CAMERA CALIBRATION USING ITERATIVE REFINEMENT WITH DENSITY FUNCTION SELECTION OVER CONCENTRIC RINGS, CHESSBOARD AND ASYMMETRIC DISKS PATTERNS

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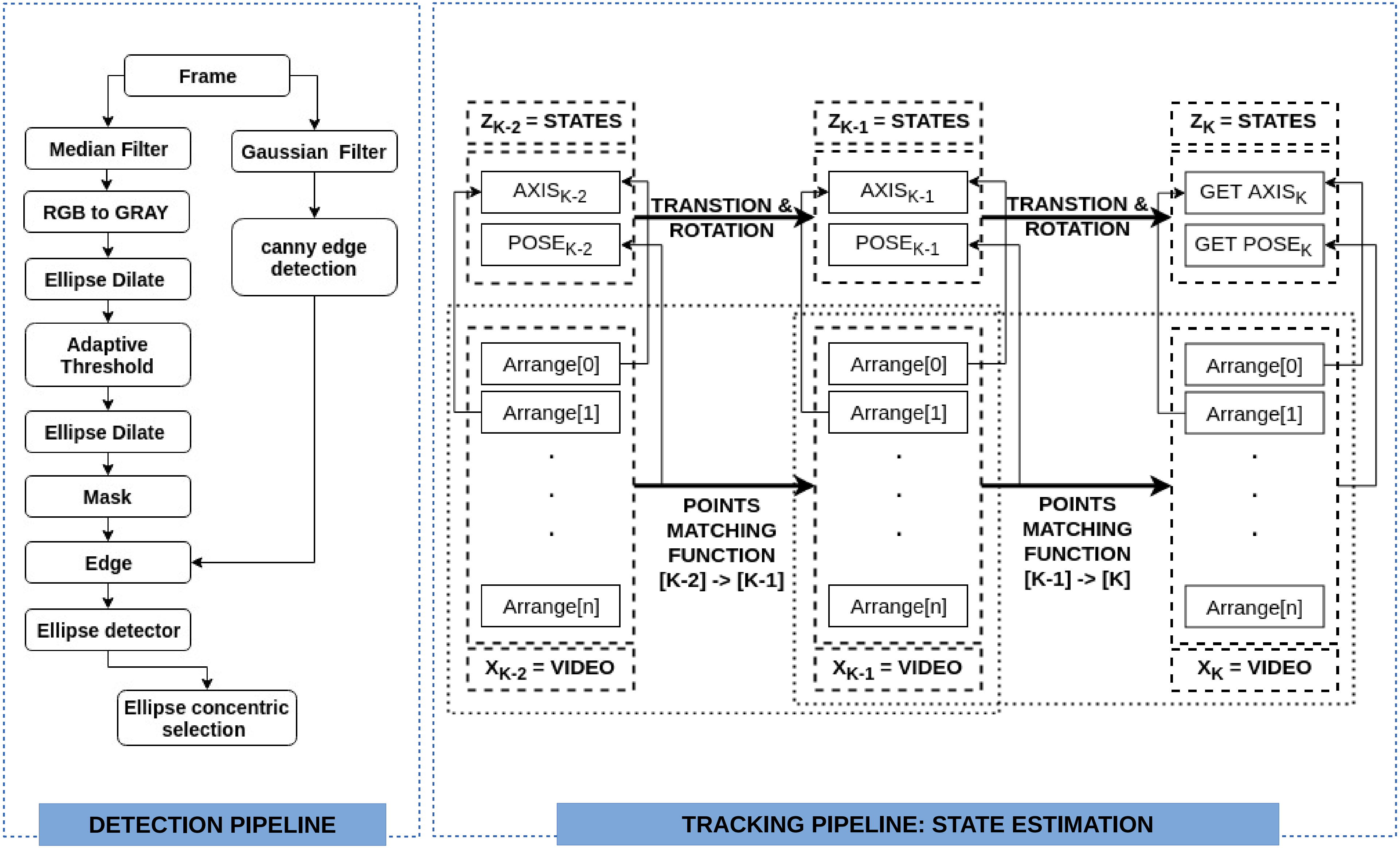
DETECTION AND TRACKING STEP



