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Optimisation of patterned illumination to improve depth estimation from a plenoptic camera

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Abstract: Depth maps of featureless planar scenes acquired using a plenoptic camera contain large errors. The accuracy of the depth estimation can be improved by projecting a random pattern onto the imaged plane

1. Introduction

One method for gaining a three dimensional representation of the world in a single image is by the use of a plenoptic camera [1]. This is achieved by placing a microlens array between the sensor and main lens, splitting rays which would originally be incident onto a single pixel onto a 2D array, often called a microimage [2]. The raw data captured contains both spatial and angular information from which digital refocussing, perspective shift, synthetic aperture, extended depth of field and the generation of a depth map can all be achieved from a single image acquisition. The calculation of depth maps, unlike some of the other attributes of plenoptic imaging, is not a rigid function. Instead, the depth maps rely on the registration of features between neighbouring microimages. This then poses problems when attempting to image scenes with no or very little texture, as the registration algorithms may become less reliable or generate incorrect depths. This problem can be corrected by projecting patterns onto scenes with limited texture or features. The aim of this investigation is to determine how different patterns affect the depth calculation and attempt to optimise this pattern to improve the accuracy of the depth map.

2. Methods and results

The imaging system for the investigation comprised of a Raytrix R11 camera (Raytrix GmbH, Kiel, Germany) and an LED projector to illuminate the scene. The scene being imaged was a featureless flat white sheet, which was rotated at 2.5° intervals from parallel to the sensor of the camera to 30° to the sensor of the camera, as shown in Fig. 1. The scene was illuminated with a variety of patterns using the projector, including a regular grid of black and green dots, a randomly generated pattern, a penrose pattern that is quasi-periodic and vertical stripes(orientated parallel to the y-axis from Fig. 1). In order to avoid distortion of the projected pattern, the projector was moved along with the scene so that they were always perpendicular to each other.

The depth maps were generated using the software provided with the Raytrix camera (RxLive 2.10). Depth maps were generated for every angle and pattern, then from each of these depth maps the mean of each column was taken (parallel to the y-axis from Fig. 1). These means were then plotted onto a graph and a straight line was fitted to calculate the angle of the slope from each depth map. The calculated angle was then compared to the known angle of the scene and the difference between the two has been calculated. The results of this can be seen in Fig. 2. and Table 1.

3. Conclusion

The results presented can provide many useful insights into the impact of projecting different patterns onto a featureless scene on depth maps generated by plenoptic cameras. Firstly, from looking at Table 1 it appears the random pattern to be the most accurate, as it has the lowest total and mean differences between the actual and calculated angles as well as the smallest standard deviation. The second interesting point to note from Table 1 is the

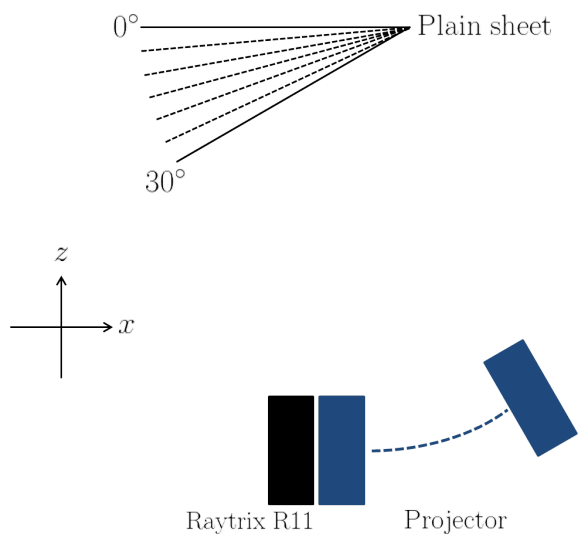

Fig. 1. A schematic diagram of the experiment. The black box is the Raytrix R11 camera, the blue box is the LED projector and the black line represents the featureless sheet. The diagram shows how the sheet and projector have both being rotated by 30° in 2.5° intervals. The Raytrix camera stays in a constant position throughout the experiment.

