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UTILIZING THE HOUGH TRANSFORM WHEN CALIBRATING A 3D STEREO IMAGING SYSTEM

HP INC

Utilizing the Hough Transform when calibrating a 3D stereo imaging system

This disclosure relates to the need for calibrating a 3D stereo imaging system in a broad sense where the totality of the required calibration grid is not known or contains missing elements. The methodology utilizes the Hough Transform for interpreting the calibration grid amid various image distortions and returning the aligned grid points for use in subsequent calibration steps.

Image processing software is disclosed that applies the Hough Transform (Hough) to a series of images taken of a regular grid used for the calibration of a 3D stereo vision system. The Hough Transform is used for aligning the imaged calibration points into the associated straight lines on the physical calibration grid (grid). The requirement is for a generic solution that allows the calibration grid to extend outside the field of view (fov), have varying magnification, dimensions, and distortions, along with not being constrained by any hard-defined calibration point shapes (circles, squares, grids, etc).

Prior to this disclosure, open source methodologies required the whole calibration grid to be contained within the image, have prior knowledge of the grid layout (rows by columns), and in some cases are limited to a chess board type of pattern. In the general sense, these limitations constrained the calibration process to grids small enough to fit within the fov for all viewing angles and rotations.

Various methodologies can be used for locating the center of a dot or the intersection of chessboard-type gridded squares within an image. In the most general sense, these methodologies can return a randomly sorted list of points that need to be sorted into the grouped points associated with the linearly laid out grid lines. Many methods exist for sorting points that can be augmented with some type of a (x,y) hash method to determine the point order in a linear sense. Figure 1 shows an example random point listing associated with the easiest case of a non-rotated vertically aligned imaged grid. In this example, even a simple case of zero rotation of the grid still possess a random ordering of the points associated with the line. Considering greater complexities associated with grids imaged at various angles containing perspective and lensing distortions, the sorting problem becomes N-fold complex.

With the understanding that the Hough for straight lines, Eq 1, returns a set of values for a given angle, when all the given points lie on a single line the returned Hough values will be equal within some small noise distribution. This understanding can be taken advantage of by viewing the grid points as samples along a continuous line, hence a single point within the Hough space will represent a given column (or row) “line” on the imaged grid. As an example, when considering the zero-degree rotated grid, the associated grid columns separated in the X-axis will appear as consecutive groupings spaced vertically at the zero-degree angle in the Hough space, see Fig 2.

Also present in Fig 2 are groupings that occur with other Hough angles. These groupings are the result of Hough lines that transcribe diagonally through points not associated with a row or column. These other groupings do possess a challenge when analysing the Hough space, and will be further explored. As with most problems, quite often if the analysis space can be limited in some sort or fashion, the resulting system analysis can be simplified. The first challenge to be addressed is in separating out lines associated with columns and those associated with rows. The general Hough can sweep the theta angle from 0 – 360 degrees, completing a full revolution around the theta space. When this occurs, both groupings associated with rows and columns are present in the Hough space data causing confusion. If the swept angle is limited to something less than 360 degrees, the desire would be to have only groupings associated with rows or columns, but not both at the same time present in the Hough space. In Fig 3, candidate lines have been drawn through rows and columns on imaged calibration grid as well as their resulting Hough lines. By observing the associated Hough angle for the rows and columns in Fig 3 (a) it is seen that by limiting the swept Hough angle from 0 – 90 degrees, then the confusion between rows and column angles in the Hough space are removed. However, in Fig 3 (b), it is seen that there will still be cases where some confusion between rows and columns occurs, albeit the confusion is greatly simplified. The resulting simplification will be to limit the swept Hough angle to 0 – 90 degrees.

As previously mentioned, when sweeping the Hough angle, various other groupings will be present in the Hough space resulting from Hough lines that transcribe diagonally through points associated with neither a row nor column. The challenge becomes how to determine the groupings associated with rows or columns, and those associated with diagonal lines. An understanding of the Hough space is made when considering a family of swept angles slightly perturbated around the true Hough angle for the current sample under test. As the swept Hough angle lines up better with a line transcribing through the actual point centroids of a column (or row), the resulting Hough data values will gather closer to each other, and at the true angle all the Hough data values will collapse on top of each other as demonstrated in Fig 4. This is a powerful observation that can be greatly leveraged. For all angles not associated with the true rows or columns, the returned Hough values will not be well converged and the data points will smear out not forming any tight groupings. This observation manifests itself in the Hough space as the region best aligned with the rows or columns of the grid and will also be the most compact region, see Fig 5.