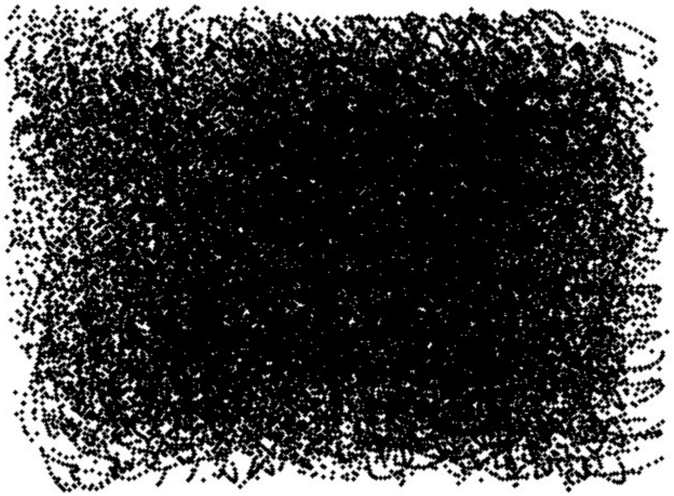
DENSITY DISTRIBUTION

The sector density method include quad segmentation over scene, in our case we define 4x5 sectors due the window size and proportion. To set the maximum number of points per zone or density (p), we establish a maximun number of frames to use in calibration process (N_{frames}), then based on number of elements per arrange ($N_{arrange}$) and total number of sections ($N_{sections}$), we define equation 1:

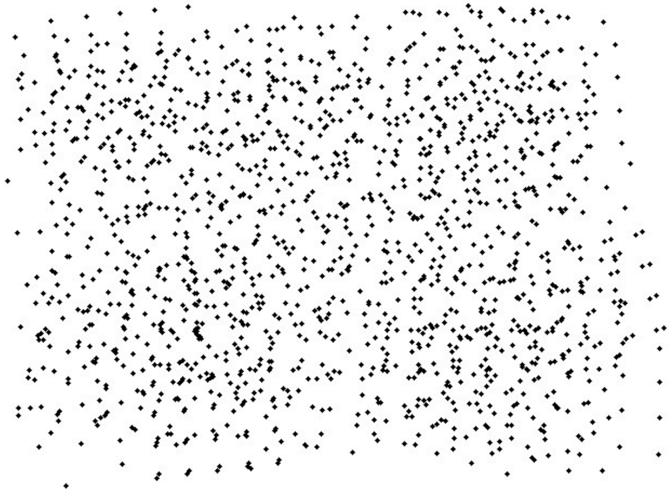
$$p = \frac{N_{frames} * N_{arrange}}{N_{sections}} \quad (1)$$

Algorithm Density Distribution (Vector of IFrames):
$p = N_{frames} * N_{arrange} / N_{sections}$
for $S = 1$ **to** $N_{sections}$ **do**
  for $F = 1$ **to** N_{frames} **do**
    Evaluate density with Iframes[F]
    if Pass evaluation **then**
      Add frame to OFrames
    end if
  end for
end for
return Vector of OFrames

