

Implementation: Accurate Camera Calibration using Iterative Refinement of Control Points

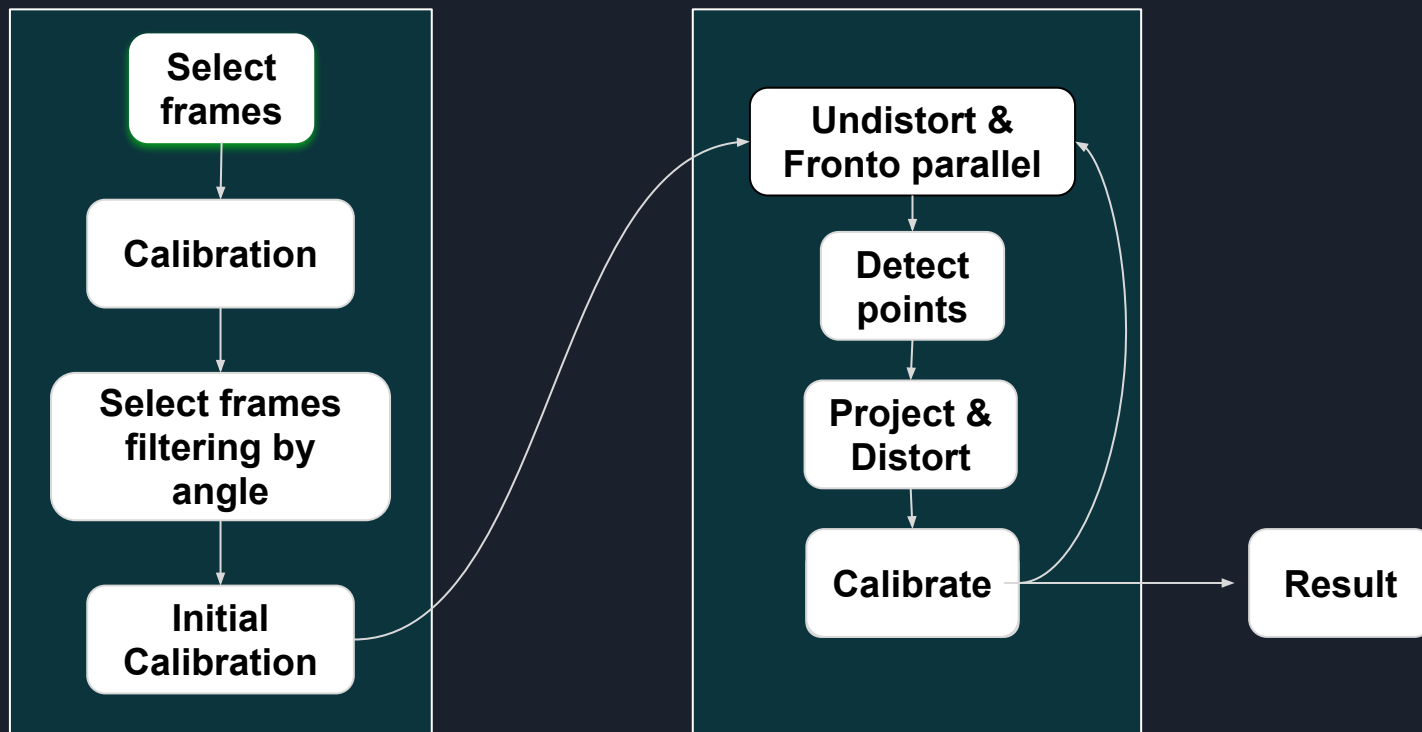
Authors:

Raúl Romaní Flores

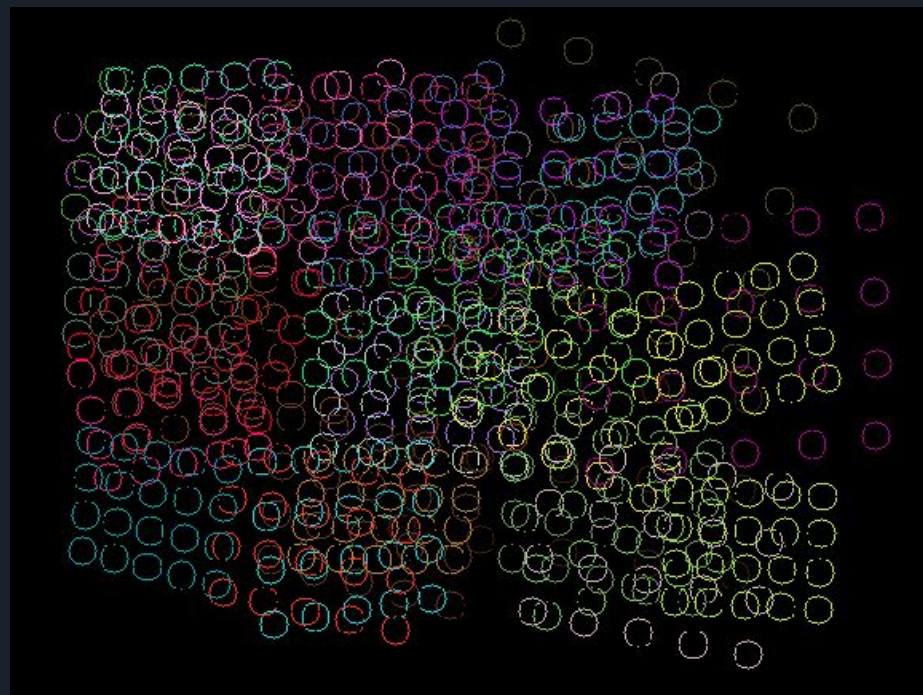
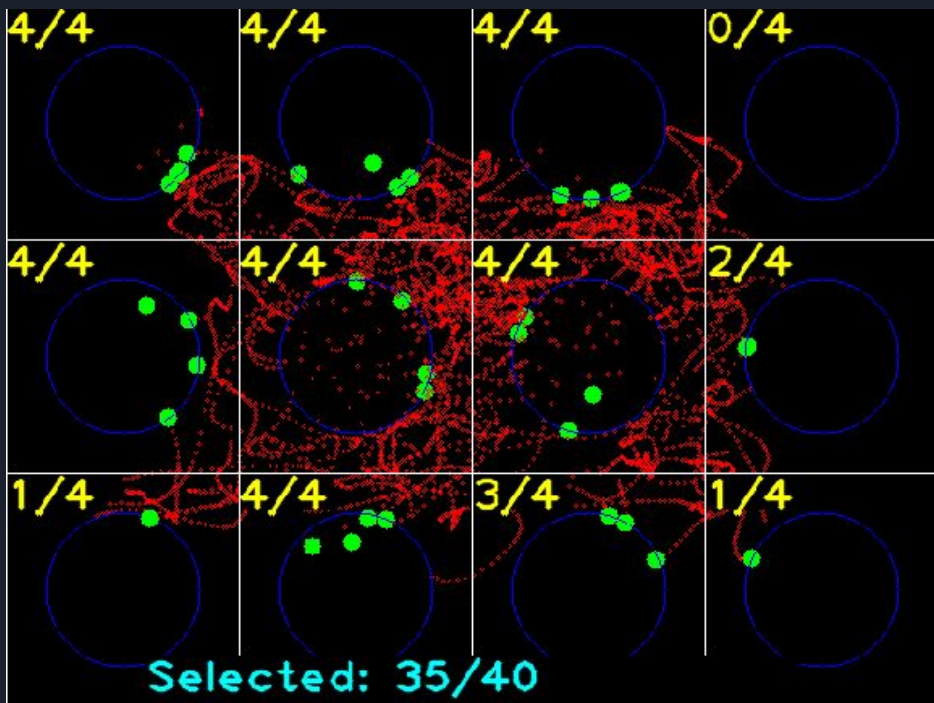
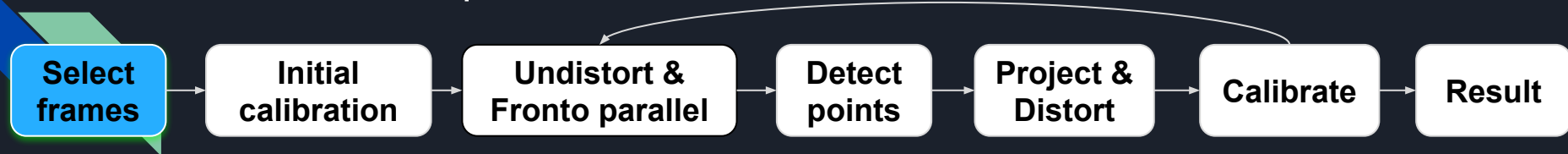
Paul Alonzo Quio Añamuro

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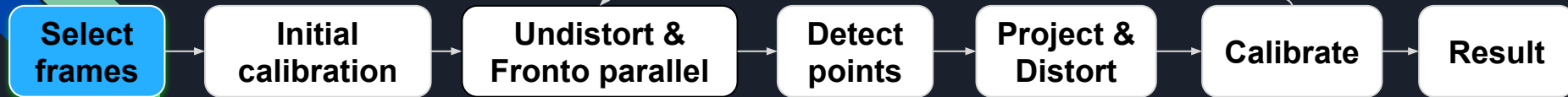
Iterative process for camera calibration



