensity in each quadrant; adjusts light position until distribution of light across quadrants is such that centroid is at position (0,0)	Puts centroid at center of subwindow; and hence should be more accurate than weighted average algorithm	Can be more complex to program; can find a false centroid when starlight not present;

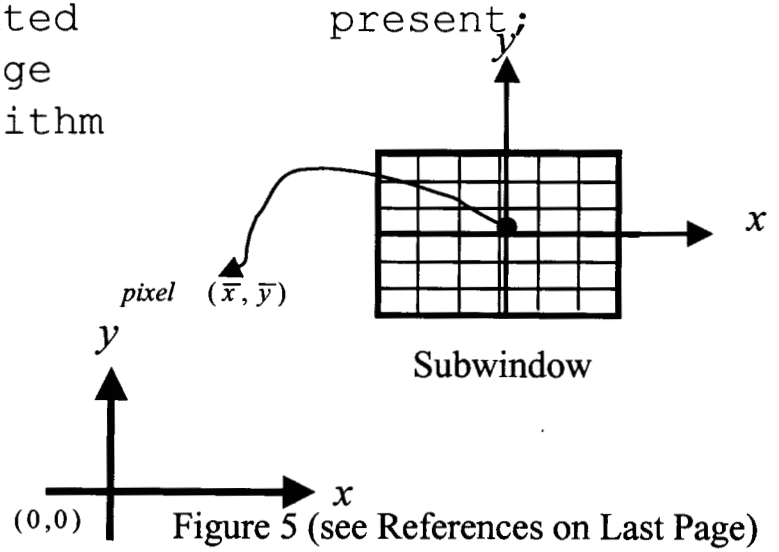


Figure 5 (see References on Last Page)

Method for Measuring Centroid Algorithm Accuracy
Accuracy Criteria Used to Select a Centroid Algorithm

Performance Requirements

- To get the 0.07 arc-second positioning, the static centroid error needs To be less than 0.018 pixels.
- 50 Hz generation rate
- Photon rate:
  8.8×10^2 e^-/pixel/frame
  to 8.8×10^4 e^-/pixel/frame

Note: During testing, estimate stray light, check effect on centroids of ghost images, glint and background light

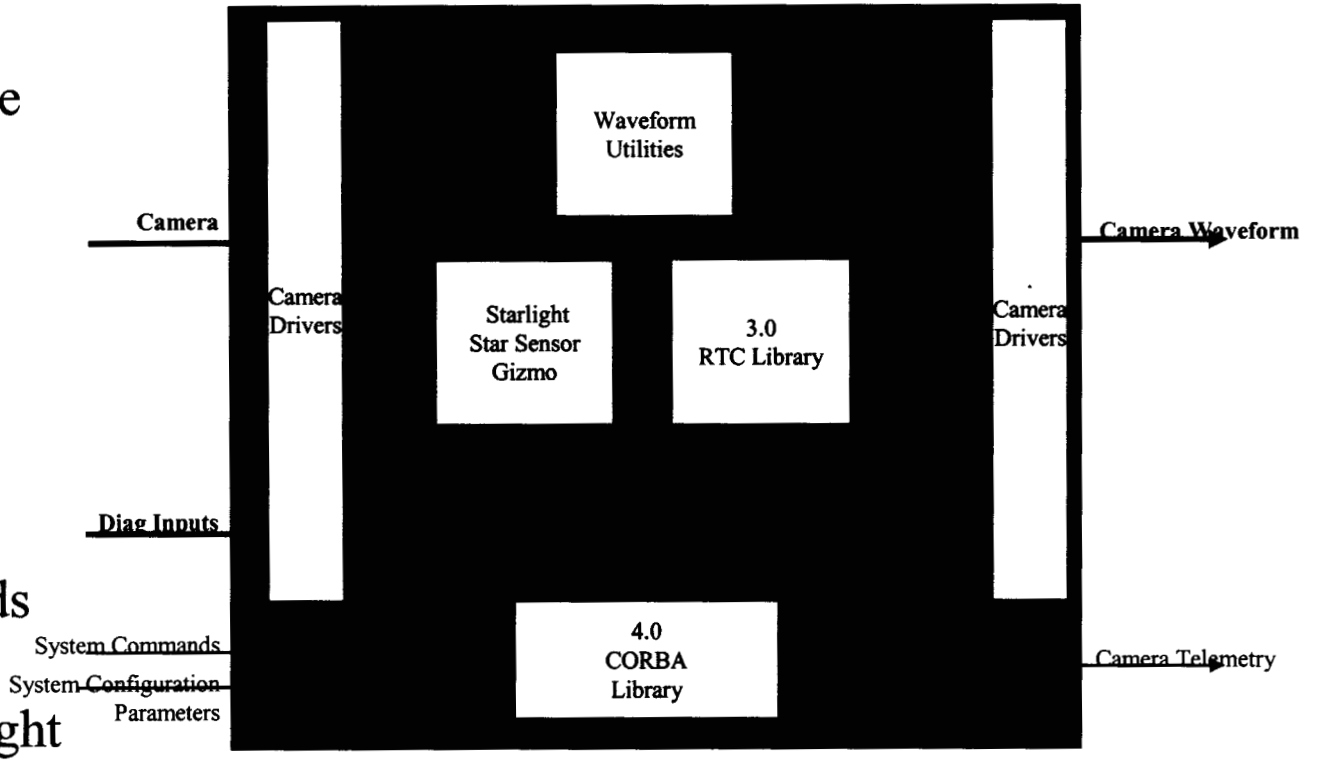


Figure 6 (see References on Last Page)

Method for Measuring Centroid Algorithm Accuracy W
Why Weighted Averaging Was Selected

Modeling with Gaussian Beam Profile suggests Weighted Average would provide Centroids that meet Performance Accuracy Requirements if Spot > 1 Pixel

$$I(x,y) = \frac{1}{2\pi \cdot w^2} e^{-\frac{1}{2}\left(\frac{x - x_0}{w}\right)^2} e^{-\frac{1}{2}\left(\frac{y - y_0}{w}\right)^2}$$

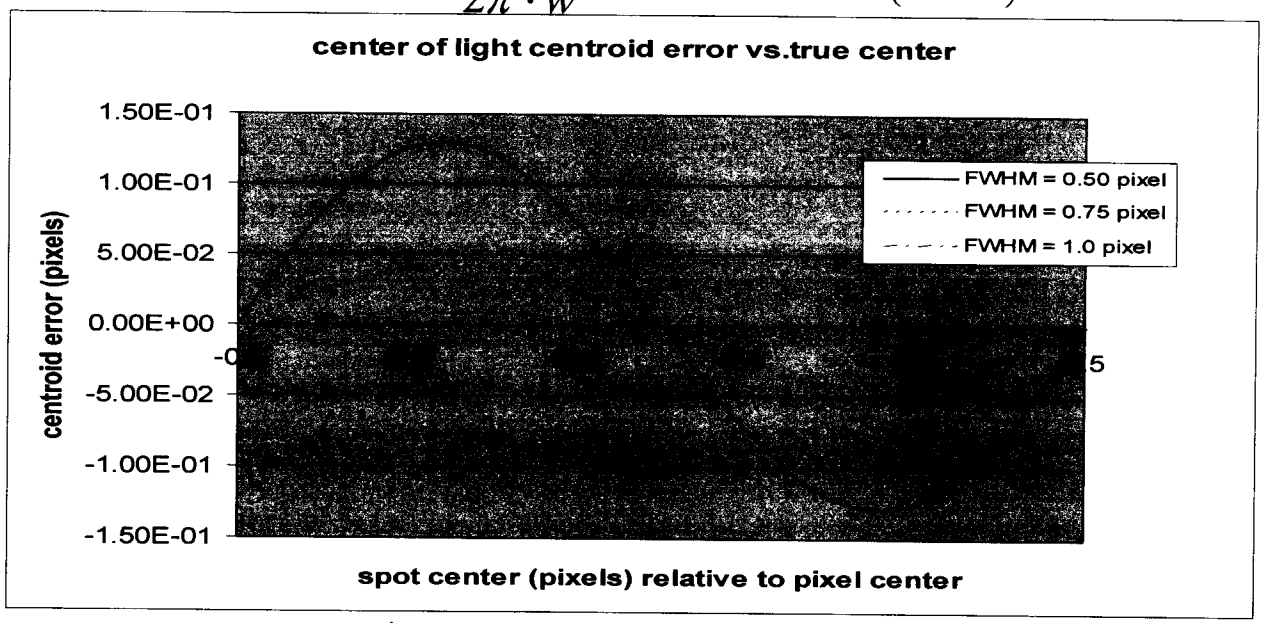


Figure 7 (Kurt Liewer, see References on Last Page)

The Figure shows the error in the estimated centroid position as a function of the true center of the image

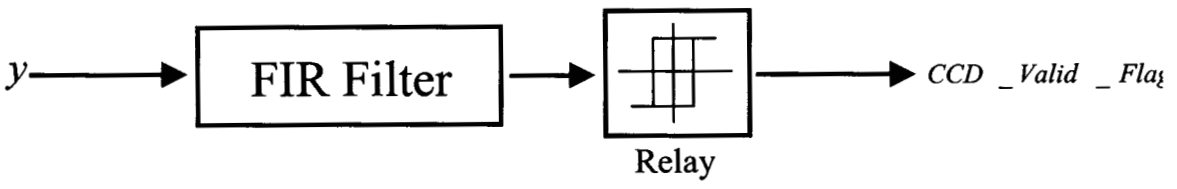
Method for Measuring Centroid Algorithm Accuracy
Why Weighted Averaging Was Selected

Weighted Average Should Find Valid Centroids If A Centroid Validity Algorithm Is Added

Suggested Algorithm Calculation

$$y = \sum_{i=1}^{7} \sum_{i=1}^{7} \left(\frac{F_{sw}(i,j) - V_{bias}}{\max(F_{sw}(i,j))} \right) \cdot F_{template}(i,j)$$

$$F_{template}(i,j) = e^{-1/2\left[\left(\frac{x_i - m_x}{\sigma_x}\right)^2 + \left(\frac{y_j - m_y}{\sigma_y}\right)^2\right]}$$



Ideal Valid Centroid

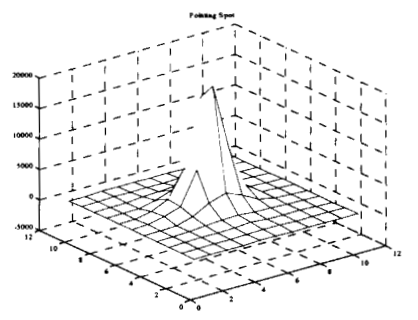


Figure 8 (Joel Shields, see References on Last Page)

Method for Measuring Centroid Algorithm Accuracy
Initial Conclusions about Accuracy of Algorithm Selected

The use of the simple 'center of light' algorithm appears to be useful in phase 1 of the Project if several different conditions are met.