In Fig 5 it is also observed that when the grid image has perspective distortion, there is no single Hough angle that lines up simultaneously with all the rows or columns, resulting in groupings spanning across several angles. Also noted is there can be more groupings than the associated number of rows or columns in the grid (40 versus 20 in this example). This occurs when a given Hough angle is approximately equal distance from the true angles of neighbouring grid lines, resulting in groups in two neighbouring Hough angles associated with one line in the grid. For these cases, a further winnowing step is required to down select the best groups for the given grid image. At this point, the algorithm searches for the most compact angle within the Hough space, then selects a region around it to encompass all possible groupings associated with the current imaged grid. Of the Hough angles contained within the local region, considering one angle at a time, the Hough data values are gathered into groups by looking at the maximum and minimum spacing between data values, statistically determining the points that align within the current group and those that belong to the next group, see Fig 6. Utilizing the knowledge that all rows or columns have equal number of points, possibly minus a few due to the grid extending beyond the fov, the gathered groups are sorted by the number of points in each group, and the most common group count is selected as the points associated with the grid rows or columns, depending on grid orientation. The final step is to keep only the Hough angles in the local region containing groups with the most common count.

At this point in the algorithm, all candidate groups within the Hough have been found and selected. The last processing step is to map the related Hough values back to the original grid (x,y) points relating to the row (or column). Fig 7 shows an example Hough and the grid points associated with each of the selected Hough angle groups. As mention previously, it is possible for the same grid points to appear in more than one Hough group when the Hough angle bisects the angles associated with two grid lines deformed by perspective distortion. In Fig 7 this is apparent when adding up the number of rows across all the Hough groups to be 23, when the actual grid only had 20 rows.

The last step is to remove the overlap (redundant points) between associated Hough groups. This step is easily enough achieved by comparing the (x,y) values of one group to those of the next group.

The amount of overlap is determined by evaluating edge points in successive groups; overlap exists when the last coordinate of a group lines up with the first coordinate of the next group. Since these values all come from the same grid points, it is only necessary to remove the redundant points from one of the two groups sharing the common points. Once the overlap has been removed, the remaining values can be reassembled into one grid with the points all aligned in either a row or column, depending on the original orientation of the grid under the camera.

In summary, this disclosure demonstrated the need for a means to take a random list of points from a rectangular calibration grid, and apply the Hough Transform as a robust method for sorting the calibration grid points into those associated with either a row or a column, but not both at the same time. The required processing steps to interpret the Hough Transform space were covered, with steps to select the correct groups pertaining to the rows or columns of the calibration grid, and to then transform back to the original grid values (x,y) and assemble points into appropriate rows or columns.

Disclosed by Andreas H Queisser, Daniel Mosher and Brad N Dixon, HP Inc.

