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Improving depth estimation from a plenoptic camera by patterned illumination

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1. INTRODUCTION

Plenoptic (light-field) imaging is a technique that allows a simple CCD-based imaging device to acquire both spatially and angularly resolved information about the "light-field" from a scene. It requires a microlens array to be placed between the objective lens and the sensor of the imaging device[1] and the images under each microlens (which typically span many pixels) can be computationally post-processed to shift perspective, digital refocus, extend the depth of field, manipulate the aperture synthetically and generate a depth map from a single image. Some of these capabilities are rigid functions that do not depend upon the scene and work by manipulating and combining a well-defined set of pixels in the raw image. However, depth mapping requires specific features in the scene to be identified and registered between consecutive microimages. This process requires that the image has sufficient features for the registration, and in the absence of such features the algorithms become less reliable and incorrect depths are generated. The aim of this study is to investigate the generation of depth-maps from light-field images of scenes with insufficient features for accurate registration, using projected patterns to impose a texture on the scene that provides sufficient landmarks for the registration methods.

2. PLENOPTIC IMAGING THEORY

A ray of light can be described as a five dimensional function represented as $\mathrm{L}(x, y, z, \theta, \phi)$, which includes both spatial and angular information about the radiance. However, in the absence of any occluders, one dimension is lost. The ray can then be parameterised by a ray of light between two planes (u, v) and (s, t) to create the plenoptic function $\mathrm{L}(u, v, s, t)$. One method of capturing this four dimensional function is by using a plenoptic camera, in which a microlens array is placed between the main lens of the system and the sensor. The traditional plenoptic camera is configured such that the microlens array is placed on the focal plane of the main lens, and the sensor on the focal plane of the microlens array.[1,2] When in this configuration, the pixels in each microimage represent the angular information and the spatial resolution is a function of the number of microimages. The second configuration has been named the focused plenoptic camera,[3] where the microlens array is no longer placed on the focal plane of the main lens, but instead forms a relay system such that the it obeys the thin lens equation. One of the major advantages to using the focused over the traditional plenoptic camera is the decoupling of the spatio-angular trade off from the number of microimages in the raw data.[4] This allows greater flexibility in both the design of the system and the achievable results. Schematic diagrams for both the traditional and focused plenoptic cameras can be see in Figure 1.

3. IMPROVING DEPTH BY PATTERN PROJECTION

With the use of a projector to add texture to a scene validated in Section 4, an investigation into whether adding texture via patterned illumination to a scene does improve depth can be performed.

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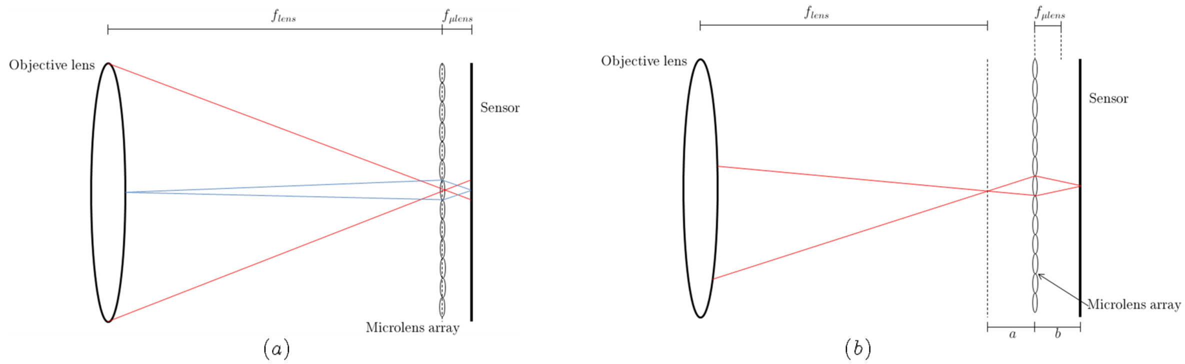

Figure 1. Configurations of two different plenoptic cameras: (*a*) The traditional plenoptic camera. (*b*) The focused plenoptic camera.

3.1 Method

The imaging system comprised a Raytrix R11 camera (Raytrix GmbH, Kiel, Germany) and a projector, arranged as shown in Figure 2(*a*). A plain featureless sheet was positioned in front of the system at a number of different angles in relation to the cameras sensor plane, from 0° to 45° at intervals of 15° as shown in Figure 2(*a*). The sheet was illuminated first with unstructured white light and then with a structured pattern as shown in Figure 2(*b*). The projector was also rotated by the same amount as the plane and kept at the same distance away to ensure the projected pattern remained the same throughout the experiment. Depth maps were computed using software supplied with the Raytrix plenoptic camera (RxLive 2.10).