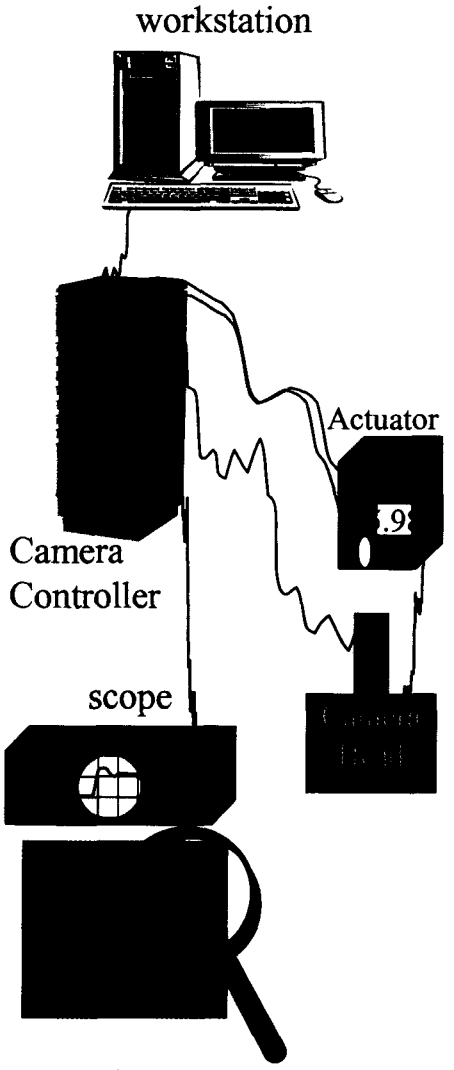
- Those conditions are:
  a) A source near the upper brightness limit is used with short integration times, or
  b) A longer (2 ms) integration time is used, or
  c) The CCD is mildly cooled to around 0° C.

The absolute accuracy of the centroid appears to good enough to allow direct positioning of the fringe spots if the pointing spots are at least a pixel in diameter.

Method for Measuring Centroid Algorithm Accuracy

Testing Centroid Accuracy:

A General Description of Test Method



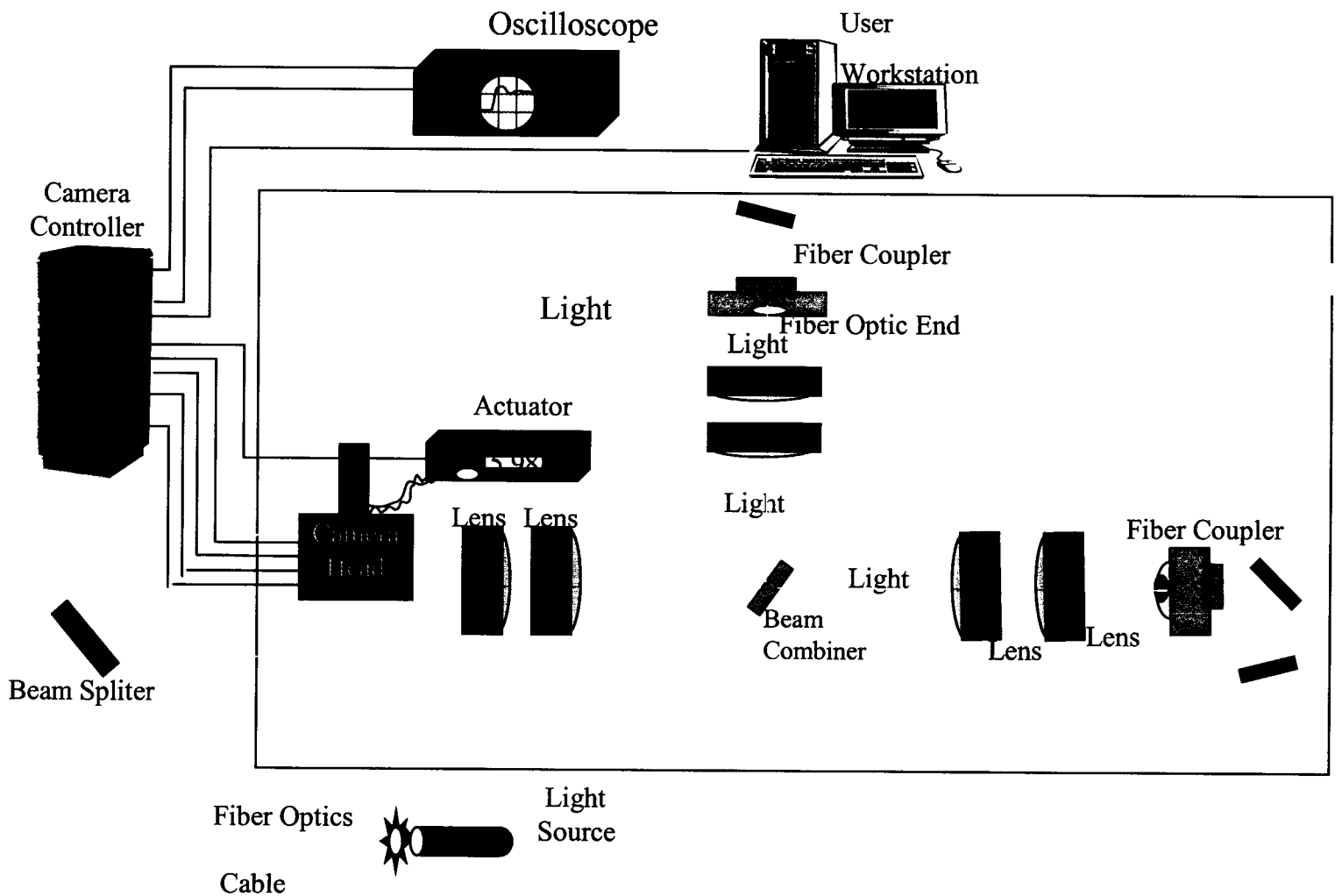
1) **Develop Test Software that will cause an actuator to move the camera head a known distance based upon amount of voltage applied; Cause the voltage fed to the actuator to change camera position at periodic (step) intervals along X then along Y Axis while a light source always remains stationary**

2) **Measure**
   - **→ the initial centroid position,**
   - **→ the expected centroid position change,**
   - **→ the actual centroid position change**

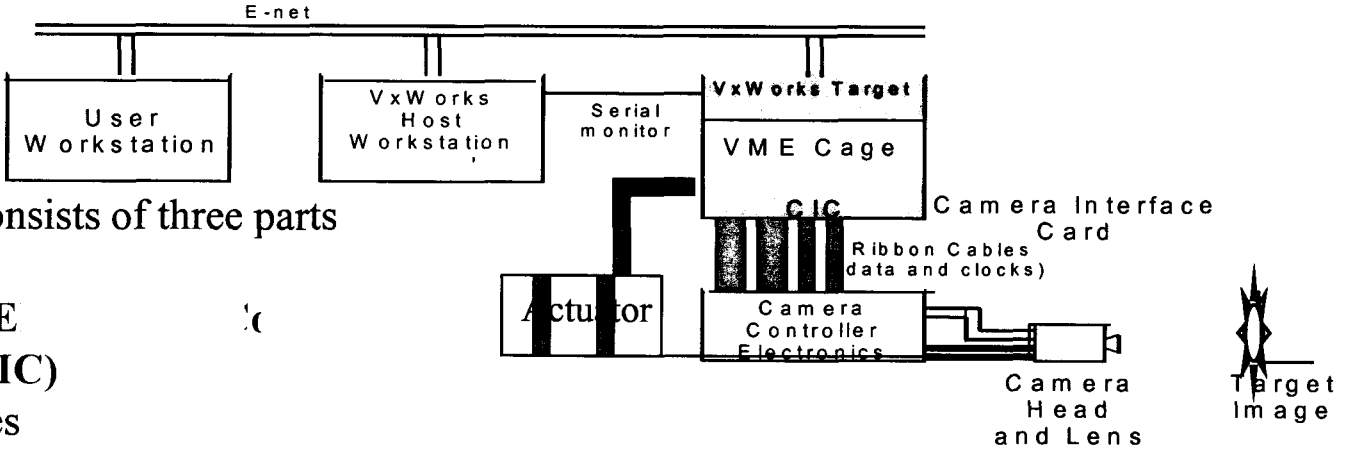
   when the camera changes position by a known amount on either x or y axis

3) **Analyze and characterize the difference between the expected and actual changes in centroid position relative to the initial position**

Method for Measuring Centroid Algorithm Accuracy
The Hardware Setup



Method for Measuring Centroid Algorithm Accuracy
The Software Setup



EEV39 CCD camera consists of three parts
- **Camera Head**
- **Camera Controller E**
- **CIC driver board (CIC)**

And four interface cables
- **A Power Supply Cable,**
- **A Clocking Cable, and**
- **Two Analog Video Cables**

The Cables connect the **CIC in VME Cage**
- to the Controller
- to a **Power PC CPU VXWorks Target**
- via a **VME bus** and
- to an external trigger **Timing Board**

The **Power** PC interfaces with a **User workstation**
Though **Serial** and **Ethernet Connections**.