Iterative process

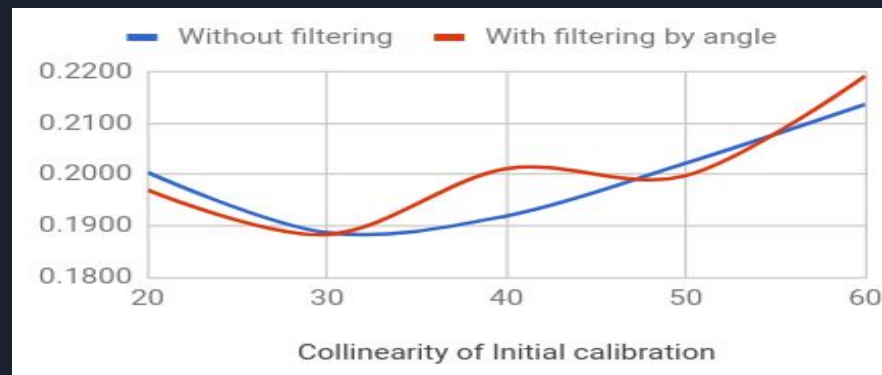
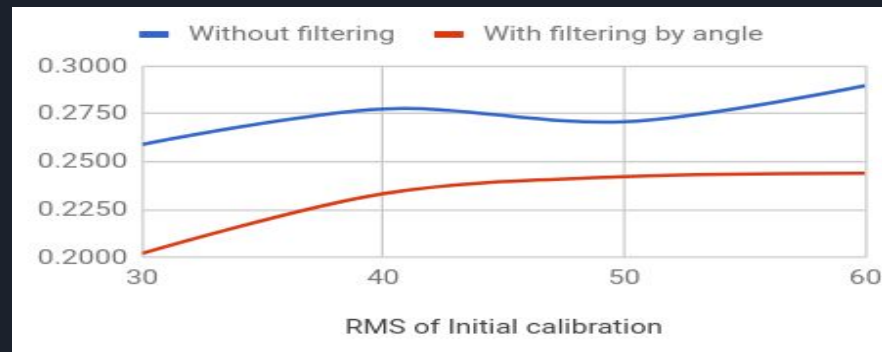


Iterative process

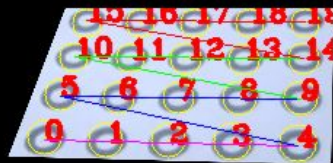
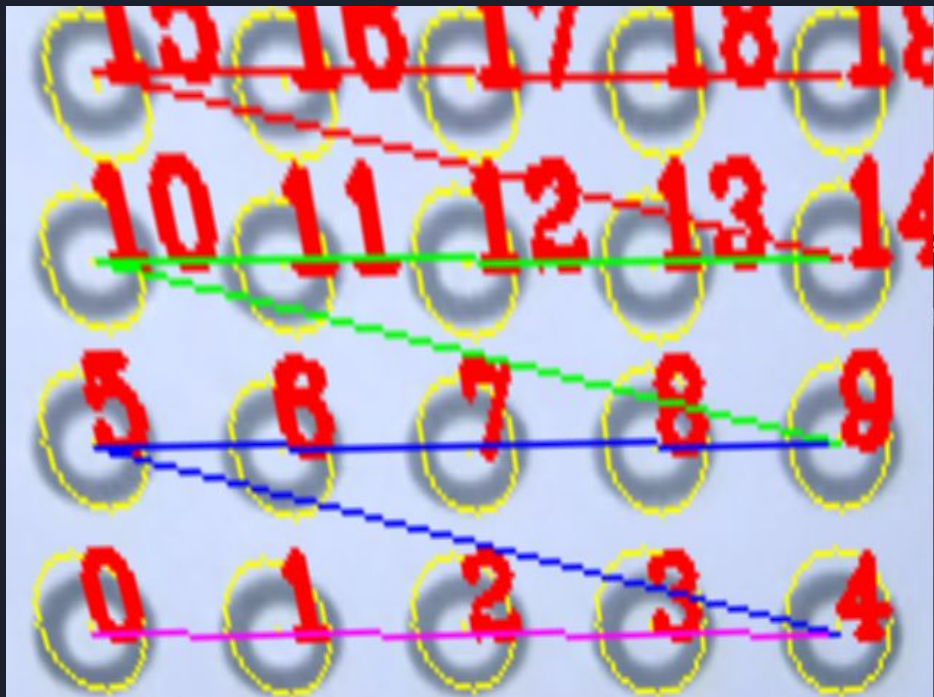
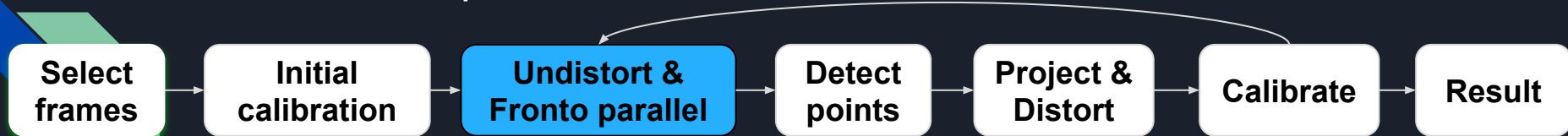


Filter by angle

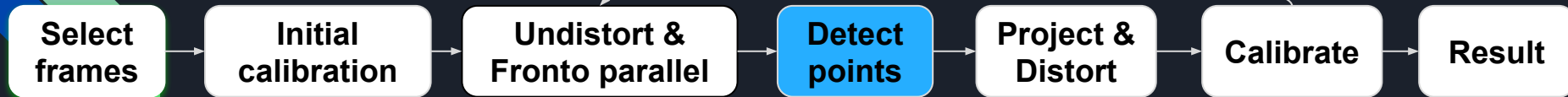
Initial calibration					
RMS/Samples	20	30	40	50	60
Without filtering	0.2590	0.2776	0.2709	0.2898	0.2890
With filtering by angle	0.2020	0.2333	0.2421	0.2439	0.2684
Initial calibration					
Collinearity/Samples	20	30	40	50	60
Without filtering	0.2004	0.1886	0.1919	0.2021	0.2136
With filtering by angle	0.1969	0.1883	0.2011	0.1997	0.2191



Iterative process



Iterative process

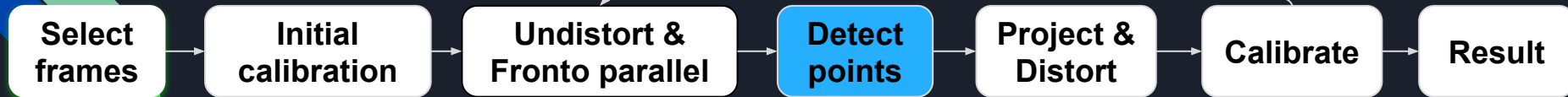


1.- fitEllipse

2.- Center of mass

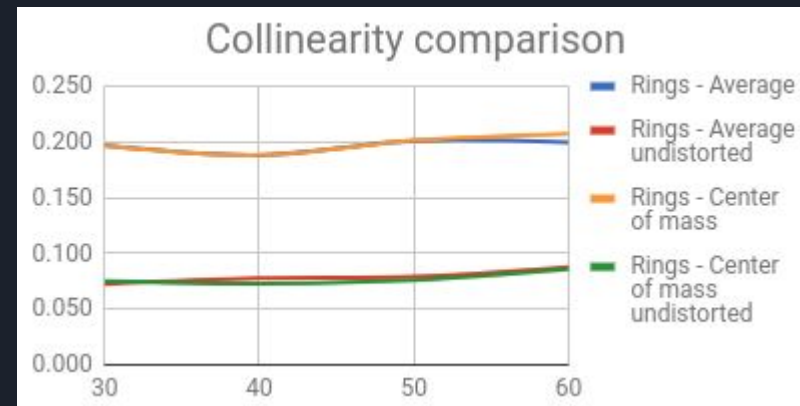
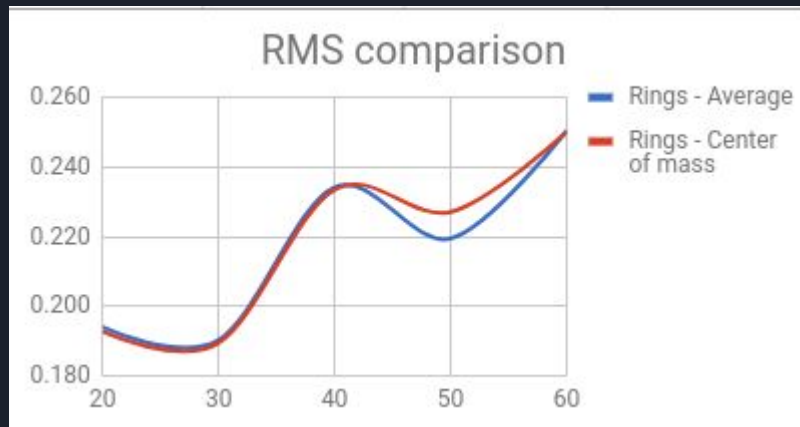
	Rings - Average					Rings - Center of mass				
Samples	20	30	40	50	60	20	30	40	50	60
Rms	0.194	0.190	0.234	0.219	0.251	0.193	0.189	0.234	0.227	0.250
fx	844.143	832.426	823.290	819.639	811.885	844.570	829.719	823.771	799.462	812.651
fy	838.616	826.569	818.583	813.977	807.060	838.924	824.023	819.144	796.585	807.890
cx	328.923	311.706	304.667	299.790	298.915	329.150	312.364	305.356	294.199	298.840
cy	241.277	237.382	244.639	259.618	259.824	241.039	237.254	243.683	255.140	260.558
Collinearity	0.197	0.188	0.201	0.200	0.219	0.197	0.188	0.201	0.207	0.216
Collinearity undistorted	0.073	0.078	0.079	0.088	0.089	0.075	0.073	0.076	0.086	0.087