DENSITY DISTRIBUTION ALGORITHM

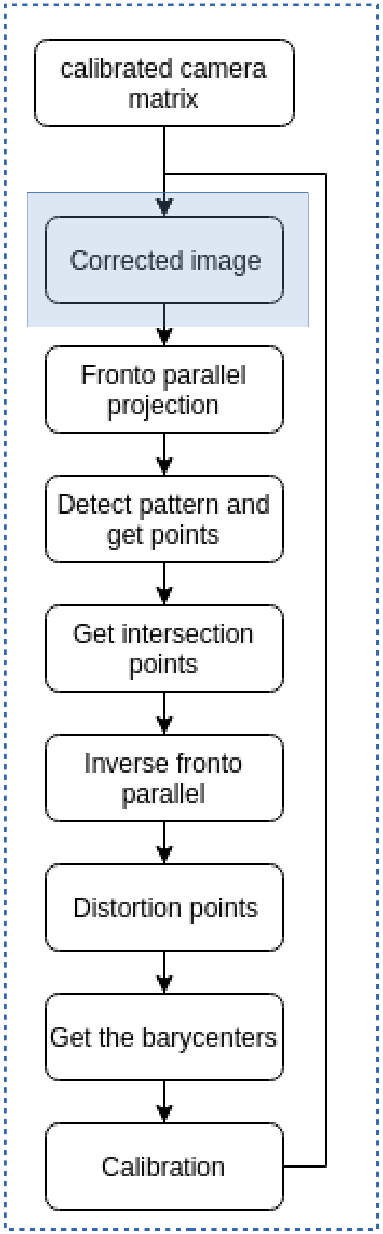


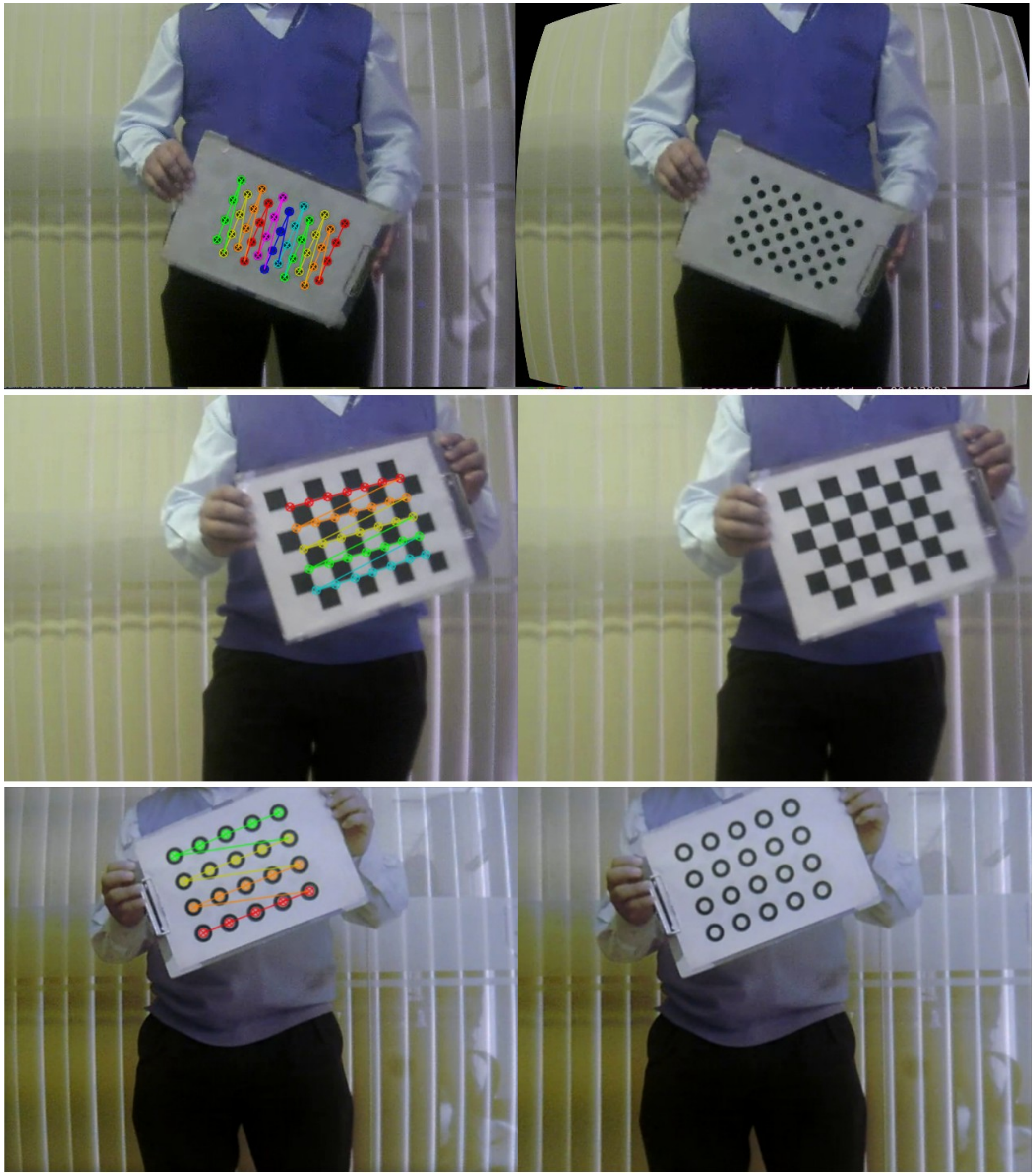
NO SAMPLED DISTRIBUTION: CONCENTRIC RING