The **CIC** uses **Timing Board** to reset **clocking kernels**

Operation:

Software sends voltage to **Actuator**

Actuator repositions the Camera Head

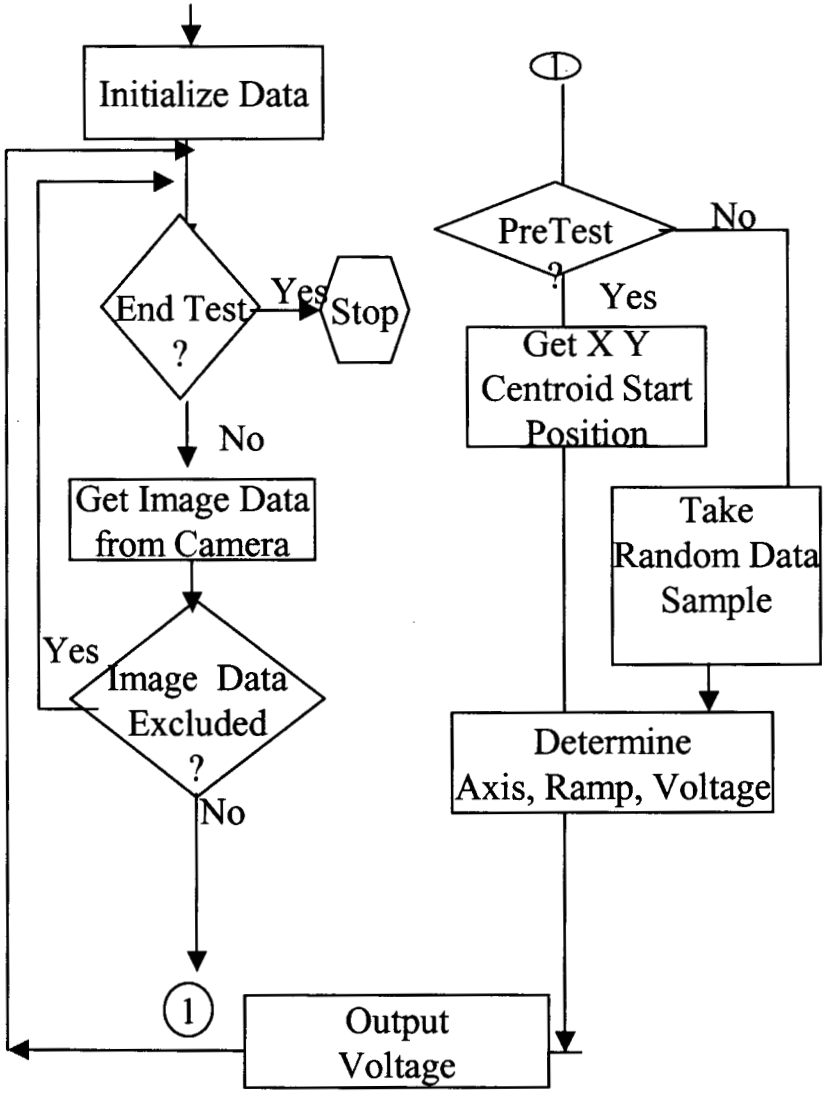
Software commands **Camera Controller**

Camera Controller sends clock signals and power to **Camera Head,**

Software receives analog video signals and telemetry

Software processes Telemetry to determine centroid

Method for Measuring Centroid Algorithm Accuracy
The Test Procedure

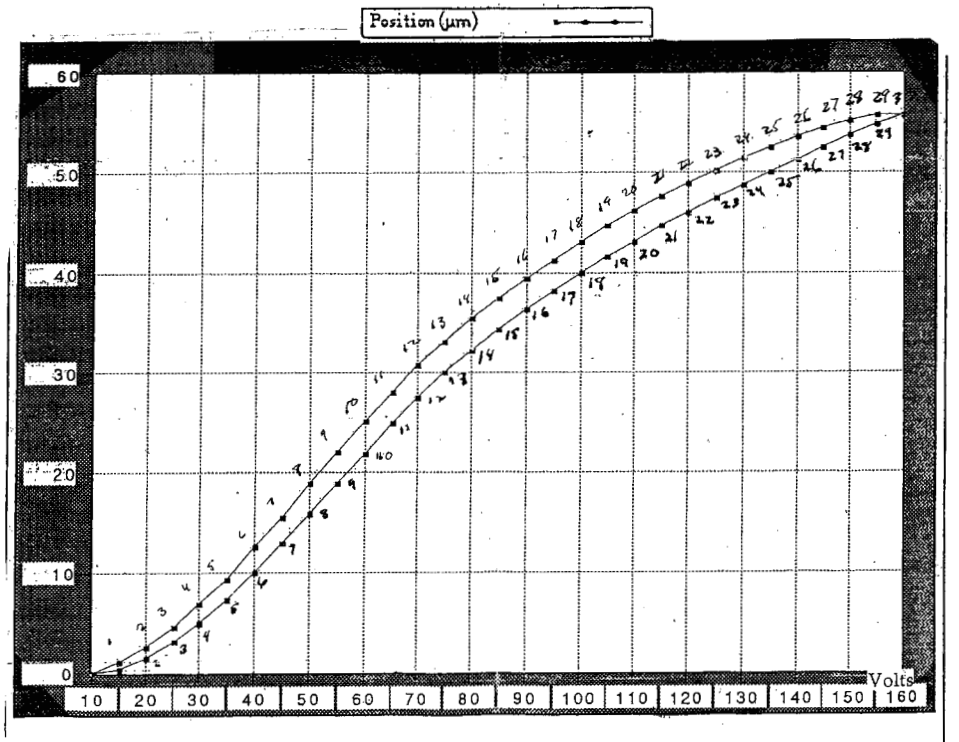


1) Initialize data
2) Check to see if End of Test (all sampling is complete)
3) If not, get image frame telemetry from camera
4) Check to see if Image Data Is Excluded (i.e. Discard the first N number of frames)
5) If the mode is Pre-Test, fetch the initial centroid position, else take random data sample
6) Determine the axis, ramp, and voltage for next output to the actuator
7) Output voltage to the actuator
8) Continue from 2) until all sampling has been completed ✓

Method for Measuring Centroid Algorithm Accuracy Determining the Expected X,Y Centroid Position

Based Upon Actuator Performance Graphs

X Axis Example



Hysteresis curve of position vs commanded voltage

The calibration graph for the Actuator Provided by Newport

Figure 9 (see References on Last Page)

Method for Measuring Centroid Algorithm Accuracy Determining the Expected X,Y Centroid Position

Based Upon Caliper Measurements & 4th Order Polynomial Fit

X Axis Ramp Up

	Serial No. 2398	Values for X Lower Line		y= 60*B4/4.412 B4 = 0.017		Given Start Point Expected PositionX	Given Start Point Expected PositionY	Given Start Point Expected PositionX Base Units	Given Start Point Expected PositionY
X Axis, Ramp Up Lower Curve	Caliper Reading Inches	Caliper Reading in Microns	X Axis Increasing Voltage	Fourth Degree Polynomial in Microns	Difference between Equations & Calipered Data	571.656	582.1752	23.819	24.2573
0			5	-1.30264674					
1	0.017	0.23118767	10	-0.2048778	0.43606547	571.4511222	582.1752	23.8104634	24.2573
2	0.089	1.210335449	15	1.316036763	-0.105701314	572.9720368	582.1752	23.8738349	24.2573
3	0.233	3.168631006	20	3.1907152	-0.022084194	574.8467152	582.1752	23.9519465	24.2573
4	0.364	4.950135993	25	5.354264063	-0.40412807	577.0102641	582.1752	24.0420943	24.2573
5	0.56	7.615593835	30	7.7462782	-0.130684365	579.4022782	582.1752	24.1417616	24.2573
6	0.753	10.24025385	35	10.31084076	-0.070586909	581.9668408	582.1752	24.2486184	24.2573
7	0.916	12.45693563	40	12.9965232	-0.53958757	584.6525232	582.1752	24.3605218	24.2573
8	1.16	15.77515866	45	15.75638526	0.018773396	587.4123853	582.1752	24.4755161	24.2573
9	1.34	18.22302811	50	18.547975	-0.324946895	590.203975	582.1752	24.5918323	24.2573
10	1.578	21.45965549	55	21.33332876	0.126326723	592.9893288	582.1752	24.7078887	24.2573
11	1.783	24.2475068	60	24.0789712	0.1685356	595.7349712	582.1752	24.8222905	24.2573
12	2	27.19854941	65	26.75591526	0.442634148	598.4119153	582.1752	24.9338298	24.2573
13	2.2	29.91840435	70	29.3396622	0.578742152	600.9956622	582.1752	25.0414859	24.2573
14	2.362	32.12148685	75	31.81020156	0.311285292	603.4662016	582.1752	25.1444251	24.2573
15	2.498	33.97098821	80	34.1520112	-0.181022986	605.8080112	582.1752	25.2420005	24.2573
16	2.677	36.40525839	85	36.35405726	0.051201124	608.0100573	582.1752	25.3337524	24.2573
17	2.78	37.80598368	90	38.4097942	-0.603810519	610.0657942	582.1752	25.4194081	24.2573
18	2.936	39.92747053	95	40.31716476	-0.389694228	611.9731648	582.1752	25.4988819	24.2573
19	3.042	41.36899365	100	42.0786	-0.709606346	613.7346	582.1752	25.572275	24.2573
20	3.176	43.19129646	105	43.70101926	-0.509722798	615.3570193	582.1752	25.6398758	24.2573
21	3.246	44.14324569	110	45.1958302	-1.052584506	616.8518302	582.1752	25.7021596	24.2573
22	3.398	46.21033545	115	46.57892876	-0.368593314	618.2349288	582.1752	25.7597887	24.2573
23	3.502	47.62466002	120	47.8706992	-0.246039182	619.5266992	582.1752	25.8136125	24.2573
24	3.603	48.99818676	125	49.09601406	-0.097827299	620.7520141	582.1752	25.8646673	24.2573
25	3.676	49.99093382	130	50.2842342	-0.293300383	621.9402342	582.1752	25.9141764	24.2573
26	3.787	51.50045331	135	51.46920876	0.031244547	623.1252088	582.1752	25.9635504	24.2573
27	3.872	52.65639166	140	52.6892752	-0.032883541	624.3452752	582.1752	26.0143865	24.2573
28	3.979	54.11151405	145	53.98725926	0.12425479	625.6432593	582.1752	26.0684691	24.2573
29	4.026	54.75067996	150	55.410475	-0.659795036	627.066475	582.1752	26.1277698	24.2573
30	4.112	55.92021759	155	57.01072476	-1.090507174	628.6667248	582.1752	26.1944469	24.2573

A caliper was used to obtain data from the actuator calibration graphs provided by Newport

Method for Measuring Centroid Algorithm Accuracy
The 4th Order Polynomial Equations