Iterative process

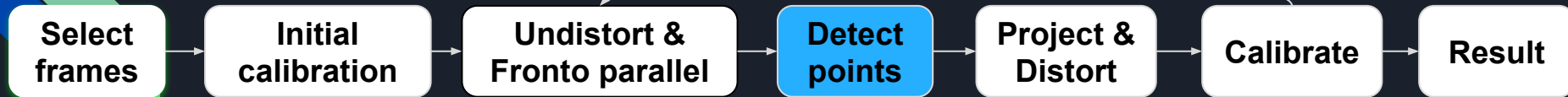


1.- fitEllipse

2.- Center of mass



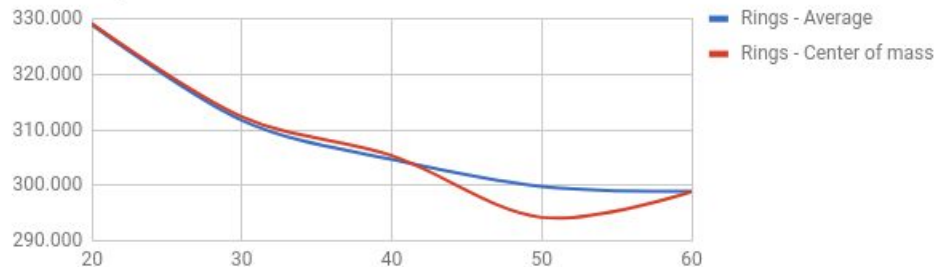
Iterative process



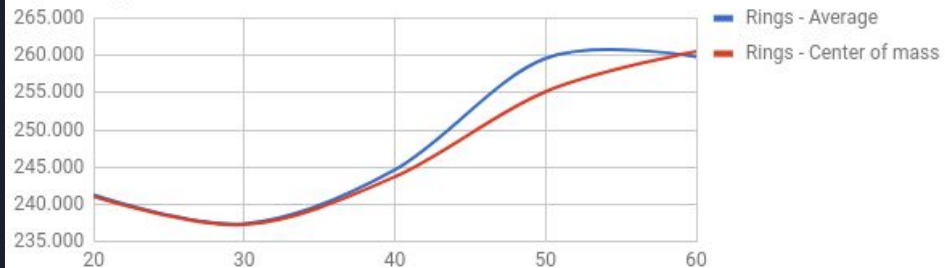
1.- fitEllipse

2.- Center of mass

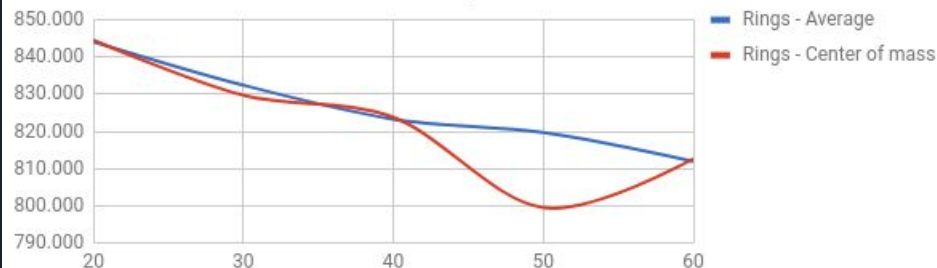
cx comparison



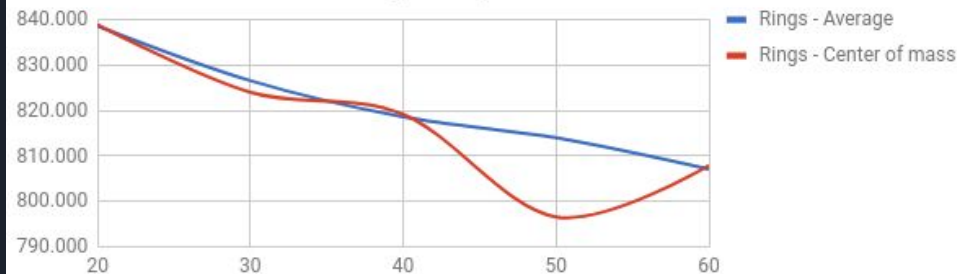
cy comparison



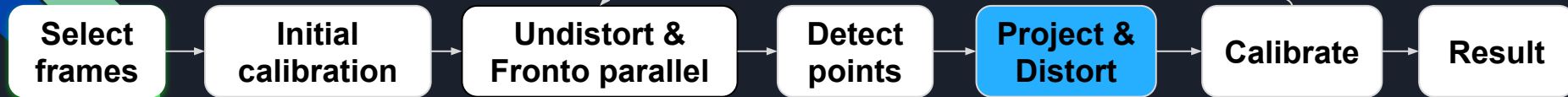
fx comparison



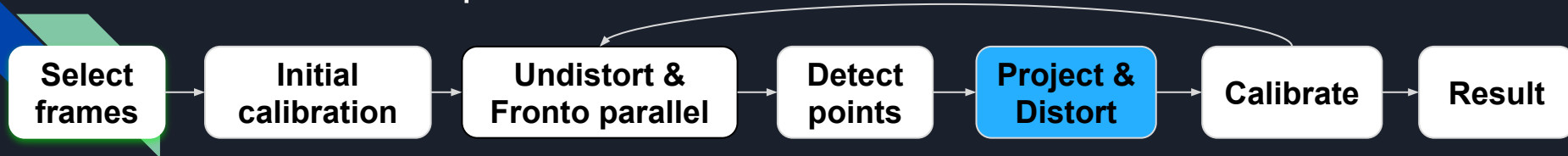
fy comparison



Iterative process



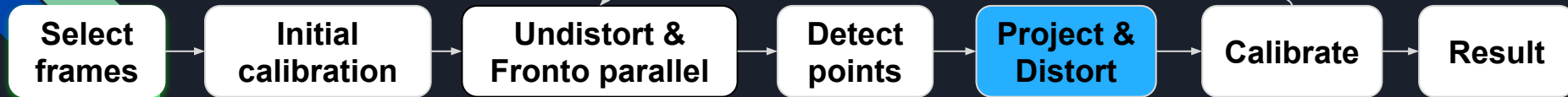
Iterative process



Refinement comparison

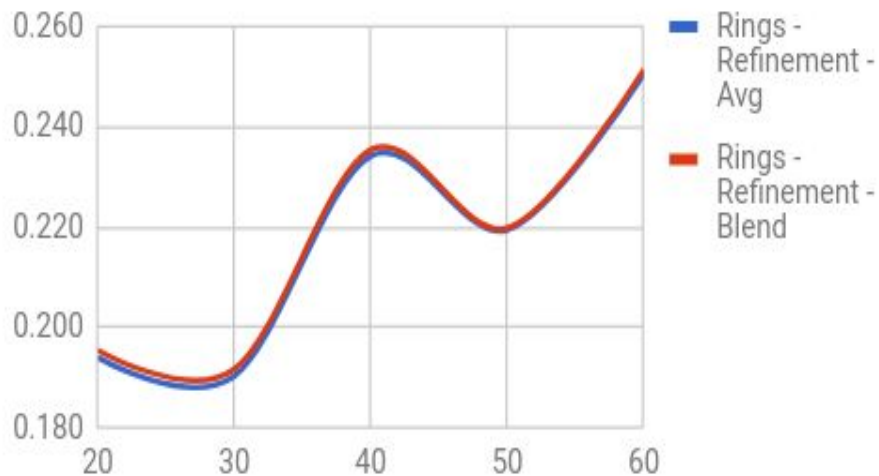
	Rings - Refinement - Avg					Rings - Refinement - Blend				
Samples	20	30	40	50	60	20	30	40	50	60
Rms	0.194	0.190	0.234	0.219	0.251	0.195	0.192	0.235	0.220	0.251
fx	844.143	832.426	823.290	819.639	811.885	845.748	829.826	823.726	819.288	812.192
fy	838.616	826.569	818.583	813.977	807.060	840.082	824.040	819.035	813.653	807.466
cx	328.923	311.706	304.667	299.790	298.915	329.338	312.016	304.019	299.733	298.165
cy	241.277	237.382	244.639	259.618	259.824	241.683	238.191	244.391	259.171	259.310
Collinearity	0.197	0.188	0.201	0.200	0.219	0.197	0.188	0.201	0.200	0.219
Collinearity undistorted	0.073	0.078	0.079	0.088	0.089	0.075	0.077	0.078	0.086	0.089