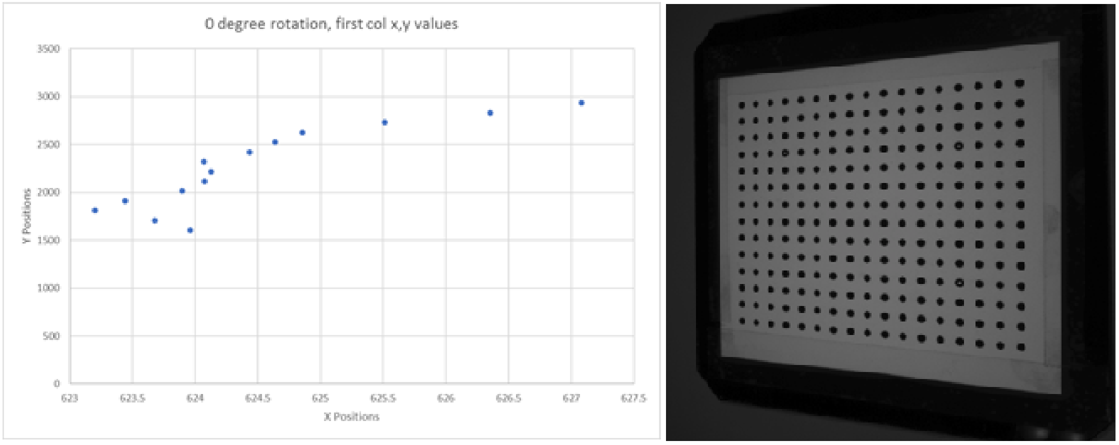


Figure 1:
One column of found dot locations, showing the random nature of point locations, even when sorted using Excel (for demonstration).

$$r = x\cos\theta + y\sin\theta\,,$$

Eq 1
The Hough Transform equation for straight lines

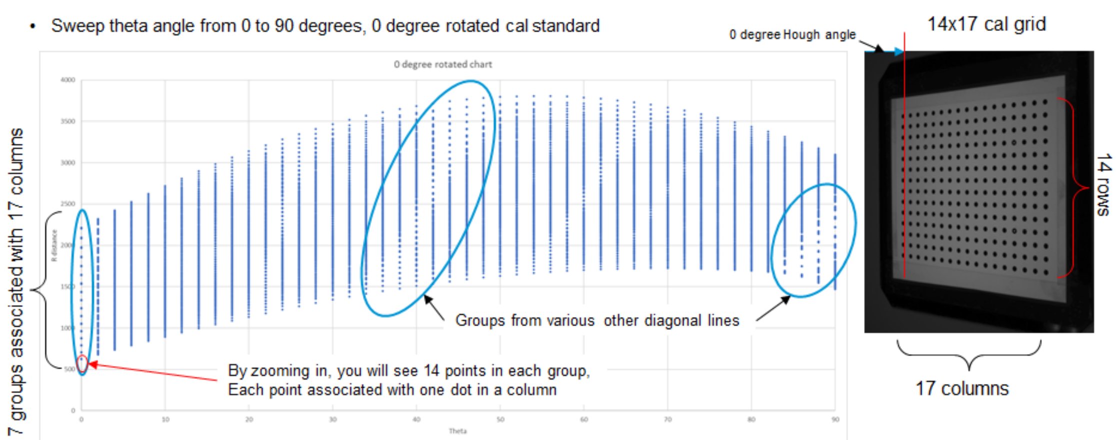
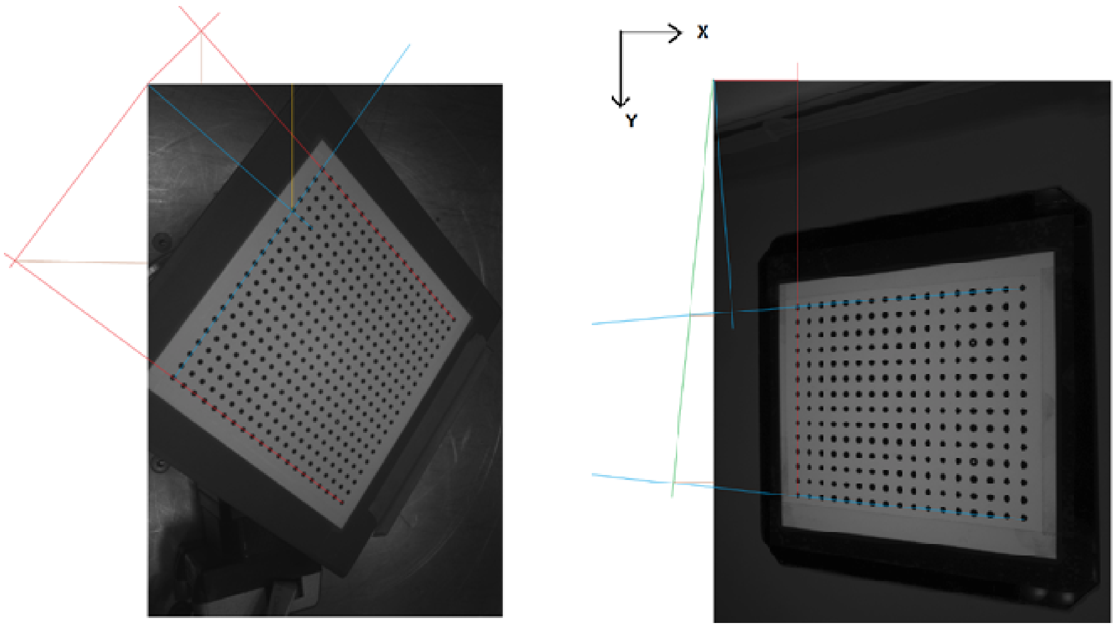