Used to Predict Centroid Position

Axis	& Ramp	Equations
X	Up	$0.00000029922V^4 - 0.00010747V^3 + 0.0115V^2 + 0.0653V - 1.9034$
X	Dwn	$0.00000026945V^4 - 0.00009864V^3 + 0.0101V^2 + 0.1702V - 2.4628$
Y	Up	$0.00000047097V^4 - 0.00016685V^3 + 0.0175V^2 + 0.0083V - 2.3234$
Y	Dwn	$0.00000033727V^4 - 0.00011449V^3 + 0.0105V^2 + 0.3196V - 2.4586$

Where V= voltage

Method for Measuring Centroid Algorithm Accuracy
Actual Centroid Measurements

Centroid X Coordinates Based upon Actuator Readings

SubWindow Start Position in Lower Left Corner: x=21 y =20 base pixel units
Starting Centroid Position (@ 0.04 Volts): x=23.819 y=24.2573 Base Pixel Units

Pt Start	X Axis in Base Pixel Units		Volts
Lower Line	Centroid Value X	Centroid Value Y	
1	23.84	24.203	10
2	23.846	24.204	15
3	23.884	24.186	20
4	23.941	24.204	25
5	24.014	24.193	30
6	24.105	24.178	35
7	24.197	24.18	40
8	24.274	24.159	45
9	24.451	24.163	50
10	24.576	24.144	55
11	24.674	24.191	60
12	24.777	24.13	65
13	24.889	24.128	70
14	24.98	24.12	75
15	25.072	24.096	80
16	25.153	24.082	85
17	25.228	24.064	90
18	25.31	24.057	95
19	25.339	24.667	100
20	25.41	24.067	105
21	25.458	24.052	110
22	25.514	24.047	115
23	25.563	24.046	120
24	25.625	24.031	125
25	25.664	24.032	130
26	25.706	24.03	135
27	25.744	24.039	140
28	25.775	24.024	145
29	25.811	24.024	150
30	25.847	24.01	155

SubWindow Start Position in Lower Left Corner:
Ending Centroid Position (@ 0.04 Volts): Not Taken

	X Axis in Base Pixel Units		
Pt Start	X Axis		Volts
Upper Curve	Centroid Value X	Centroid Value Y	
30	25.878	24.075	155
29	25.859	24.011	150
28	25.835	24.012	145
27	25.831	24.045	140
26	25.817	24.002	135
25	25.766	24.045	130
24	25.706	24.049	125
23	25.682	24.056	120
22	25.623	24.04	115
21	26.601	24.059	110
20	25.521	24.045	105
19	25.476	24.074	100
18	25.409	24.064	95
17	25.372	24.071	90
16	25.363	24.102	85
15	25.231	24.091	80
14	25.138	24.084	75
13	25.063	24.115	70
12	24.953	24.125	65
11	24.857	24.124	60
10	24.838	24.151	55
9	24.627	24.155	50
8	24.517	24.169	45
7	24.401	24.171	40
6	24.284	24.168	35
5	24.194	24.188	30
4	24.097	24.201	25
3	24.023	24.222	20
2	23.958	24.203	15
1	23.971	24.234	10

Method for Measuring Centroid Algorithm Accuracy
Expected Vs Actual Centroid Position Readings

X Axis – Voltage Ramp Up

X Axis, Ramp Up	Expected Position X in Microns	Expected Position Y in Microns	Expected Position X in Base Units	Expected Position Y In Base Units	Actual X Axis Sample Data Taken Manually in Base Units	Actual Y Axis Sample Data Taken Manually in Base Units	Difference Expected - Actual X in Base Units	Difference Expected - Actual Y in Base Units
X Axis Increasing Voltage	571.656	582.1752	23.819	24.2573	23.819	24.2573	0	0
10	571.451122	582.1752	23.81046343	24.2573	23.84	24.203	-0.02953657	0.0543
15	572.972037	582.1752	23.87383487	24.2573	23.846	24.204	0.02783487	0.0533
20	574.846715	582.1752	23.95194647	24.2573	23.884	24.186	0.06794647	0.0713
25	577.010264	582.1752	24.04209434	24.2573	23.941	24.204	0.10109434	0.0533
30	579.402278	582.1752	24.14176159	24.2573	24.014	24.193	0.12776159	0.0643
35	581.966841	582.1752	24.24861837	24.2573	24.105	24.178	0.14361837	0.0793
40	584.652523	582.1752	24.3605218	24.2573	24.197	24.18	0.1635218	0.0773
45	587.412385	582.1752	24.47551605	24.2573	24.274	24.159	0.20151605	0.0983
50	590.203975	582.1752	24.59183229	24.2573	24.451	24.163	0.14083229	0.0943
55	592.989329	582.1752	24.7078887	24.2573	24.576	24.144	0.1318887	0.1133
60	595.734971	582.1752	24.82229047	24.2573	24.674	24.191	0.14829047	0.0663
65	598.411915	582.1752	24.9338298	24.2573	24.777	24.13	0.1568298	0.1273
70	600.995662	582.1752	25.04148593	24.2573	24.889	24.128	0.15248593	0.1293
75	603.466202	582.1752	25.14442507	24.2573	24.98	24.12	0.16442507	0.1373
80	605.808011	582.1752	25.24200047	24.2573	25.072	24.096	0.17000047	0.1613
85	608.010057	582.1752	25.33375239	24.2573	25.153	24.082	0.18075239	0.1753
90	610.065794	582.1752	25.41940809	24.2573	25.228	24.064	0.19140809	0.1933
95	611.973165	582.1752	25.49888187	24.2573	25.31	24.057	0.18888187	0.2003
100	613.7346	582.1752	25.572275	24.2573	25.339	24.667	0.233275	-0.4097
105	615.357019	582.1752	25.6398758	24.2573	25.41	24.067	0.2298758	0.1903
110	616.85183	582.1752	25.70215959	24.2573	25.458	24.052	0.24415959	0.2053
115	618.234929	582.1752	25.7597887	24.2573	25.514	24.047	0.2457887	0.2103
120	619.526699	582.1752	25.81361247	24.2573	25.563	24.046	0.25061247	0.2113
125	620.752014	582.1752	25.86466725	24.2573	25.625	24.031	0.23966725	0.2263
130	621.940234	582.1752	25.91417643	24.2573	25.664	24.032	0.25017643	0.2253
135	623.125209	582.1752	25.96355037	24.2573	25.706	24.03	0.25755037	0.2273
140	624.345275	582.1752	26.01438647	24.2573	25.744	24.039	0.27038647	0.2183
145	625.643259	582.1752	26.06846914	24.2573	25.775	24.024	0.29346914	0.2333
150	627.066475	582.1752	26.12776979	24.2573	25.811	24.024	0.31676979	0.2333
155	628.666725	582.1752	26.19444687	24.2573	25.847	24.01	0.34744687	0.2473

Method for Measuring Centroid Algorithm Accuracy
Expected Vs Actual Centroid Position Readings

X Axis – Voltage Ramp Down

Volts X Increasing Voltage	Fourth Degree Polynomial	X Axis Decreasing Voltage Difference from Actual Calibered Data	Given Start Point Expected PositionX	Given Start Point Expected PositionY	Given Start Point Expected PositionX Base Units	Given Start Point Expected PositionY Base Units	Actual Data From CCD Centroid X Position	Actual Data From CCD Centroid Y Position	Difference Expected - Actual X	Difference Expected - Actual Y
			571.656	582.1752	23.819	24.2573	23.819	24.2573		
			627.5762176	582.1752	26.1490091	24.2573	25.847	24.01		
155	54.77437841	0.030698656	626.4303784	582.1752	26.1012658	24.2573	25.878	24.075	0.2232658	0.1823
150	53.8162625	0.988814563	625.4722625	582.1752	26.0613443	24.2573	25.859	24.011	0.2023443	0.2463
145	52.96287091	1.080646773	624.6188709	582.1752	26.0257863	24.2573	25.835	24.012	0.1907863	0.2453
140	52.168952	1.316995416	623.824952	582.1752	25.9927063	24.2573	25.831	24.045	0.1617063	0.2123
135	51.39329591	1.222297929	623.0492959	582.1752	25.9603873	24.2573	25.817	24.002	0.1433873	0.2553
130	50.5987345	0.983314457	622.2547345	582.1752	25.9272806	24.2573	25.766	24.045	0.1612806	0.2123
125	49.75214141	1.013951069	621.4081414	582.1752	25.8920059	24.2573	25.706	24.049	0.1860059	0.2083
120	48.824432	1.098505443	620.480432	582.1752	25.8533513	24.2573	25.682	24.056	0.1713513	0.2013
115	47.79056341	-0.383491783	619.4465634	582.1752	25.8102735	24.2573	25.623	24.04	0.1872735	0.2173
110	46.6295345	-0.24240848	618.2855345	582.1752	25.7618973	24.2573	26.601	24.059	-0.839103	0.1983
105	45.32438591	-0.188393159	616.9803859	582.1752	25.7075161	24.2573	25.521	24.045	0.1865161	0.2123
100	43.8622	-0.208528196	615.5182	582.1752	25.6465917	24.2573	25.476	24.074	0.1705917	0.1833
95	42.23410091	-0.253139891	613.8901009	582.1752	25.5787542	24.2573	25.409	24.064	0.1697542	0.1933
90	40.4352545	0.022587748	612.0912545	582.1752	25.5038023	24.2573	25.372	24.071	0.1318023	0.1863
85	38.46486841	0.102674658	610.1208684	582.1752	25.4217029	24.2573	25.363	24.102	0.0587029	0.1553
80	36.326192	0.500643902	607.982192	582.1752	25.3325913	24.2573	25.231	24.091	0.1015913	0.1663
75	34.02651641	1.018814509	605.6825164	582.1752	25.2367715	24.2573	25.138	24.084	0.0987715	0.1733
70	31.5771745	0.313124684	603.2331745	582.1752	25.1347156	24.2573	25.063	24.115	0.0717156	0.1423
65	28.99354091	1.264845313	600.6495409	582.1752	25.0270642	24.2573	24.953	24.125	0.0740642	0.1323
60	26.295032	0.590734092	597.951032	582.1752	24.9146263	24.2573	24.857	24.124	0.0576263	0.1333
55	23.50510591	0.633606696	595.1611059	582.1752	24.7983794	24.2573	24.838	24.151	-0.039621	0.1063
50	20.6512625	0.155627799	592.3072625	582.1752	24.6794693	24.2573	24.627	24.155	0.0524693	0.1023
45	17.76504341	0.009208634	589.4210434	582.1752	24.5592101	24.2573	24.517	24.169	0.0422101	0.0883
40	14.882032	-0.34440734	586.538032	582.1752	24.4390847	24.2573	24.401	24.171	0.0380847	0.0863
35	12.04185341	-0.632061928	583.6978534	582.1752	24.3207439	24.2573	24.284	24.168	0.0367439	0.0893
30	9.2881745	-0.870223457	580.9441745	582.1752	24.2060073	24.2573	24.194	24.188	0.0120073	0.0693
25	6.668703906	-0.209048421	578.3247039	582.1752	24.0968627	24.2573	24.097	24.201	-0.000137	0.0563
20	4.235192	0.225370103	575.891192	582.1752	23.9954663	24.2573	24.023	24.222	-0.027534	0.0353
15	2.043430906	0.295644343	573.6994309	582.1752	23.904143	24.2573	23.958	24.203	-0.053857	0.0543
10	0.1532545	0.322720115	571.8092545	582.1752	23.8253856	24.2573	23.971	24.234	-0.145614	0.0233