Iterative process

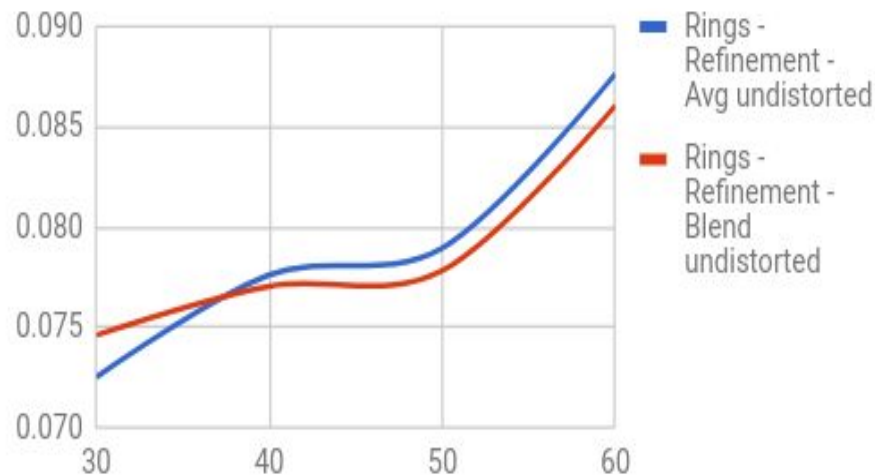


Refinement comparison

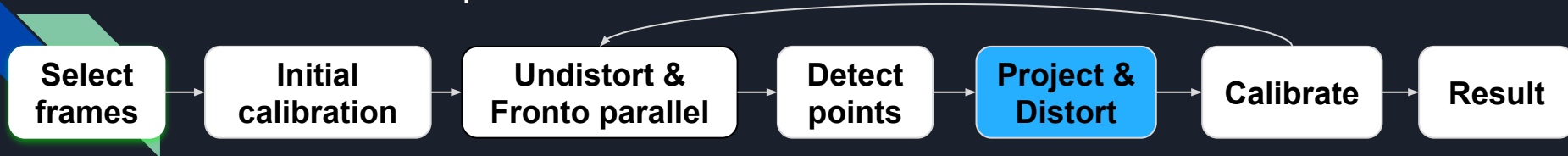
RMS comparison



Collinearity comparison



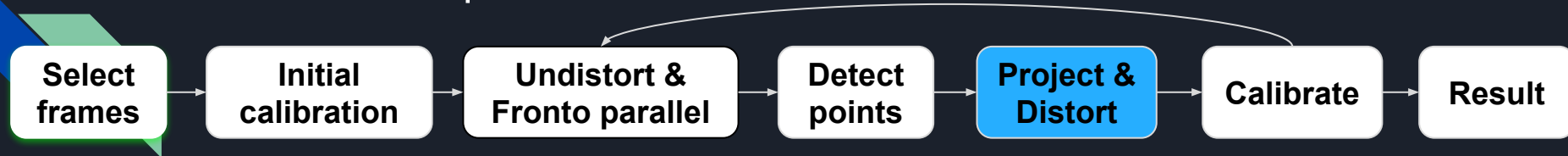
Iterative process



Refinement using ideal points

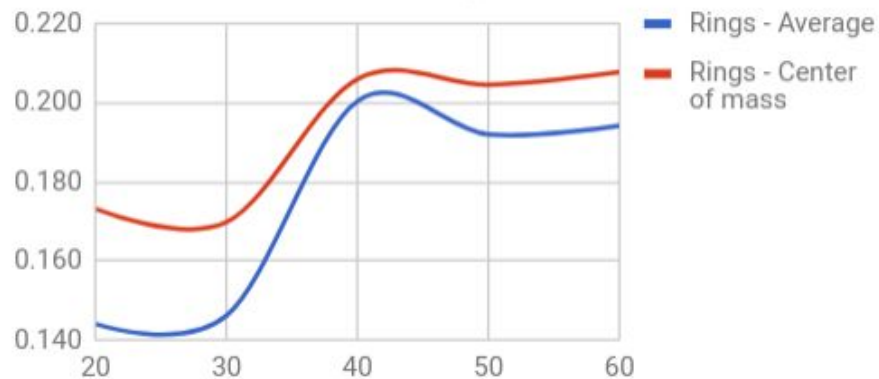
	Rings - Average					Rings - Center of mass				
Samples	20	30	40	50	60	20	30	40	50	60
Rms	0.144	0.146	0.200	0.192	0.194	0.173	0.170	0.206	0.205	0.208
fx	831.698	829.754	818.353	819.020	827.578	837.996	841.098	822.289	819.604	827.559
fy	826.859	823.600	813.559	813.132	821.988	833.216	835.851	818.738	816.035	822.820
cx	321.502	311.597	317.957	311.591	303.610	309.248	316.610	305.148	309.821	303.397
cy	257.509	247.419	252.088	254.260	254.331	246.846	248.250	231.453	233.980	245.119
Collinearity	0.190	0.184	0.191	0.189	0.200	0.191	0.184	0.186	0.185	0.198
Collinearity undistorted	0.083	0.077	0.083	0.082	0.089	0.069	0.070	0.081	0.083	0.078