SAMPLED DISTRIBUTION WITH RANDOM_SHUFFLE: CONCENTRIC RING

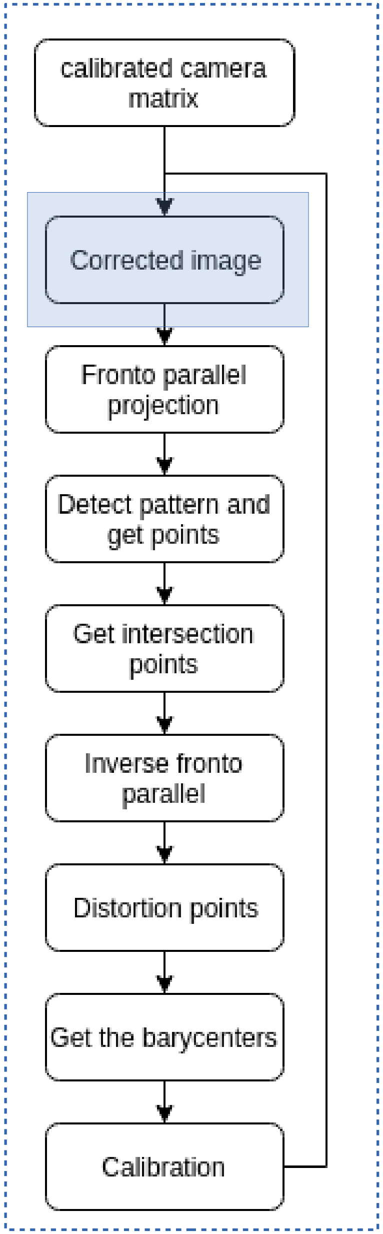
ITERATIVE REFINEMENT – CORRECTED IMAGES

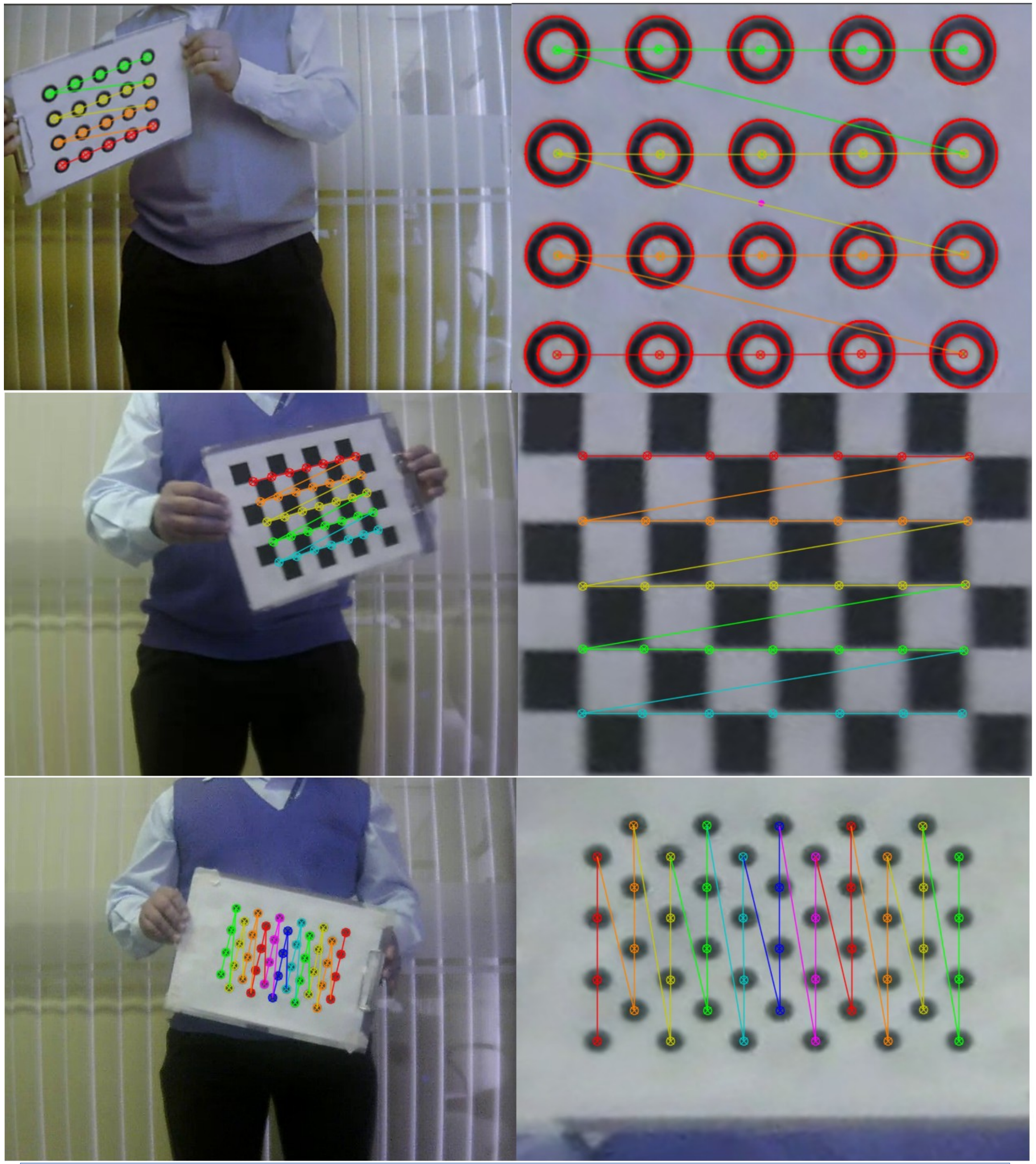




DISTORTION CORRECTION AFTER CALIBRATION

ITERATIVE REFINEMENT – FRONTO PARALLEL





FRONTO PARALLEL PROJECTION

RESULTS: LIFECAM CAMERA

P	F_x	F_y	C_x	C_y	$Coll$	RMS
$N_F = 25$						
0	598.095	593.730	348.270	235.708	0.0056899	0.4408
1	619.877	615.677	359.883	217.080	0.0041629	0.2495
2	587.567	582.977	310.336	222.569	0.0052875	0.2555
$N_F = 35$						
0	588.038	589.47	315.49	228.460	0.0054542	0.7608
1	622.340	625.00	340.08	205.049	0.0048213	0.1734
2	615.420	617.19	325.00	223.590	0.0054572	0.1817

TABLE 1. LIFECAM CALIBRATION RESULTS

- **(Cx, Cy)** : is a principal point that is usually at the image center.
- **(Fx, Fy)** : focal lengths expressed in pixel units.
- **Coll** : is collinearity calculated using average deviation of points from vectors formed with arrange corners.