Method for Measuring Centroid Algorithm Accuracy Findings :View of Centroid Movement in X Direction - Voltage Ramp Up

Original Position

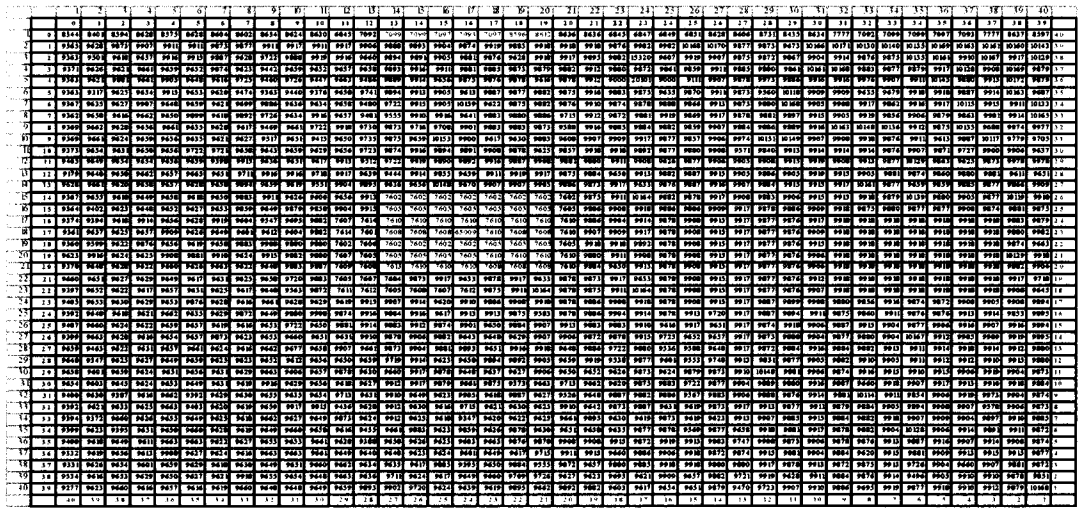
		12	13	14	15	16	17	18	19	20	21	22	23
		11	12	13	14	15	16	17	18	19	19	20	21
		7099	7099	7099	7099	7097	7093	7097	8596	8612	7099	7099	7097
14	13	9913	9512	9722	9919	9890	9892	9916	9887	9908	9881	9880	29
13	12	9917	9639	9444	9914	9855	9659	9911	9919	9917	9875	9884	28
14	13	9904	9895	9636	9656	10148	9670	9907	9907	9905	9886	9873	27
15	14	9656	9913	7602	7602	7602	7602	7602	7602	7602	7602	9875	26
16	15	9904	9915	7605	7605	7605	7605	7605	7605	7605	7605	9886	25
17	16	7607	7614	7610	7610	7610	7610	7610	7610	7610	7610	9886	24
18	17	7614	7601	7608	7608	7608	65009	7610	7608	7608	7610	9907	23
19	18	7602	7606	7602	7602	7602	7602	7605	7605	7605	7605	9918	22
20	19	7607	7605	7605	7605	7605	7605	7610	7610	7610	7610	9880	21
21	20	7609	7608	7613	7610	7610	7610	7608	7608	7608	7610	9884	20
		29	28	27	26	25	24	23	22	21	20	19	

Movement of the Centroid on X axis was in the expected direction based upon Newport Tests of actuator behavior

Movement when Actuator Voltage is Incremented

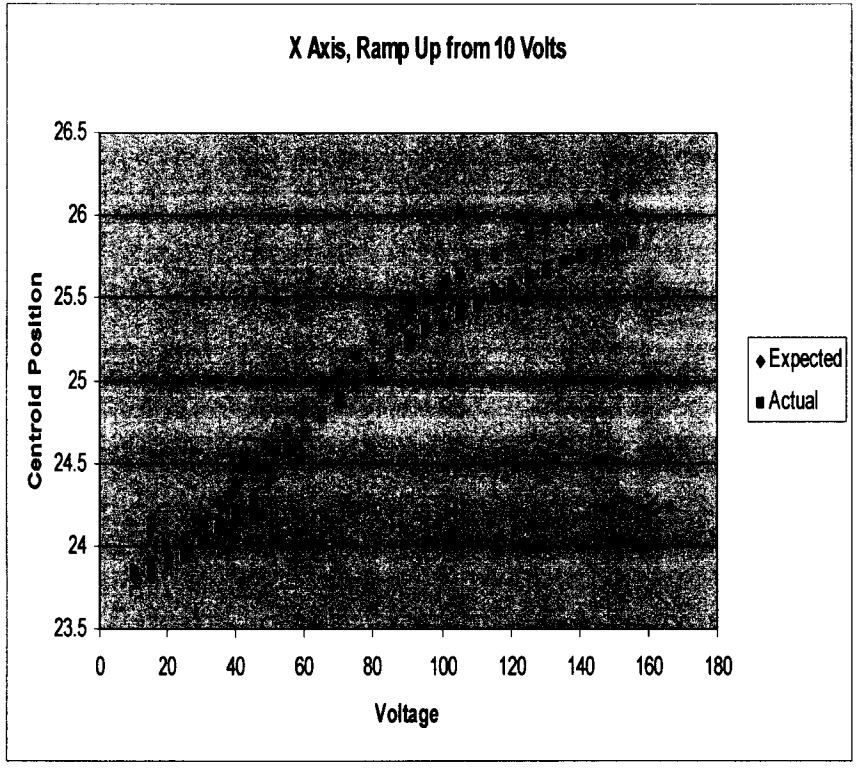
		12	13	14	15	16	17	18	19	20	21	22	23
		11	12	13	14	15	16	17	18	19	19	20	21
		7099	7099	7099	7099	7097	7093	7097	8596	8612	7099	7099	7097
14	13	9913	9512	9722	9919	9890	9892	9916	9887	9908	9881	9880	29
13	12	9917	9639	9444	9914	9855	9659	9911	9919	9917	9875	9884	28
14	13	9904	9895	9636	9656	10148	9670	9907	9907	9905	9886	9873	27
15	14	9656	9913	7602	7602	7602	7602	7602	7602	7602	7602	9875	26
16	15	9904	9915	7605	7605	7605	65009	7605	7605	7605	7605	9886	25
17	16	7607	7614	7610	7610	7610	7610	7610	7610	7610	7610	9886	24
18	17	7614	7601	7608	7608	7608	7608	7610	7608	7608	7610	9907	23
19	18	7602	7606	7602	7602	7602	7602	7605	7605	7605	7605	9918	22
20	19	7607	7605	7605	7605	7605	7605	7610	7610	7610	7610	9880	21
21	20	7609	7608	7613	7610	7610	7610	7608	7608	7608	7610	9884	20
		29	28	27	26	25	24	23	22	21	20	19	

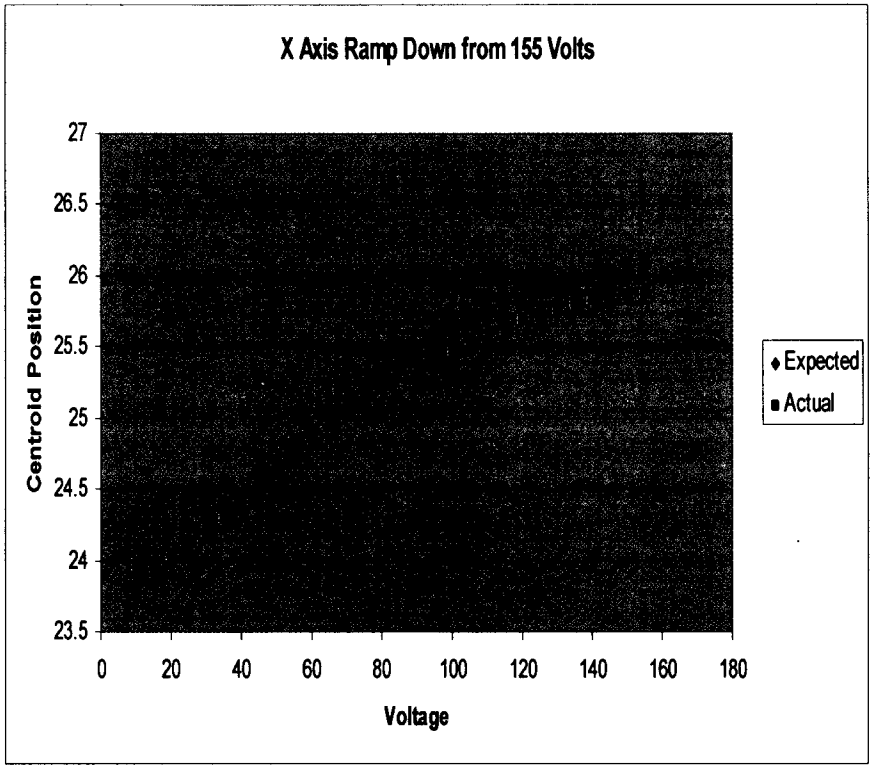
Starting Centroid Position (@ 0.04 Volts): x=23.819 y=24.2573 Base Pixel Units, CCD Coordinates