Iterative process

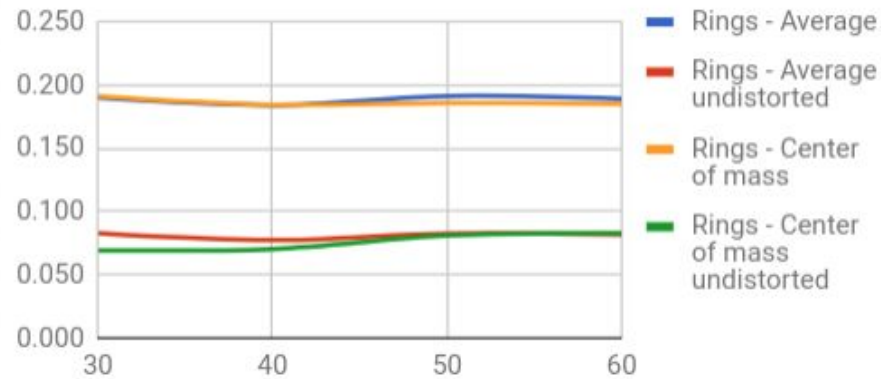


Refinement using ideal points

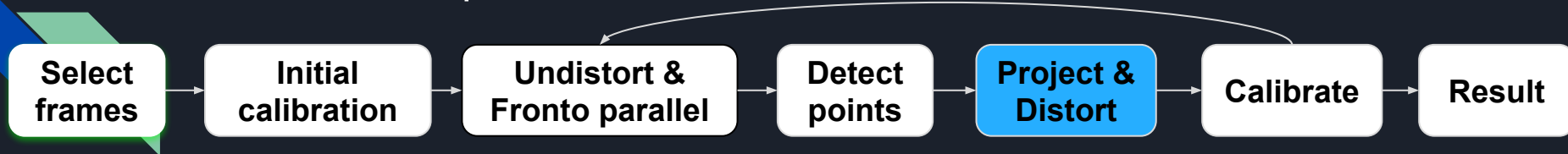
RMS comparison



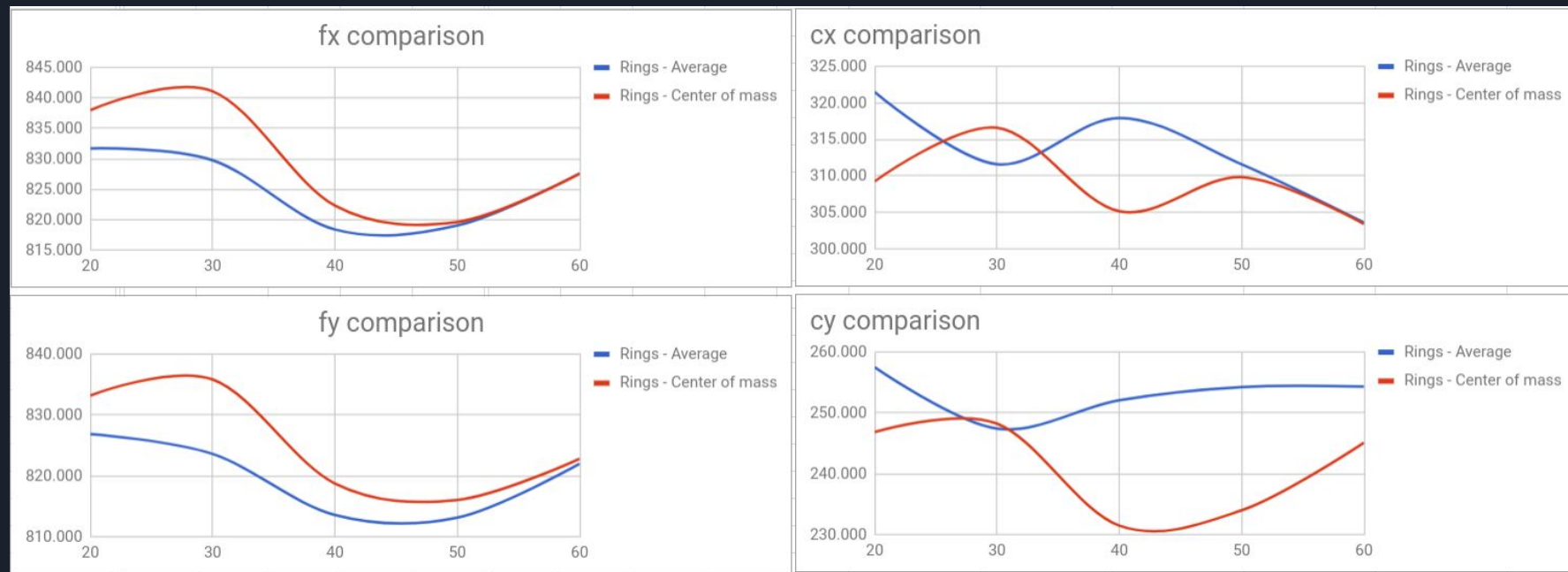
Collinearity comparison



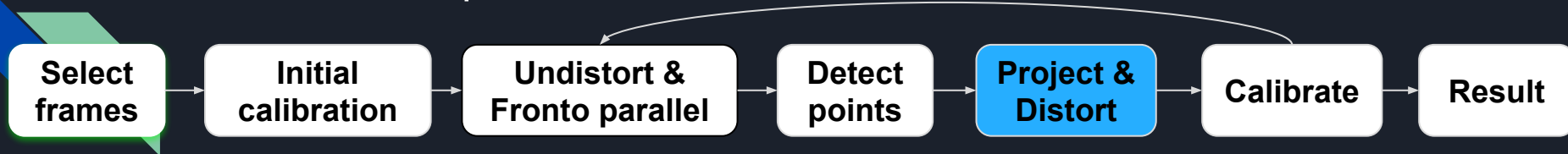
Iterative process



Refinement using ideal points



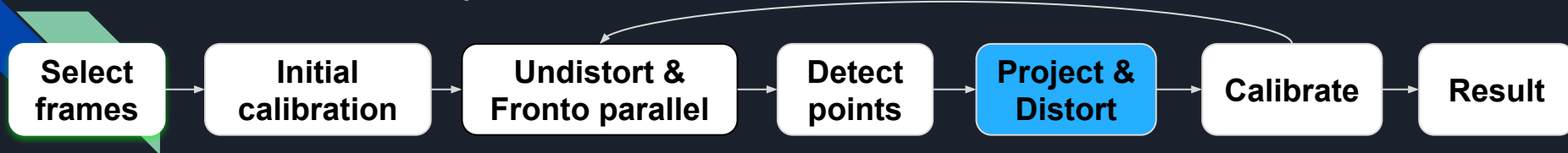
Iterative process



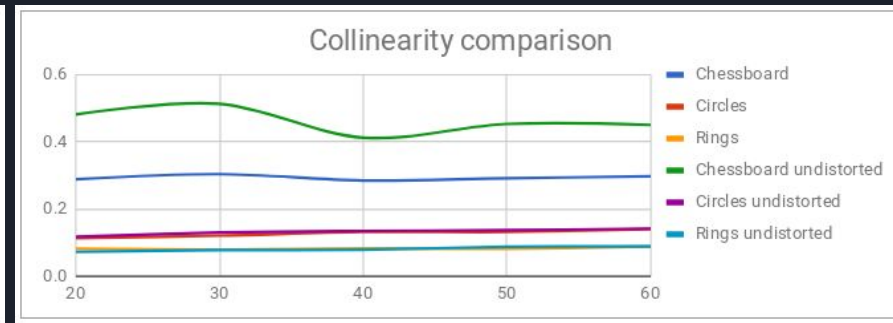
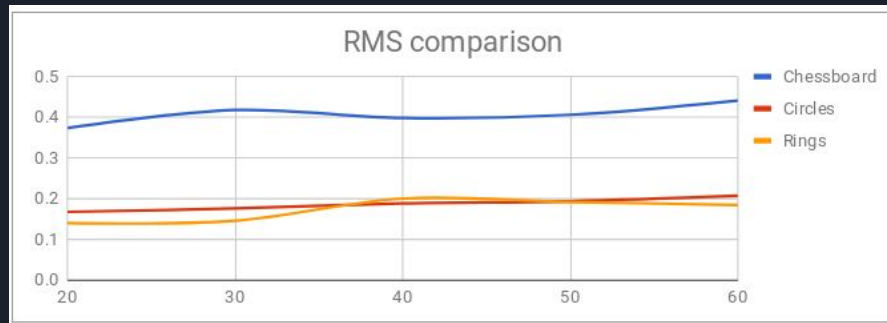
Comparison of Rings, Circles and Chessboard

	PS3 calibration														
	Chessboard					Circles					Rings				
Samples	20	30	40	50	60	20	30	40	50	60	20	30	40	50	60
Rms	0.37	0.42	0.40	0.41	0.44	0.17	0.18	0.19	0.19	0.21	0.1400	0.1459	0.2004	0.1919	0.1846
fx	823.89	819.86	843.96	835.28	830.64	850.45	839.22	852.50	842.75	895.62	833.1850	829.0910	818.3530	819.0200	828.0430
fy	814.89	810.98	836.91	825.98	824.02	842.98	831.96	845.42	836.96	883.76	828.1400	822.9450	813.5590	813.1320	822.1230
cx	349.30	321.55	316.79	285.87	272.75	321.46	323.86	332.26	325.48	306.94	324.0690	312.2580	317.9570	311.5910	310.6480
cy	244.39	220.75	242.71	235.41	253.10	249.47	248.94	256.37	255.07	250.69	257.7690	247.2230	252.0880	254.2600	256.0240
Collinearity	0.29	0.30	0.29	0.29	0.30	0.11	0.12	0.13	0.13	0.14	0.0816	0.0795	0.0827	0.0818	0.0888
Collinearity undistorted	0.48	0.51	0.41	0.45	0.45	0.12	0.13	0.13	0.14	0.14	0.07	0.08	0.08	0.09	0.09

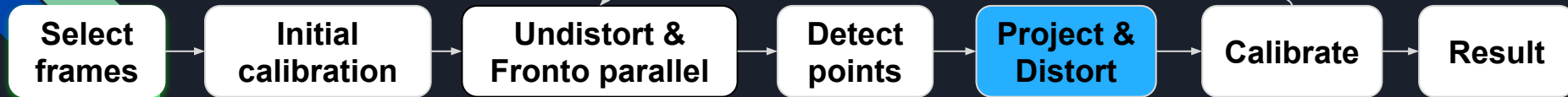
Iterative process



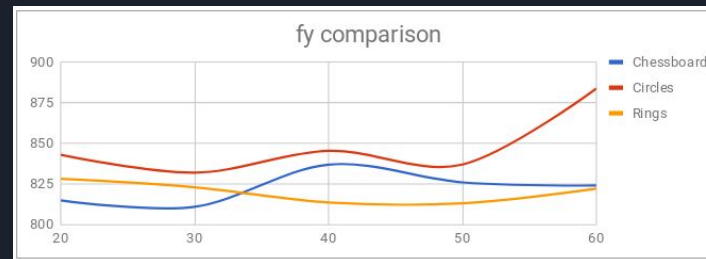
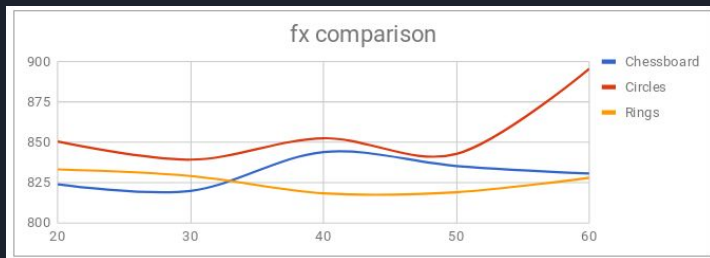
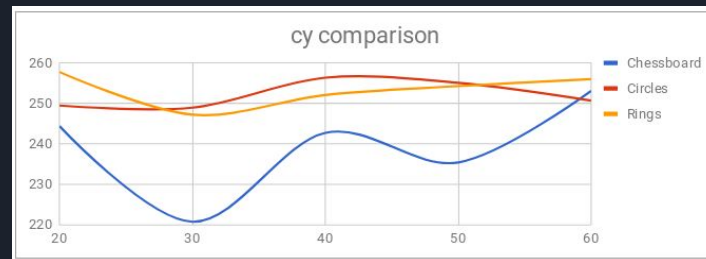
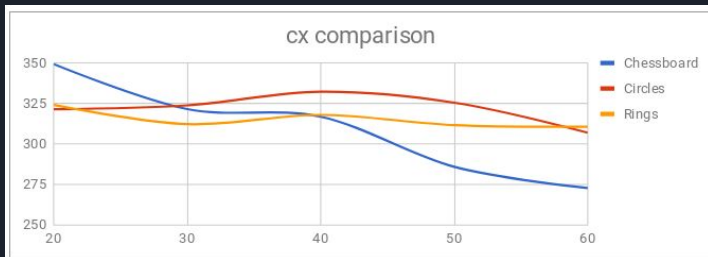
Comparison of Rings, Circles and Chessboard