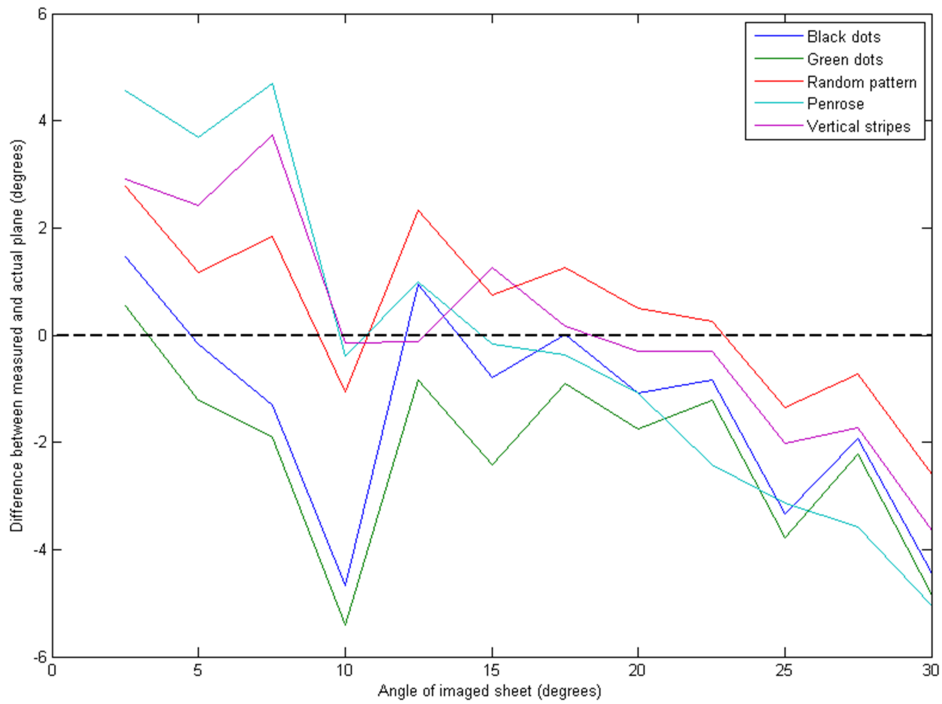

Fig. 2. A graph showing the difference between the angle calculated from the depth maps and the actual known angle of the scene. A value below zero represents the calculated angle being lower than the real and above zero represents the calculated angle being greater than the real angle.

Table 1. Statistics showing the total and mean differences between the actual angle and the calculated angle from the Raytrix depth maps. The values include all angles from 2.5° to 30° in steps of 2.5° for all five patterns. The standard deviations for each pattern are also presented.

	Black dots	Green dots	Random pattern	Penrose	Vertical stripes
Total difference	21.0	27.0	16.7	30.1	18.7
Mean difference	1.8	2.3	1.4	2.5	1.6
Standard deviation	1.57	1.61	0.83	1.84	1.39

difference between the black and green dotted patterns. As these two patterns are identical apart from their colour, this indicates that the plenoptic camera produces a more accurate depth map when a black pattern is projected onto a white surface rather than a coloured pattern.

From evaluating Fig. 2. certain conclusions can be drawn. The figure shows that at small angles (2.5° to 7.5°) the calculated angle is greater than the actual angle of the plane for all patterns apart from the black and green dots. Then from 12.5° to 20° the results for all patterns are close to zero, indicating an accurate depth estimate. When the plane is at the largest angles however (25° to 30°), every pattern calculates the angle to be less than the actual angle of the scene. That is, the depth is not well estimated when objects are either perpendicular to or tending towards being parallel to the camera axis (z-axis in Fig. 1). The latter of these is not surprising as a small error in registration will give a large error in estimated depth, the former is more surprising as the depth is more or less constant and so you'd expect it to be very error-tolerant.

Future work on this topic will involve completing the same experiment to larger angles to see if the trend of underestimating the angle continues. It would then also be interesting to see if the random pattern still appears to be the most accurate pattern, or if there is some angular dependence on which pattern is optimal. A future experiment will also involve experimenting with the percentage of black and white in the random pattern. For this experiment, the pattern contained 75% white pixels and 25% black, but it could be interesting to see if there is an optimum ratio between black and white. Future work will also involve imaging non planar objects to test if similar depth accuracies can be achieved and if the optimum pattern is related to the object being imaged.

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