Method for Measuring Centroid Algorithm Accuracy Findings: Centroid Accuracy Graph

Expected Vs Actual Results X Direction





Method for Measuring Centroid Algorithm Accuracy
Actual Centroid Measurements

Based upon Actuator Readings Y Axis

Starting Centroid Position (@ 0.04 Volts): x=23.819 y=24.2573 Base Pixel Units
Starting Centroid Position (@ 0.04 Volts):

Pt Start	Y Axis		Volts
LowerLine	Centroid Value X	Centroid Value Y	
1	23.663	24.239	10
2	23.664	24.231	15
3	23.658	24.171	20
4	23.669	24.112	25
5	23.651	24.048	30
6	23.665	23.927	35
7	23.667	23.768	40
8	23.666	23.679	45
9	23.674	23.554	50
10	23.654	23.419	55
11	23.649	23.339	60
12	23.646	23.266	65
13	23.636	23.115	70
14	23.638	22.984	75
15	23.644	22.851	80
16	23.632	22.815	85
17	23.638	22.729	90
18	23.622	22.694	95
19	23.632	22.576	100
20	23.627	22.506	105
21	23.627	22.45	110
22	23.629	22.374	115
23	23.629	22.314	120
24	23.627	22.291	125
25	23.623	22.266	130
26	23.623	22.215	135
27	23.626	22.119	140
28	23.62	22.077	145
29	23.621	22.063	150
30	23.624	22.053	155

Starting Centroid Position (@ 0.04 Volts): x=23.819 y=24.2573 Base Pixel Units
Ending Centroid Position (@ 0.04 Volts): 23.62 24.18

Pt Start	Y Axis		Volts
Upperline	Centroid Value X	Centroid Value Y	
30	23.622	21.998	155
29	23.609	22.015	150
28	23.614	22.038	145
27	23.62	22.073	140
26	23.613	22.092	135
25	23.612	22.121	130
24	23.602	22.161	125
23	23.601	22.202	120
22	23.603	22.255	115
21	23.605	22.302	110
20	23.602	22.346	105
19	23.591	22.407	100
18	23.592	22.47	95
17	23.576	22.541	90
16	23.591	22.609	85
15	23.585	22.7	80
14	23.581	22.768	75
13	23.588	22.878	70
12	23.586	22.974	65
11	23.582	23.077	60
10	23.583	23.249	55
9	23.605	23.349	50
8	23.607	23.488	45
7	23.616	23.636	40
6	23.613	23.747	35
5	23.618	23.059	30
4	23.626	23.95	25
3	23.617	24.041	20
2	23.623	24.093	15
1	23.62	24.151	10

Method for Measuring Centroid Algorithm Accuracy Expected Vs Actual Centroid Position Readings

in Y Direction – Voltage Ramp Up

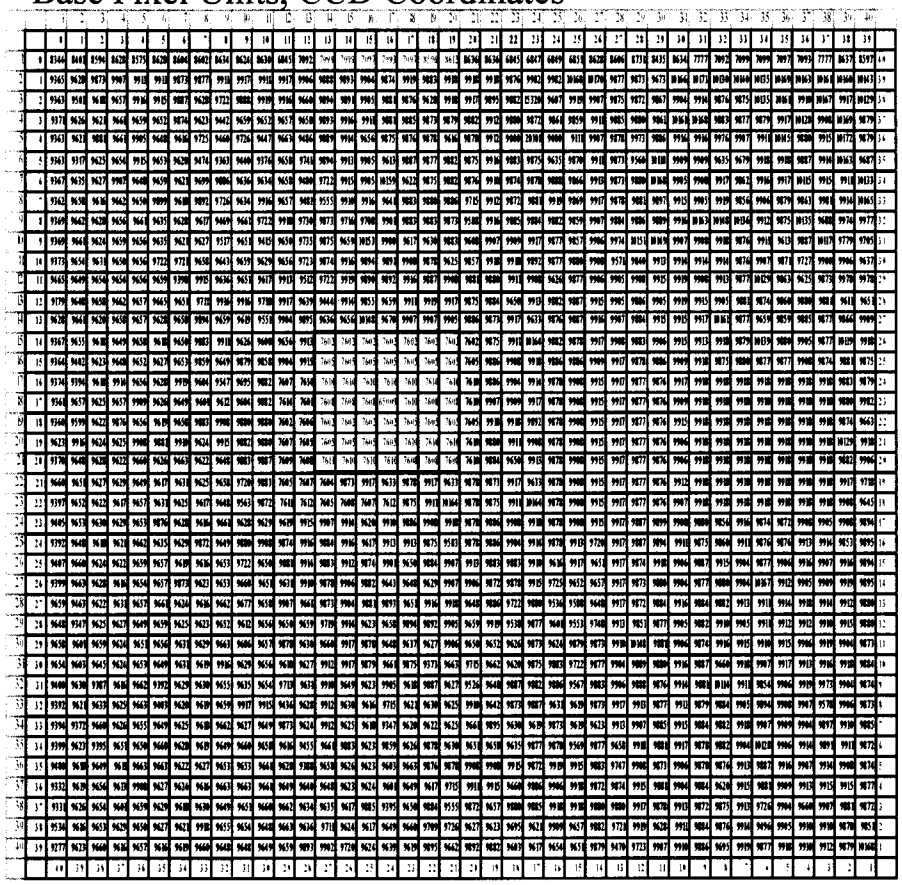
Y Axis, Ramp Up	Corrected Expected Position X in Microns	Corrected Expected Position Y in Microns	Corrected Expected Position X in Base	Corrected Expected Position Y In Base	Actual X Axis Sample Data	Actual Y Axis Sample Data	Difference Expected - Actual X in Base	Difference Expected - Actual Y in Base
Y Axis Increasing Voltage	575.304	581.616	23.971	24.234	23.971	24.234	0	0
10	575.304	581.355	23.971	24.22311	23.663	24.239	0.308	-0.01589
15	575.304	583.123	23.971	24.29677	23.664	24.231	0.307	0.065772
20	575.304	585.422	23.971	24.3926	23.658	24.171	0.313	0.221598
25	575.304	588.154	23.971	24.50641	23.669	24.112	0.302	0.394406
30	575.304	591.223	23.971	24.63431	23.651	24.048	0.32	0.586306
35	575.304	594.545	23.971	24.7727	23.665	23.927	0.306	0.845702
40	575.304	598.039	23.971	24.9183	23.667	23.768	0.304	1.150295
45	575.304	601.634	23.971	25.06808	23.666	23.679	0.305	1.389078
50	575.304	605.264	23.971	25.21934	23.674	23.554	0.297	1.665338
55	575.304	608.872	23.971	25.36966	23.654	23.419	0.317	1.950658
60	575.304	612.406	23.971	25.51692	23.649	23.339	0.322	2.177915
65	575.304	615.823	23.971	25.65928	23.646	23.266	0.325	2.39328
70	575.304	619.085	23.971	25.79522	23.636	23.115	0.335	2.680218
75	575.304	622.164	23.971	25.92349	23.638	22.984	0.333	2.939489
80	575.304	625.036	23.971	26.04315	23.644	22.851	0.327	3.192147
85	575.304	627.685	23.971	26.15354	23.632	22.815	0.339	3.338541
90	575.304	630.103	23.971	26.25431	23.638	22.729	0.333	3.525312
95	575.304	632.29	23.971	26.3454	23.622	22.694	0.349	3.651399
100	575.304	634.249	23.971	26.42703	23.632	22.576	0.339	3.851033
105	575.304	635.994	23.971	26.49974	23.627	22.506	0.344	3.99374
110	575.304	637.544	23.971	26.56434	23.627	22.45	0.344	4.11434
115	575.304	638.927	23.971	26.62195	23.629	22.374	0.342	4.247948
120	575.304	640.175	23.971	26.67397	23.629	22.314	0.342	4.359972
125	575.304	641.331	23.971	26.72212	23.627	22.291	0.344	4.431117
130	575.304	642.441	23.971	26.76838	23.623	22.266	0.348	4.502379
135	575.304	643.561	23.971	26.81505	23.623	22.215	0.348	4.60005
140	575.304	644.753	23.971	26.86472	23.626	22.119	0.345	4.745718
145	575.304	646.086	23.971	26.92026	23.62	22.077	0.351	4.843263
150	575.304	647.637	23.971	26.98486	23.621	22.063	0.35	4.921859
155	575.304	649.487	23.971	27.06198	23.624	22.053	0.347	5.008976

Method for Measuring Centroid Algorithm Accuracy
Some Unexpected Results

Y Direction – Voltage Ramp Up

Starting Centroid Position (@ 0.04 Volts): x=23.819 y=24.2573

Base Pixel Units, CCD Coordinates



Original Position

		14	15	16	17	18	19	20	21	22	23	24
		13	14	15	16	17	18	19	20	21	22	23
		7092	7099	7099	7097	7093	7097	8596	8612	8636	8636	6845
15	14	7602	7602	7602	7602	7602	7602	7602	7602	9875	9911	26
16	15	7605	7605	7605	7605	7605	7605	7605	7605	9886	9908	25
17	16	7610	7610	7610	7610	7610	7610	7610	7610	9886	9904	24
18	17	7608	7608	7608	65009	7610	7608	7608	7610	9907	9909	23
19	18	7602	7602	7602	7602	7605	7605	7605	7605	9918	9918	22
20	19	7605	7605	7605	7605	7610	7610	7610	7610	9880	9911	21
21	20	7613	7610	7610	7610	7608	7608	7608	7610	9884	9650	20
		27	26	25	24	23	22	21	20	19	18	

Position After Incrementing Actuator Voltage

		14	15	16	17	18	19	20	21	22	23	24	
		13	14	15	16	17	18	19	20	21	22	23	
		7092	7099	7099	7097	7093	7097	8596	8612	8636	8636	6845	
	12	9444	9914	9855	9659	9911	9919	9917	9875	9884	9650	9913	28
	13	9636	9656	10148	9670	9907	9907	9905	9886	9873	9917	9633	27
15	14	7602	7602	7602	7602	7602	7602	7602	7602	9875	9911	10164	26
16	15	7605	7605	7605	7605	7605	7605	7605	7605	9886	9908	9918	25
17	16	7610	7610	7610	7610	7610	7610	7610	7610	9886	9904	9914	24
18	17	7608	7608	7608	7610	7610	65009	7608	7608	9907	9909	9917	23
19	18	7602	7602	7602	7602	7602	7605	7605	7605	9918	9918	9892	22
20	19	7605	7605	7605	7605	7605	7610	7610	7610	9880	9911	9908	21
21	20	7613	7613	7610	7610	7610	7608	7608	7608	9884	9650	9913	20
		7604	9873	9917	9633	9878	9917	9633	9878	9873	9917	9633	
			27	26	25	24	23	22	21	20	19	18	