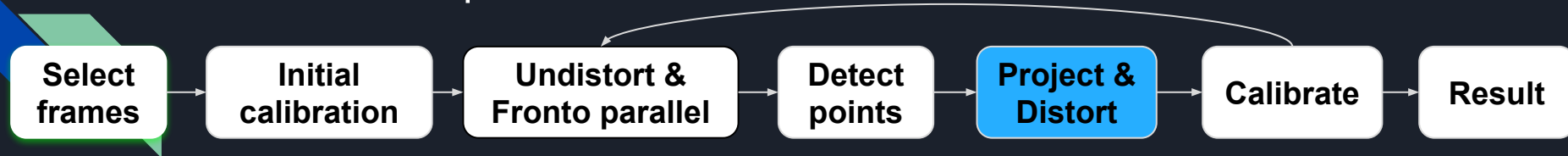
Iterative process



Comparison of Rings, Circles and Chessboard



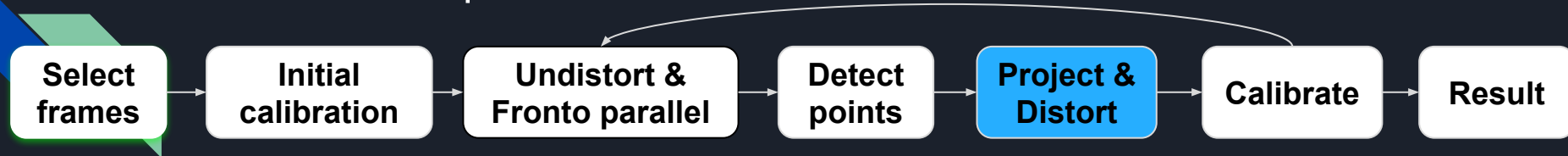
Iterative process



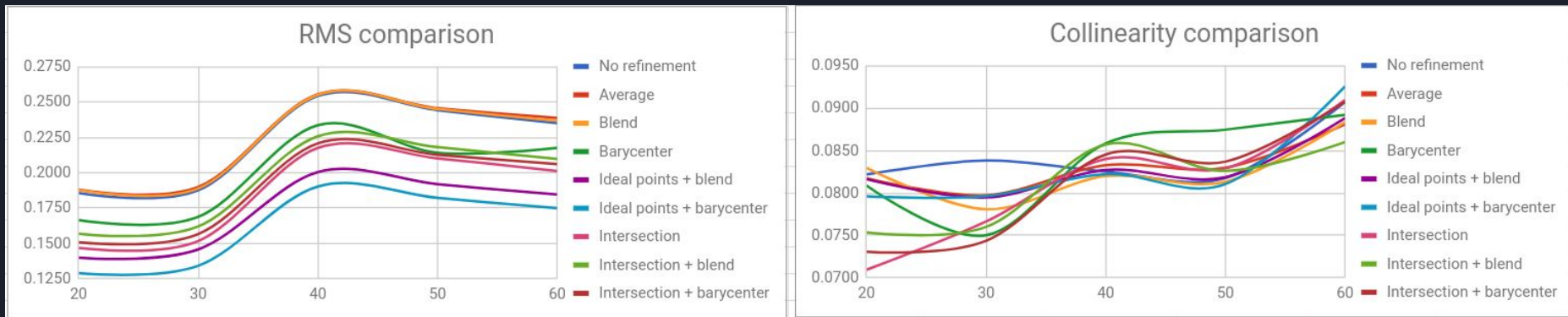
Refinement methods comparison

	RMS					Avg		Collinearity					Avg
	20	30	40	50	60			20	30	40	50	60	
No refinement	0.1857	0.1877	0.2542	0.2442	0.2350	0.2214	No refinement	0.0822	0.0838	0.0825	0.0818	0.0907	0.0842
Average	0.1882	0.1899	0.2554	0.2456	0.2387	0.2236	Average	0.0817	0.0797	0.0833	0.0830	0.0881	0.0832
Blend	0.1877	0.1889	0.2551	0.2450	0.2367	0.2227	Blend	0.0830	0.0781	0.0820	0.0813	0.0883	0.0825
Barycenter	0.1666	0.1689	0.2336	0.2141	0.2176	0.2001	Barycenter	0.0809	0.0750	0.0858	0.0874	0.0892	0.0837
Ideal points + blend	0.1400	0.1459	0.2004	0.1919	0.1846	0.1726	Ideal points + blend	0.0816	0.0795	0.0827	0.0818	0.0888	0.0829
Ideal points + barycenter	0.1291	0.1343	0.1903	0.1822	0.1750	0.1622	Ideal points + barycenter	0.0796	0.0796	0.0822	0.0810	0.0925	0.0830
Intersection	0.1469	0.1518	0.2176	0.2102	0.2012	0.1855	Intersection	0.0710	0.0766	0.0840	0.0829	0.0910	0.0811
Intersection + blend	0.1570	0.1621	0.2257	0.2180	0.2097	0.1945	Intersection + blend	0.0754	0.0760	0.0857	0.0826	0.0860	0.0811
Intersection + barycenter	0.1509	0.1567	0.2207	0.2127	0.2061	0.1894	Intersection + barycenter	0.0731	0.0744	0.0845	0.0837	0.0907	0.0813

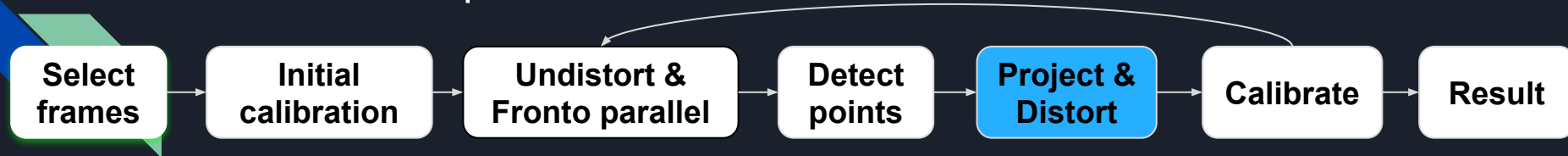
Iterative process



Refinement methods comparison



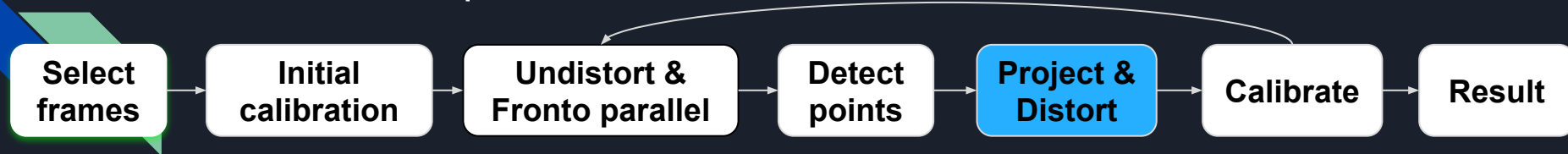
Iterative process



Refinement methods comparison

	fx					Avg		fy					Avg
	20	30	40	50	60			20	30	40	50	60	
No refinement	830.2840	832.0740	819.5810	820.5180	829.3350	826.3584	No refinement	825.3040	825.5540	814.8990	814.6960	823.1870	820.7280
Average	829.3140	831.5500	818.3000	818.7230	828.5570	825.2888	Average	824.3790	825.0750	813.6920	812.9780	822.4690	819.7186
Blend	831.0040	831.2590	819.1470	818.4130	828.5040	825.6654	Blend	826.1480	824.8040	814.6380	812.6680	822.3850	820.1286
Barycenter	829.5770	831.4950	819.8600	820.2040	828.1170	825.8506	Barycenter	824.6230	825.0400	815.2670	813.9210	822.1120	820.1926
Ideal points + blend	833.1850	829.0910	818.3530	819.0200	828.0430	825.5384	Ideal points + blend	828.1400	822.9450	813.5590	813.1320	822.1230	819.9798
Ideal points + barycenter	830.3490	830.7220	819.1240	817.6170	827.9820	825.1588	Ideal points + barycenter	825.6070	824.3540	814.3540	811.8320	822.0720	819.6438
Intersection	831.3480	833.4310	822.7050	821.2950	828.8150	827.5188	Intersection	826.0720	826.8490	817.9990	815.4400	822.6510	821.8022
Intersection + blend	831.0570	831.6340	820.5260	819.0520	827.5020	825.9542	Intersection + blend	825.8980	825.2470	815.9380	813.3050	821.5330	820.3842
Intersection + barycenter	832.2990	832.0090	820.7480	819.8010	828.1460	826.6006	Intersection + barycenter	827.1230	825.4990	816.0520	814.0220	822.1410	820.9674

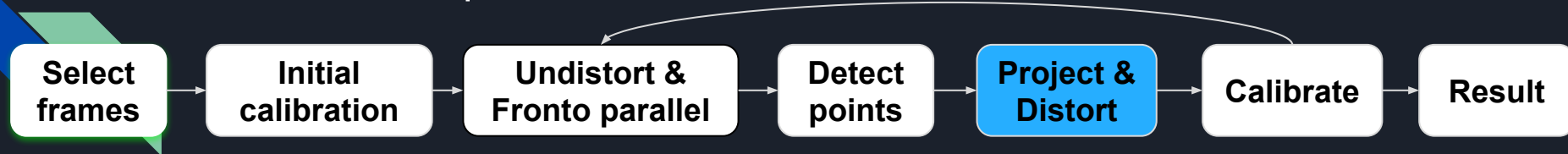
Iterative process



Refinement methods comparison



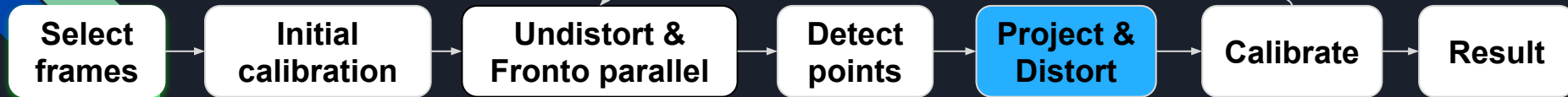
Iterative process



Refinement methods comparison

	cx					Avg		cy					Avg
	20	30	40	50	60			20	30	40	50	60	
No refinement	324.2040	313.9430	315.3700	307.4000	309.4310	314.0696	No refinement	254.9200	244.3250	248.6220	250.7140	252.9440	250.3050
Average	324.5770	312.8960	315.2980	307.7510	309.3240	313.9692	Average	255.7460	245.7230	247.5420	250.1670	253.0400	250.4436
Blend	324.0780	312.2710	315.3540	307.2610	309.6790	313.7286	Blend	255.8790	245.2500	247.7890	250.3870	252.7200	250.4050
Barycenter	322.6010	310.9050	316.6480	318.3980	309.3440	315.5792	Barycenter	252.9820	243.2830	247.4630	253.7070	254.2010	250.3272
Ideal points + blend	324.0690	312.2580	317.9570	311.5910	310.6480	315.3046	Ideal points + blend	257.7690	247.2230	252.0880	254.2600	256.0240	253.4728
Ideal points + barycenter	323.4050	307.1460	318.6460	311.9630	311.9280	314.6176	Ideal points + barycenter	258.7150	246.5590	252.0530	254.5610	257.8310	253.9438
Intersection	322.3120	310.3850	318.3350	309.4780	308.2510	313.7522	Intersection	249.3520	240.6040	246.3760	250.4610	254.4870	248.2560
Intersection + blend	323.0610	313.2820	317.8100	309.9640	310.0740	314.8382	Intersection + blend	251.9730	241.8020	246.1410	249.8950	253.1680	248.5958
Intersection + barycenter	322.3760	308.4230	317.3380	309.3330	308.4420	313.1824	Intersection + barycenter	250.6110	241.5270	246.9320	250.8040	254.6670	248.9082
Ideal value	320.0000	320.0000	320.0000	320.0000	320.0000		Ideal value	240.0000	240.0000	240.0000	240.0000	240.0000	