- **RMS :** Root Mean Squar error from *OpenCV* **calibratecamera** function.
- **N_F** : Number of frames.
- **P** : Patter - Concentric rings (2), Assimetric disks (1) and Chessboard (0)

RESULTS: PS3 CAMERA

P	F_x	F_y	C_x	C_y	$Coll$	RMS
$N_F = 25$						
0	850.705	840.663	270.959	289.313	0.0067586	0.3721
1	859.836	858.969	367.794	259.614	0.0043134	0.2918
2	842.759	836.334	340.519	249.733	0.0022995	0.2956
$N_F = 35$						
0	854.051	856.016	348.220	250.09	0.0068142	0.2254
1	845.390	846.885	338.313	248.68	0.0044587	0.2104
2	844.195	847.380	340.606	260.84	0.0024955	0.2012

TABLE 2. PS3 CALIBRATION RESULTS

- **(Cx, Cy)** : is a principal point that is usually at the image center.
- **(Fx, Fy)** : focal lengths expressed in pixel units.
- **Coll** : is collinearity calculated using average deviation of points from vectors formed with arrange corners.
- **RMS :** Root Mean Squar error from *OpenCV* **calibratecamera** function.
- **N_F** : Number of frames.
- **P** : Patter - Concentric rings (2), Assimetric disks (1) and Chessboard (0)