Centroid movement in Y direction was in the opposite direction → Seen here

From what was expected based upon Newport tests of actuator behavior

Method for Measuring Centroid Algorithm Accuracy Expected Vs Actual Centroid Position in Y Direction

After Correction – Ramp Up

After correcting the expected results to take into account the actual direction the centroid is pushed (by changing a + to – in calculation for voltage ramp up) , these results are gotten

Fourth Degree Polynomial, Ramp Up Y Axis	Given Start Point Expected PositionX	Given Start Point Corrected Expected PositionY	Given Start Point Corrected Expected PositionX Base Units	Given Start Point Expected PositionY Base Units	Actual Data From CCD Centroid X Position	Actual Data From CCD Centroid Y Position	Difference Expected - Actual X	Difference Expected - Actual Y
	572.132	582.1752	23.838832	24.2573	23.663	24.239	0.17583	0.0183
-0.8205403	572.132	582.9957	23.838832	24.29149	23.663	24.239	0.17583	0.05249
0.947324106	572.132	581.2279	23.838832	24.21783	23.664	24.231	0.17483	-0.0132
3.2471552	572.132	578.928	23.838832	24.122	23.658	24.171	0.18083	-0.049
5.978541406	572.132	576.1967	23.838832	24.00819	23.669	24.112	0.16983	-0.1038
9.0481357	572.132	573.1271	23.838832	23.88029	23.651	24.048	0.18783	-0.1677
12.36965561	572.132	569.8055	23.838832	23.7419	23.665	23.927	0.17383	-0.1851
15.8638832	572.132	566.3113	23.838832	23.5963	23.667	23.768	0.17183	-0.1717
19.45866511	572.132	562.7165	23.838832	23.44652	23.666	23.679	0.17283	-0.2325
23.0889125	572.132	559.0863	23.838832	23.29526	23.674	23.554	0.16483	-0.2587
26.69660111	572.132	555.4786	23.838832	23.14494	23.654	23.419	0.18483	-0.2741
30.2307712	572.132	551.9444	23.838832	22.99768	23.649	23.339	0.18983	-0.3413
33.64752761	572.132	548.5277	23.838832	22.85532	23.646	23.266	0.19283	-0.4107
36.9100397	572.132	545.2652	23.838832	22.71938	23.636	23.115	0.20283	-0.3956
39.98854141	572.132	542.1867	23.838832	22.59111	23.638	22.984	0.20083	-0.3929
42.8603312	572.132	539.3149	23.838832	22.47145	23.644	22.851	0.19483	-0.3795
45.50977211	572.132	536.6654	23.838832	22.36106	23.632	22.815	0.20683	-0.4539
47.9282917	572.132	534.2469	23.838832	22.26029	23.638	22.729	0.20083	-0.4687
50.11438211	572.132	532.0608	23.838832	22.1692	23.622	22.694	0.21683	-0.5248
52.0736	572.132	530.1016	23.838832	22.08757	23.632	22.576	0.20683	-0.4884
53.81856661	572.132	528.3566	23.838832	22.01486	23.627	22.506	0.21183	-0.4911
55.3689677	572.132	526.8062	23.838832	21.95026	23.627	22.45	0.21183	-0.4997
56.75155361	572.132	525.4236	23.838832	21.89265	23.629	22.374	0.20983	-0.4813
58.0001392	572.132	524.1751	23.838832	21.84063	23.629	22.314	0.20983	-0.4734
59.15560391	572.132	523.0196	23.838832	21.79248	23.627	22.291	0.21183	-0.4985
60.2658917	572.132	521.9093	23.838832	21.74622	23.623	22.266	0.21583	-0.5198
61.38601111	572.132	520.7892	23.838832	21.69955	23.623	22.215	0.21583	-0.5155
62.5780352	572.132	519.5972	23.838832	21.64988	23.626	22.119	0.21283	-0.4691
63.91110161	572.132	518.2641	23.838832	21.59434	23.62	22.077	0.21883	-0.4827
65.4614125	572.132	516.7138	23.838832	21.52974	23.621	22.063	0.21783	-0.5333
67.31223461	572.132	514.863	23.838832	21.45262	23.624	22.053	0.21483	-0.6004

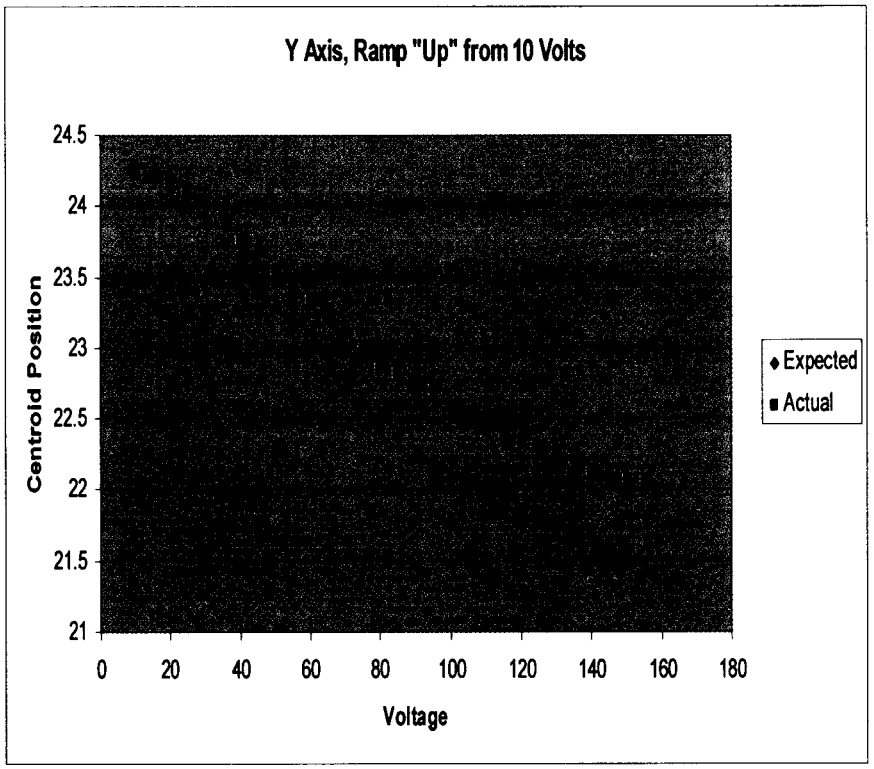
Method for Measuring Centroid Algorithm Accuracy Expected Vs Actual Centroid Position in Y Direction

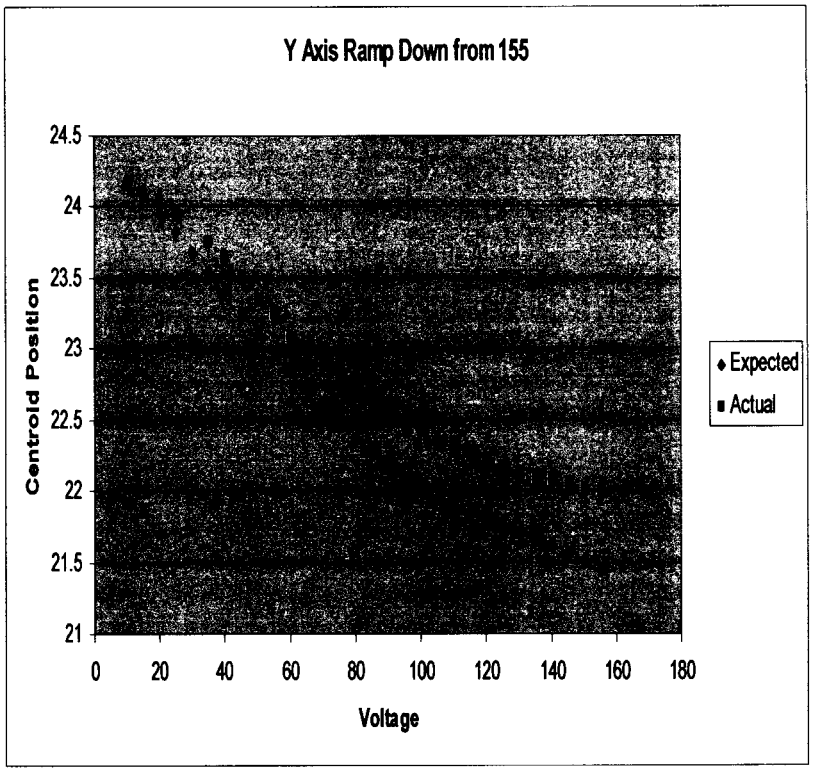
After Correction – Y Axis Ramp Down

After correcting the expected results to take into account the actual direction the centroid is pushed (by changing a + to – in calculation for voltage ramp down) , these results are gotten

