

Re-Calibration of Camera Space Manipulation Techniques Accounting For Fisheye Lens Radial Distortion

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We explore the possibility to use Linear Camera Space manipulation (LCSM) algorithm [1] to map a large workspace using cameras equipped with fisheye lenses. We tested how the distortion of the image caused by the lens influences the precision of the LCSM algorithm when used to estimate the positions of visual cues in 3-D space. We used two Hero3 GoPro® (H3GP) cameras as a good compromise between acquisition rate and number of pixel in the image.. We used a previously published correction algorithm to eliminate the fisheye distortion [2] and compare it with standard calibration. The model estimate the radial distortion with a bi-quadratic equation which coefficients K_1 and K_2 . To estimate such coefficients a non-linear calibration called Stereo Calibration Method was also used [2]. Stereo calibration uses a pair of images, also known as a stereo pair, to estimate the relative depth of points in the scene. These estimates are represented in a stereo disparity map, which is constructed by matching corresponding points within the stereo pair. These coordinates are used to calculate the distortion factors of each camera lens.

After the theoretical distortion factors values were obtained, a Monte-Carlo analysis was performed correcting each image using a range of coefficients around the theoretical values. Thus, a LCSM recalibration with the corrected images was performed. This comparison tests the robustness of the LCSM calibration algorithm and evaluate if dedicated signal pre-processing are necessary for the camera calibration.

LCSM calibration provide a set of view parameters for each camera that relate the position of a visual cue in the sensor's space with its position in the operational space. The Accuracy of the view parameters directly influences the positional error of the points in the operational space.. Such error can be analyzed via a "leave one out" method [3] and computed as the Euclidian norm between the known position and the estimated position.

Two CODA-motion scanner systems calculated the 3D positions of each calibration point. Two active markers were placed in the plane of the calibration pattern at a known distance. This allowed for the establishment of a framework for each calibration pattern for the two H3GPs consisting of a 13 by 26 checkerboard with 38.1x38.1mm squares. The cameras, calibration pattern, and CODA-Motion scanners' locations were not important when initially positioning the cameras, but had to be maintained in a fixed location for the rest of the experiment for consistency of the data image collection..

A Monte-Carlo analysis was performed creating a range of distortion coefficients (K_1 , K_2) containing those suggested by the estimation. As first step, using the distortion model and the different proposed values for the (K_1, K_2) pairs, images were corrected. For each distortion pair the LCSM calibration algorithm was run for 3900 calibration points in a workspace of 0.5x3x1 m. The first linear calibration of the camera space manipulation had an average overall error of 6.87mm, while running the linear method after radial distortion correction provided an overall error average of 6.56mm.. A one-way ANOVA test with $\alpha = 0.95$ was performed between the error distribution of undistorted images and the lowest average calibration error achieved with $K_1 = -0.468$, $K_2 = 0.842$ for the left camera, and $K_1 = -0.320$, $K_2 = 1.002$ for the right camera.. Even though there was a statistically significant difference between the corrected and un-corrected error distributons($p < 0.001$), the results show that the radial distortion does not seem to greatly degrade the accuracy of calibration when LCSM is used. This is particularly true, if the calibration space is conveniently located near to center of image. We found that a non-linear correction of the image does not affect much the calibration of H3GP. Some price advantages include the low camera costs of H3GP compared to specialized computer-vision cameras.

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RE-CALIBRATION of CAMERA SPACE MANIPULATION

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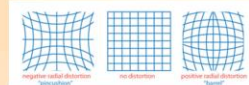
Mapping of 3-D Space



- During research, we explore the possibility of using a computer vision system to map an underwater workspace where the position of a robotic system can be tracked, using GoPro cameras.
- A successful vision-based control technique used in this literature is **Camera Space Manipulation (CSM)**.
- This mapping uses an algorithm that is expressed as a function of certain parameters vector, defining the relationship between the physical location of the visual features to map an large workspace using fish eye lens.

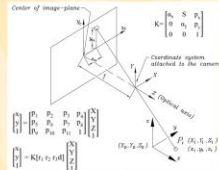
Re-Calibration of CSM

- We used a correction method to decomposed the original equations of the view parameters and intrinsic parameters to compensate for fisheye lens distortion of the GoPro Cameras.
- This allowed us to again determine distortion coefficients using a non linear versus a linear model.



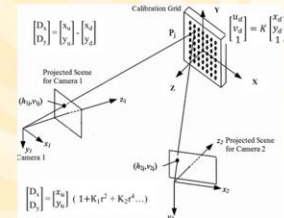
Fish Eye Lens Distortion

- The CSM calibration method used mapping based on a "pin-hole camera model" with a 3x4 matrix which uses parameter qualities to described a set of "view parameters" mapping the Cartesian coordinates to the sensor coordinates



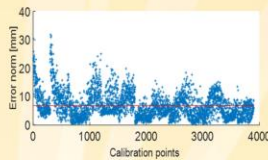
- "p" are composite parameters that take into consideration intrinsic parameters of each camera. $[r_1, r_2, r_3]$ is the 3x3 rotational matrix between (X,Y,Z) and (x,y,z) frame, "d" is the 3x1 vector pointing to (X,Y,Z) with respect to (x,y,z), K us a 3x3 matrix of intrinsic parameters

- A second method (Stereo Vision) allowed to calculate the intrinsic parameter of the camera (K) in order to calculate the distortion of the lens

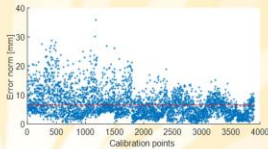


Calibration Error Analysis

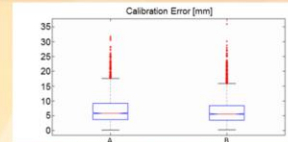
- Virtually all imaging devices introduce a certain amount of nonlinear distortion, where the radial distortion is the most severe effect.
- While generating "K" values to correct this distortion when plotting our virtual map we did an error analysis.
- We compared the distortion of the fisheye cameras without and with correction factors.



Calibration Error using distorted images without corrected model.



Calibration Error using correction value of distorted image generated by MATLAB using new model



Statistical analysis of calibration error A) Distorted B) Corrected

Source	SS	df	MS	F	Prob > F
Columns	142.4	1	142.449	7.22	0.0072
Error	153808.9	7798	19.724		
Total	153951.4	7799			

Conclusion

- The first linear calibration of the camera space manipulation had an average overall error of 6.87mm
- The second method with correction for radial distortion provided an overall error average error of 6.56mm.
- While the average calibration error decreased and was statistically significant the change was minimal.
- We conclude that the original process of CSM developed still provides many advantages including ease of use, computational efficiency, and low calibration errors.

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