RESULTS: DENSITY FUNCTION

P	F_x	F_y	C_x	C_y	$Coll$	RMS
$N_F = 25$						
0	598.095	593.730	348.270	235.708	0.0056899	0.4408
1	619.877	615.677	359.883	217.080	0.0041629	0.2495
2	587.567	582.977	310.336	222.569	0.0052875	0.2555
$N_F = 25$						
0	850.705	840.663	270.959	289.313	0.0067586	0.3721
1	859.836	858.969	367.794	259.614	0.0043134	0.2918
2	842.759	836.334	340.519	249.733	0.0022995	0.2956

P	F_x	F_y	C_x	C_y	Cl	RMS
C_T = LifeCam						
0	607.510	601.122	355.519	238.528	0.0066566	0.4881
1	598.650	599.681	361.555	216.388	0.0046648	0.2450
2	586.771	581.560	311.889	226.199	0.0049612	0.2291
C_T = PS3						
0	808.407	798.441	283.756	248.286	0.0050957	0.4330
1	878.781	883.128	395.578	319.782	0.0043304	0.3084
2	844.247	837.769	344.901	253.990	0.0023091	0.2982

TABLE 3. CALIBRATION RESULTS USING DENSITY DISTRIBUTION CAPTION OF FRAMES FOR BOTH CAMERAS FOR 25 FRAMES

RESULTS: ITERATIVE REFINEMENT

	Chessboard		Assim. disks		Concc. rings	
I	**RMS**	$Coll$	**RMS**	$Coll$	**RMS**	$Coll$
1	0.4408	0.0056899	0.2495	0.0041629	0.2554	0.0052875
2	0.4740	0.0057268	0.2178	0.0040713	0.2240	0.0049633
3	0.5177	0.0074094	0.2392	0.0045387	0.2305	0.0049960
4	0.5126	0.0081552	0.2190	0.0050206	0.2318	0.0047513
5	0.5276	0.0067847	0.2351	0.0038565	0.2260	0.0049553
6	0.4881	0.0066566	0.2448	0.0046648	0.2291	0.0049612

TABLE 4. ITERATIVE REFINEMENT CALIBRATION RESULTS USING DENSITY DISTRIBUTION CAPTION FOR LIFECAM CAMERA

	Chessboard		Assim. disks		Concc. rings	
I	**RMS**	$Coll$	**RMS**	$Coll$	**RMS**	$Coll$
1	0.3721	0.0067586	0.2918	0.0043134	0.2956	0.0022995
2	0.4424	0.0055703	0.3284	0.0044416	0.2958	0.0022504
3	0.4137	0.0047987	0.3249	0.0046165	0.3006	0.0023319
4	0.3735	0.0058645	0.3136	0.0046498	0.2975	0.0023014
5	0.4806	0.0060481	0.2894	0.0047778	0.2967	0.0023171
6	0.4329	0.0050957	0.3084	0.0043304	0.2982	0.0023091

TABLE 5. ITERATIVE REFINEMENT CALIBRATION RESULTS USING DENSITY DISTRIBUTION CAPTION FOR PS3 CAMERA

CONCLUSIONS

- As seen in the results, the asymmetric circles and rings patterns are better than the chessboard because they reduce the error by detecting their centers instead of edges and vertices, which ussually tend to fail. This generates an error in the calibration calculus obtaining very variable and distant results. This phenomenon is corrected using the iterative method but it does not apply to the rest of patterns.

- Between the assymetric circles and concentric rings, the last one have several concentric circles that help reduce the error when calculating the centers of the pattern.

- The iterative method does not imply a great advantage (in comparison with results obtained selection density function), it helps to reduce the error but it is not very significant, only in cases of cameras with greater distortion it is possible to appreciate like in ps3 case and for patterns that do not have much noise like concentric rings.

- About results presented on Ankur et al. [1], which we are trying to reproduce or at least understand and extrapolate to our case (PS3 and LifeCam cameras), we conclude that improvement percentages are proportional to the distortions level presented in cameras used. So if a video has little distortion (LifeCam) will not be improved on the corrected image, but for videos with high distortion (PS3) this correction becomes most notorious.

[1] Datta, Ankur, Jun-Sik Kim, and Takeo Kanade. "Accurate camera calibration using iterative refinement of control points." Computer Vision Workshops (ICCV Workshops), 2009 IEEE 12th International Conference on. IEEE, 2009.