Fourth Degree Polynomial, Ramp Down Y Axis	Given Start Point Expected PositionX	Given Start Point Corrected Expected PositionY	Given Start Point Corrected Expected PositionX Base Units	Given Start Point Expected PositionY Base Units	Actual Data From CCD Centroid X Position	Actual Data From CCD Centroid Y Position	Difference Expected - Actual X	Difference Expected - Actual Y	
	572.132	582.1752	23.838832	24.2573	23.663	24.239	0.17583		Original Start Position <==
	572.132	649.4874	23.838832	27.06198	23.624	22.053	0.21483		New Start Position <==
67.66790604	572.132	514.5073	23.838832	21.4378	23.622	21.998	0.21683	-0.5602	
66.0705875	572.132	516.1046	23.838832	21.50436	23.609	22.015	0.22983	-0.51064	
64.69923804	572.132	517.476	23.838832	21.5615	23.614	22.038	0.22483	-0.4765	
63.4904832	572.132	518.6847	23.838832	21.61186	23.62	22.073	0.21883	-0.46114	
62.38600754	572.132	519.7892	23.838832	21.65788	23.613	22.092	0.22583	-0.43412	
61.3325547	572.132	520.8426	23.838832	21.70178	23.612	22.121	0.22683	-0.41922	
60.28192734	572.132	521.8933	23.838832	21.74555	23.602	22.161	0.23683	-0.41545	
59.1909872	572.132	522.9842	23.838832	21.79101	23.601	22.202	0.23783	-0.41099	
58.02165504	572.132	524.1535	23.838832	21.83973	23.603	22.255	0.23583	-0.41527	
56.7409107	572.132	525.4343	23.838832	21.8931	23.605	22.302	0.23383	-0.4089	
55.32079304	572.132	526.8544	23.838832	21.95227	23.602	22.346	0.23683	-0.39373	
53.7384	572.132	528.4368	23.838832	22.0182	23.591	22.407	0.24783	-0.3888	
51.97588854	572.132	530.1993	23.838832	22.09164	23.592	22.47	0.24683	-0.37836	
50.0204747	572.132	532.1547	23.838832	22.17311	23.576	22.541	0.26283	-0.36789	
47.86443354	572.132	534.3108	23.838832	22.26295	23.591	22.609	0.24783	-0.34605	
45.5050992	572.132	536.6701	23.838832	22.36125	23.585	22.7	0.25383	-0.33875	
42.94486484	572.132	539.2303	23.838832	22.46793	23.581	22.768	0.25783	-0.30007	
40.1911827	572.132	541.984	23.838832	22.58267	23.588	22.878	0.25083	-0.29533	
37.25656404	572.132	544.9186	23.838832	22.70494	23.586	22.974	0.25283	-0.26906	
34.1585792	572.132	548.0166	23.838832	22.83403	23.582	23.077	0.25683	-0.24297	
30.91985754	572.132	551.2553	23.838832	22.96897	23.583	23.249	0.25583	-0.28003	
27.5680875	572.132	554.6071	23.838832	23.10863	23.605	23.349	0.23383	-0.24037	
24.13601654	572.132	558.0392	23.838832	23.25163	23.607	23.488	0.23183	-0.23637	
20.6614512	572.132	561.5137	23.838832	23.39641	23.616	23.636	0.22283	-0.23959	
17.18725704	572.132	564.9879	23.838832	23.54116	23.613	23.747	0.22583	-0.20584	
13.7613587	572.132	568.4138	23.838832	23.68391	23.618	23.059	0.22083	0.62491	
10.43673984	572.132	571.7385	23.838832	23.82244	23.626	23.95	0.21283	-0.12756	
7.2714432	572.132	574.9038	23.838832	23.95432	23.617	24.041	0.22183	-0.08668	
4.328570544	572.132	577.8466	23.838832	24.07694	23.623	24.093	0.21583	-0.01606	
1.6762827	572.132	580.4989	23.838832	24.18745	23.62	24.151	0.21883	0.036455	

Method for Measuring Centroid Algorithm Accuracy
Centroid Accuracy Graph
Expected Vs Actual Position in Y Direction





Method for Measuring Centroid Algorithm Accuracy
Findings: Current Conclusions

Increasing the voltage on the actuators makes them longer and because of the way the XY mount is set up, a positive voltage moves the camera to the left and up as seen from the front of the camera. In CCD coordinates this is toward -X and +Y. When the camera is moved in one direction, the spot, which is fixed, appears to move in the opposite direction across the chip. So, the apparent motion, for increasing voltages, is to +X and -Y. This is just what the data indicated.

The residuals are not as good as we had hoped. To investigate this we need automated software to do some averaging. For each step of the actuator we will calculate the standard deviation as well as the average.

There may be a rotation of the CCD axis relative to the actuator axis. We can test this by moving the spot all the way across the quadrant and recording the centroids manually. This needs to be done in both axis.

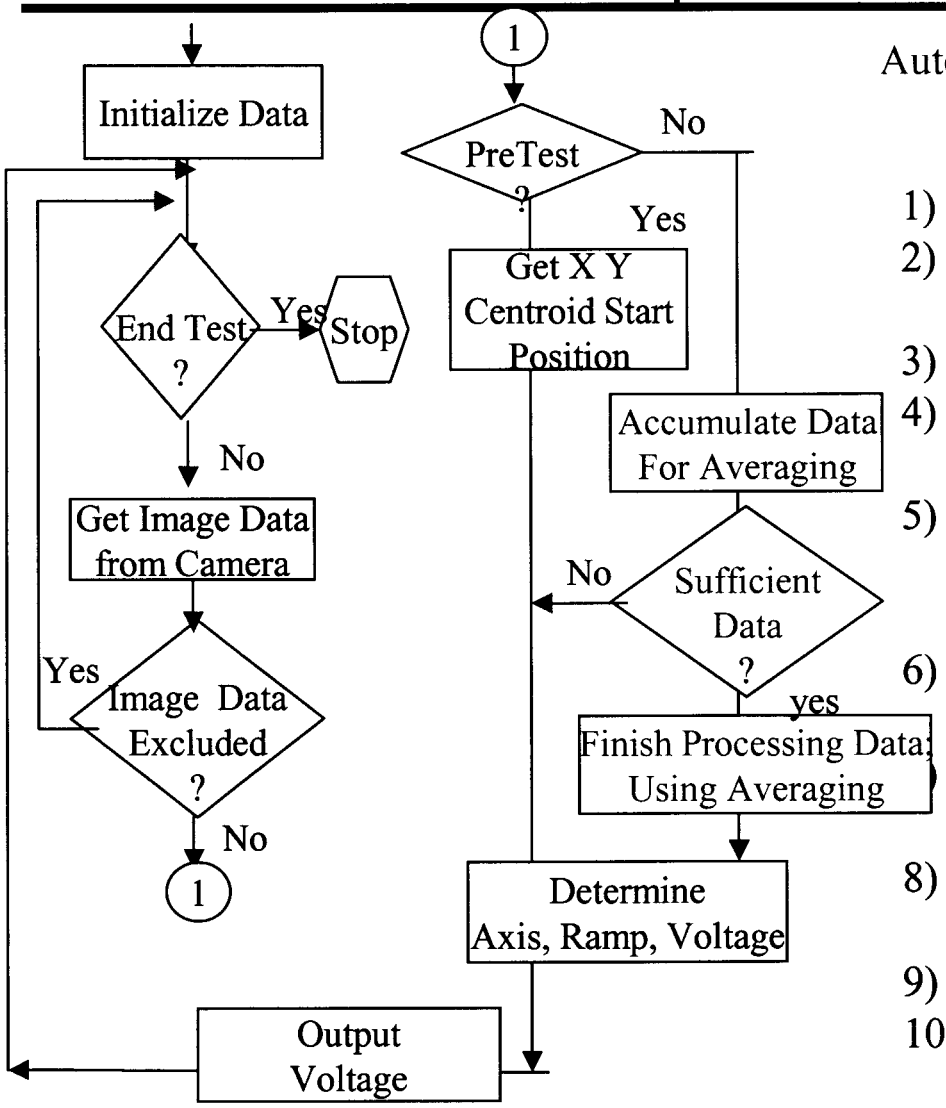
Kurt Liewer's Assessment

Method for Measuring Centroid Algorithm Accuracy
Limitations and Constraints On Methodology

There are a Number of Practical Test Constraints and Limitations Which Affect the Test Results Including:

- Electro-Strictive Actuator's Hysteresis
  -- Voltage Ramps Up & Ramps Down Not the Same
- Expected Positions Initially Taken from Graph Using a Caliper
- 4th degree Polynomial Equations Based on Caliper Measurements
- Pixel Noise fluctuations Affect Random Datum Integrity
- Random Selection of Data Points May Not be Sufficiently Accurate

Method for Measuring Centroid Algorithm Accuracy
Future Improvements to the Experiment



Automate Sampling; Increase Sampling, and Use Averaging to reduce Influence of Noise

1) Initialize data
2) Check to see if End of Test (all sampling is complete)
3) If not, get image frame telemetry from camera
4) Check to see if Image Data Is Excluded (i.e. Discard the first N number of frames)
5) If the mode is Pre-Test, fetch the initial centroid position, else accumulate data for averaging
6) If accumulating data for averaging check to see if sufficient data has been sampled
If sufficient data is sampled, get average and statistics.
8) Determine the axis, ramp, and voltage for next output to the actuator
9) Output voltage to the actuator
10) Continue from 2) until all sampling has been completed

Method for Measuring Centroid Algorithm Accuracy Summary

What Was Covered in this Presentation

Illustration of a Method for Measuring Centroid Algorithm Including

- Selection of an Algorithm
- Support for Selection Based upon Performance Requirements And Theoretical Model & Calculations
- Experimental Method for Checking and Verification
- Set Up of the Experiment for Verification
- Results: Expected and Actual
- Analysis of the Findings
- Suggested Improvements to Experimental Approach

Method for Measuring Centroid Algorithm Accuracy References

The following figures were taken from other Starlight presentations.
In most cases, they are used here in a different context that the original.

Figure 1: "Camera Error Budget Components," Oct.25, 2001. Author: Jim Alexander

Figure 2: Starlight WebSite Public Sites Education
Authors: Gary Blackwood et al

Figure 3: "Formation Interferometer Testbed Phase 1Software Architecture and Design,"
March 2002. Author: Beth McKenny

Figure 4: *"FIT Activities **1.6b**, **1.12a**, 1.12b, **1.13**, 1.16 – Presentation to the Team," 9/12/2001.*
Authors:Joel Shields (Activity Lead) et al.

Figure 5: *"FIT Activities **1.6b**, **1.12a**, 1.12b, **1.13**, 1.16 – Presentation to the Team," (9/12/2001).*
Authors:Joel Shields (Activity Lead) et al.

Figure 6: "StarLight FIT Instrument Software," 02/19/02. Author: John Mayer,Suzanne Klein et al.

Figure 7: "ST3 Prototype CCD Camera Description & I&T Testing 08/13/01 Phase 1.9 I&T Testing"
Authors: Suzanne Klein, Kurt Liewer

Figure 8: *"FIT Activities 1.6b, 1.12a, 1.12b, 1.13, 1.16 –Presentation to the Team," (9/12/2001)*
Authors:Joel Shields (Activity Lead) et al