Figure 2:
Example Hough Transform Results when sweeping the Hough angle from 0 to 90 degrees



(a) (b)

Figure 3

In (a) are three lines drawn through a set of dots associated with a row or col. Also drawn are the associated Hough R lines, with the resulting Hough theta angles for the rows extending beyond the theta range of 0 – 90 degrees. In (b) the same set of three lines are drawn again for an imaged calibration grid at a different angle. In this case the line associated with one column will be contained in the Hough data, even when limiting the theta angles in the range of 0 – 90 degrees.

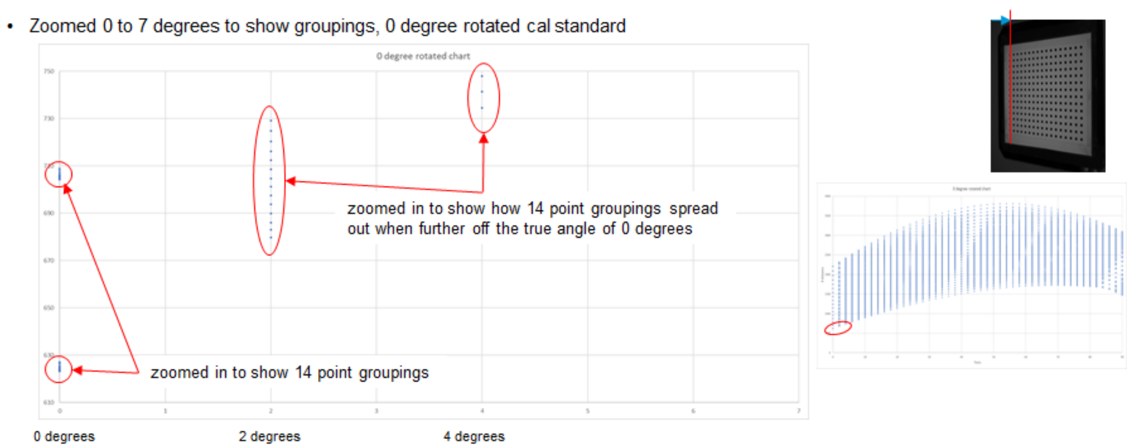


Figure 4

Demonstrated here is how the Hough space data values begin to collapse upon each other as the swept Hough angle comes closer to the actual angle of the associated grid.

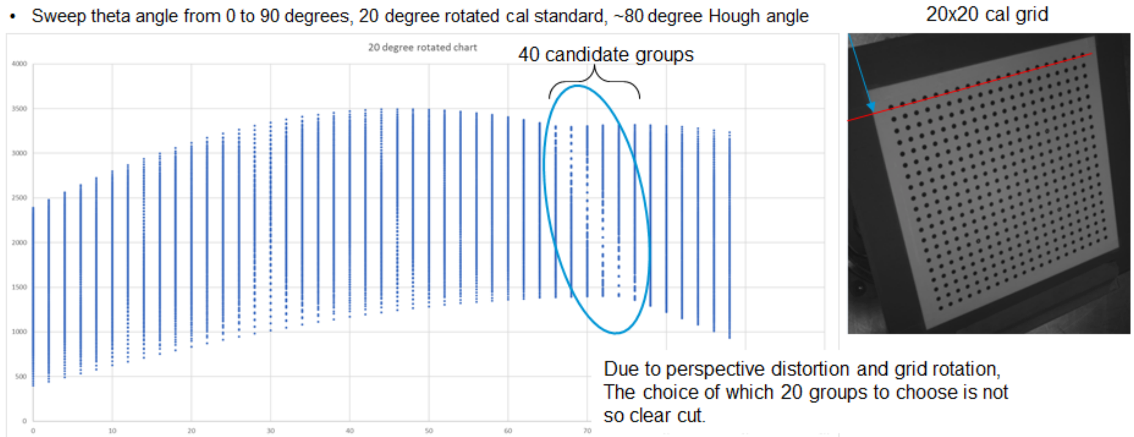


Figure 5

Demonstration of how the Hough space becomes the most compact when the candidate Hough angles line up with the actual rows or columns of the calibration grid. Also shown is when perspective distortion occurs, not one Hough angle aligns with all the rows or columns simultaneously.