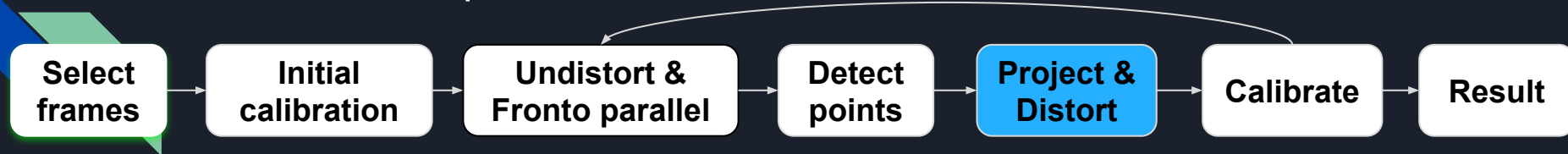
Iterative process



Refinement methods comparison



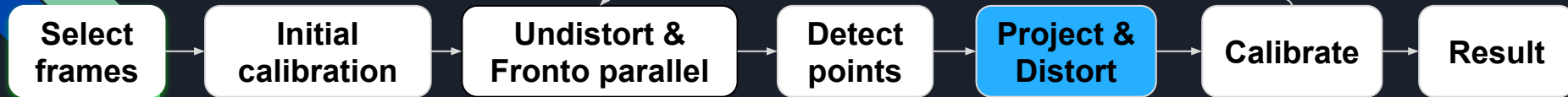
Iterative process



Refinement methods comparison

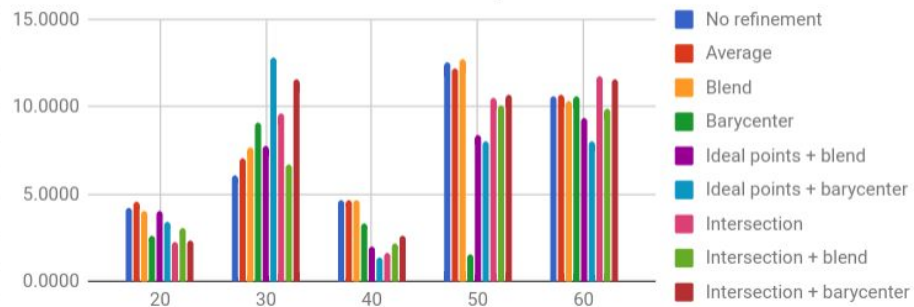
	cx error							cy error					
	20	30	40	50	60	Avg		20	30	40	50	60	Avg
No refinement	4.2040	6.0570	4.6300	12.6000	10.5690	7.6120	No refinement	14.9200	4.3250	8.6220	10.7140	12.9440	10.3050
Average	4.5770	7.1040	4.7020	12.2490	10.6760	7.8616	Average	15.7460	5.7230	7.5420	10.1670	13.0400	10.4436
Blend	4.0780	7.7290	4.6460	12.7390	10.3210	7.9026	Blend	15.8790	5.2500	7.7890	10.3870	12.7200	10.4050
Barycenter	2.6010	9.0950	3.3520	1.6020	10.6560	5.4612	Barycenter	12.9820	3.2830	7.4630	13.7070	14.2010	10.3272
Ideal points + blend	4.0690	7.7420	2.0430	8.4090	9.3520	6.3230	Ideal points + blend	17.7690	7.2230	12.0880	14.2600	16.0240	13.4728
Ideal points + barycenter	3.4050	12.8540	1.3540	8.0370	8.0720	6.7444	Ideal points + barycenter	18.7150	6.5590	12.0530	14.5610	17.8310	13.9438
Intersection	2.3120	9.6150	1.6650	10.5220	11.7490	7.1726	Intersection	9.3520	0.6040	6.3760	10.4610	14.4870	8.2560
Intersection + blend	3.0610	6.7180	2.1900	10.0360	9.9260	6.3862	Intersection + blend	11.9730	1.8020	6.1410	9.8950	13.1680	8.5958
Intersection + barycenter	2.3760	11.5770	2.6620	10.6670	11.5580	7.7680	Intersection + barycenter	10.6110	1.5270	6.9320	10.8040	14.6670	8.9082

Iterative process

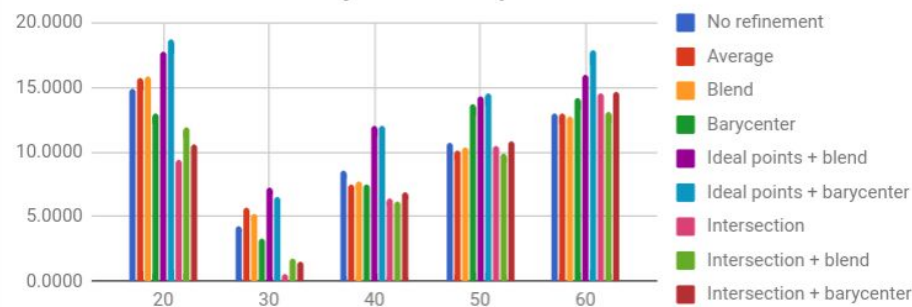


Refinement methods comparison

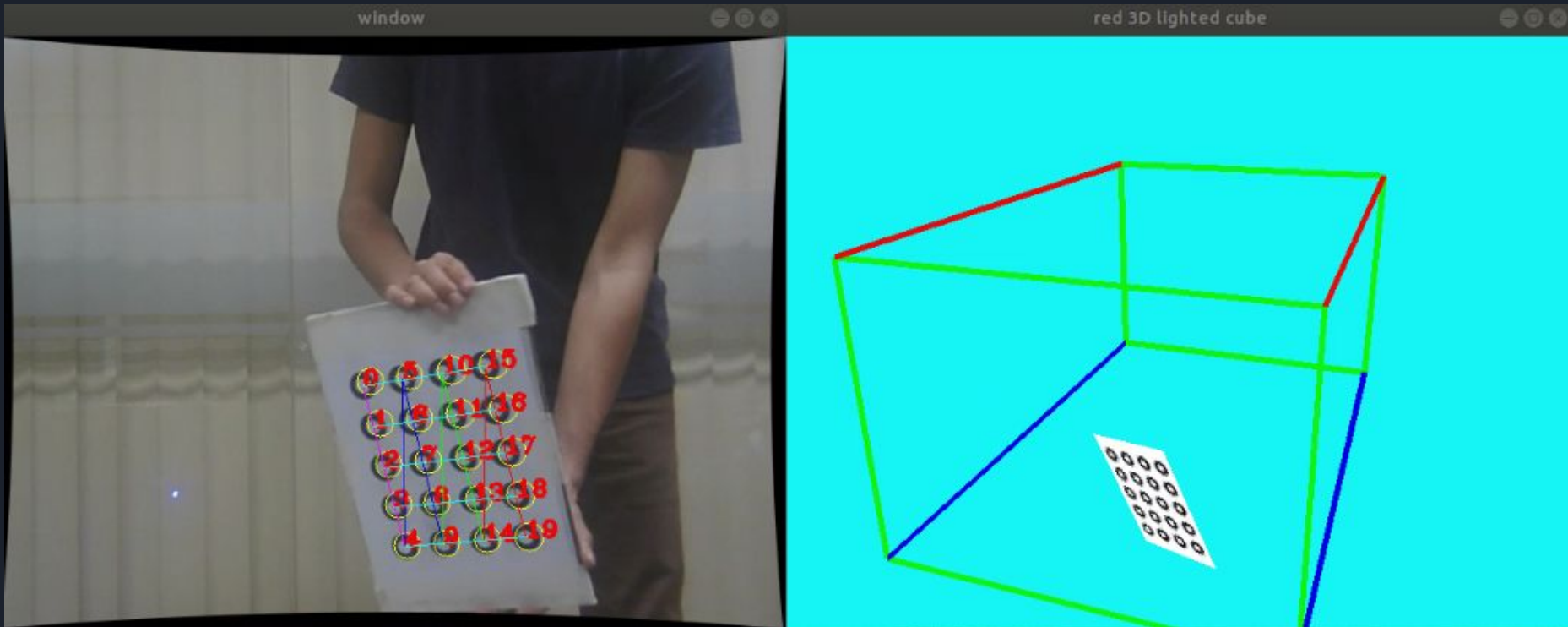
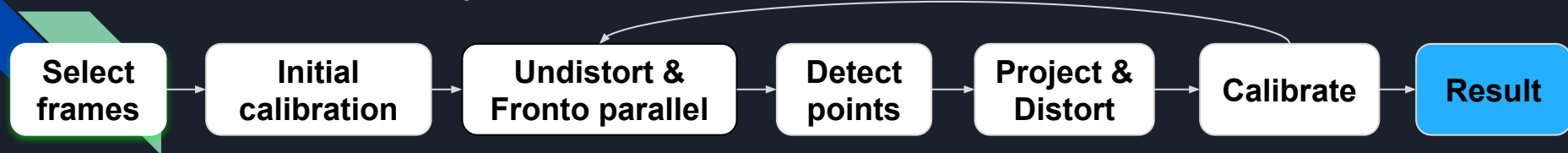
cx error comparison