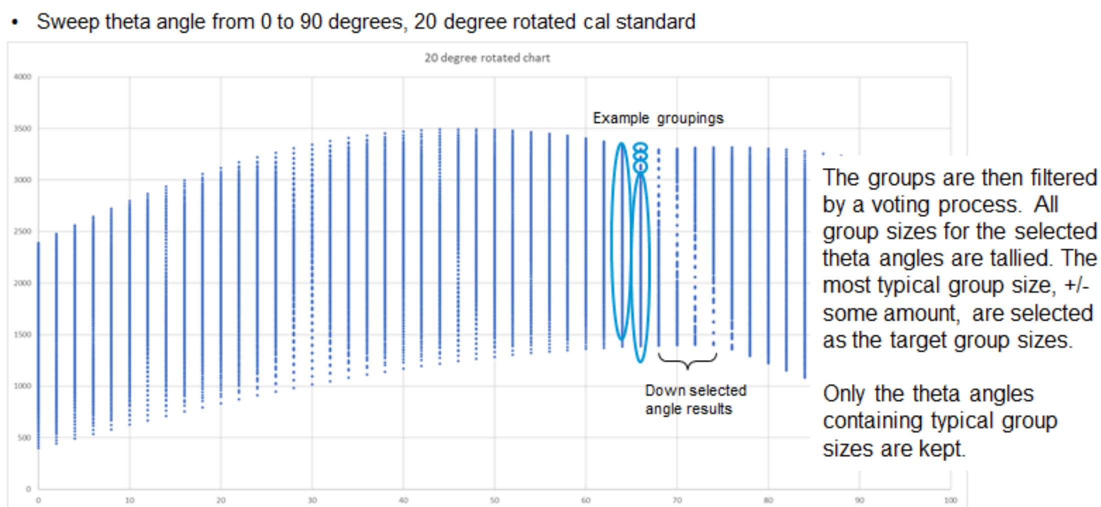


Figure 6

Demonstration of candidate groups for each Hough angle.

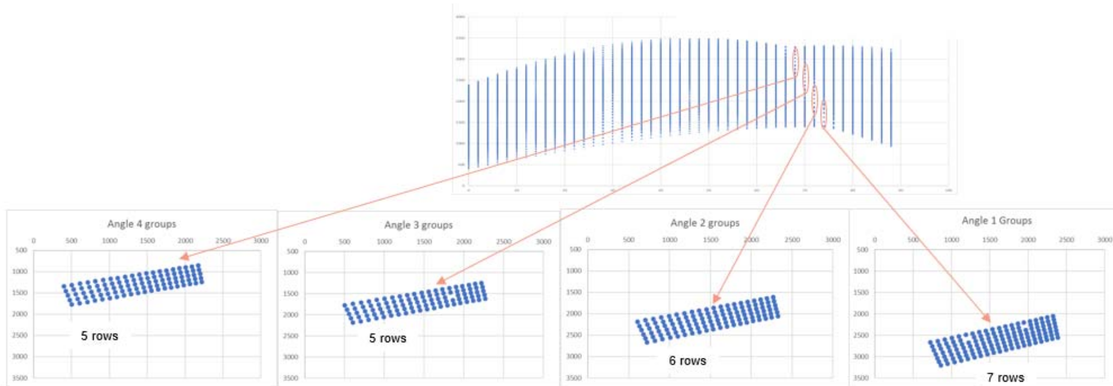


Figure 7

By retrieving and plotting the (x,y) values for the points in the typical sized Hough groups, the associated rows (or columns) within the grid can be seen associated with the different Hough angles. Also noted is the overlapping rows from one Hough group to another, expected 20 but found 23 rows.