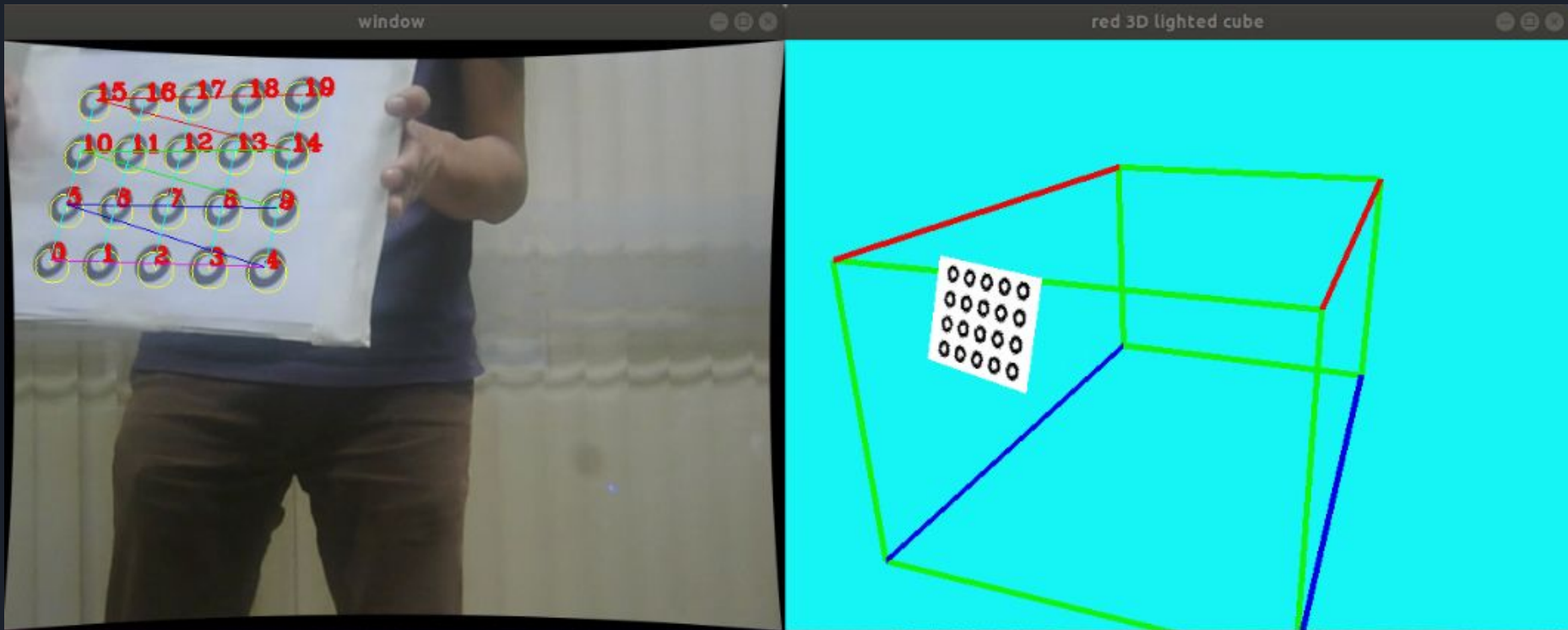
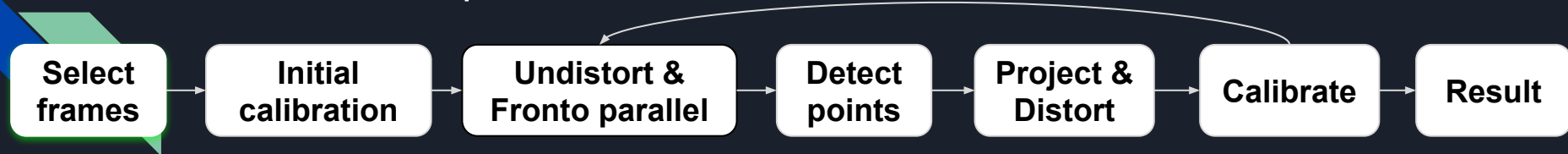
cy error comparison



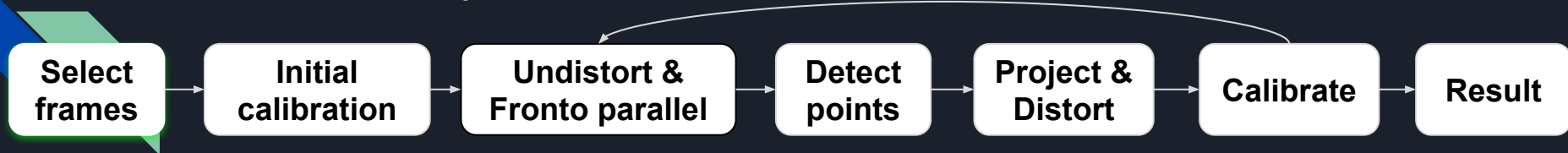
Iterative process



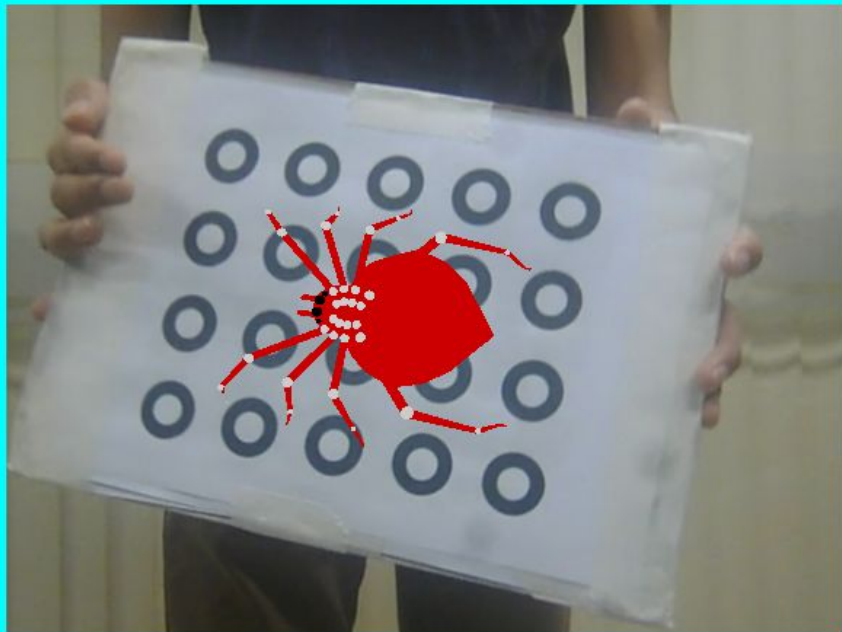
Iterative process



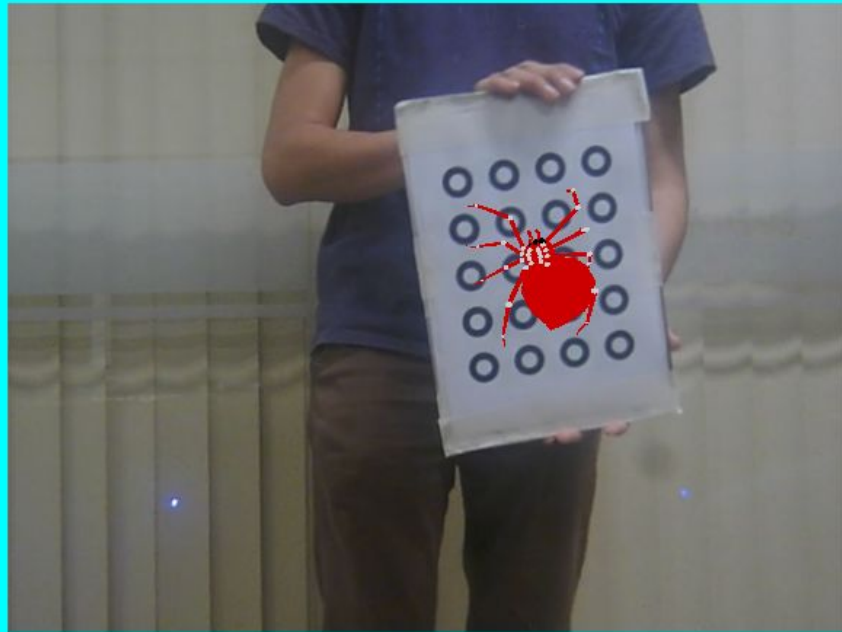
Iterative process



red 3D lighted cube



red 3D lighted cube





Thank you