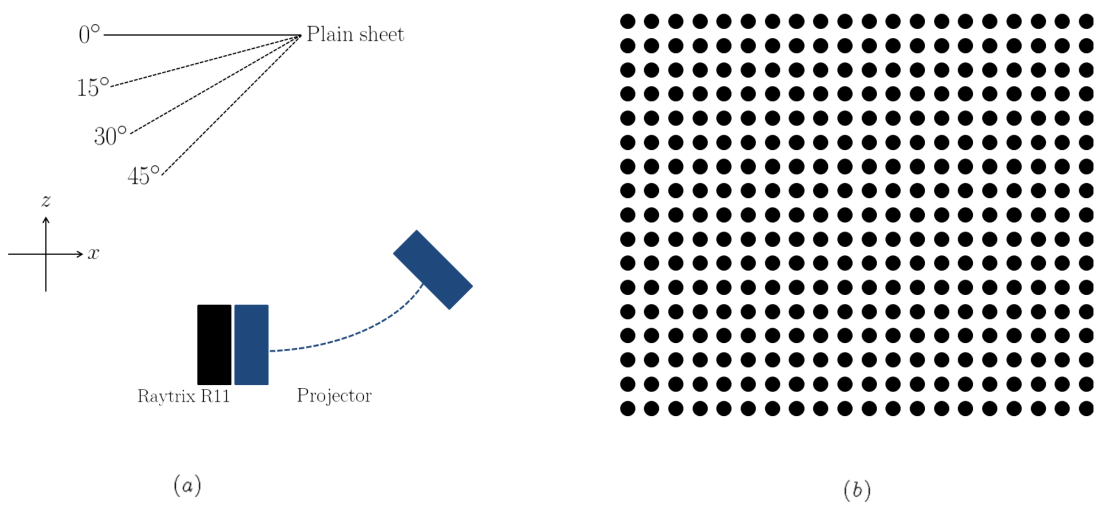

Figure 2. (*a*) An overhead view of the experimental set-up. The blue box represents the projector and the black box the Raytrix R11 plenoptic camera. The black lines represents the plane sheet being imaged at varying angles from parallel to the camera sensor to 45°. (*b*) The pattern projected onto the featureless sloped scene whose results can be seen in Figures 5 and 6.

3.2 Results

The results are presented in the form of line plots which show the mean and standard deviation of the computed depth for the points lying at the same physical depth. The computed surface angle is calculated from the relative differences in the values of the depth map between adjacent pixels. The depth maps for 0° and 45° for both the unstructured white light and the regular grid of small black circles can be seen in Figures 3 and 5 respectively. Figure 4 shows the line plots and computed depths for unstructured white light and Figure 6 the results for the projected dot pattern shown in Figure 2(*b*).

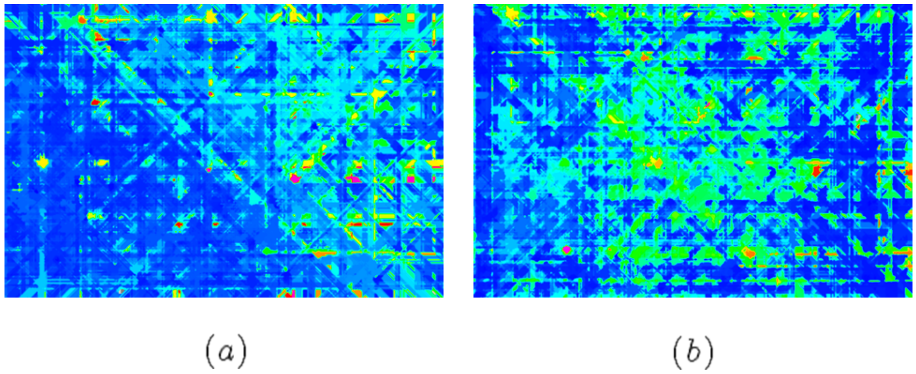

Figure 3. Depth maps produced by Raytrix software when illuminated with unstructured white light at angles of (a) 0 degrees to the sensor plane (x-axis on Figure 2(a)), and (b) 45 degrees to the sensor plane. In these images, the blue end of the visible spectrum represents a distance further away from the camera in comparison to red.

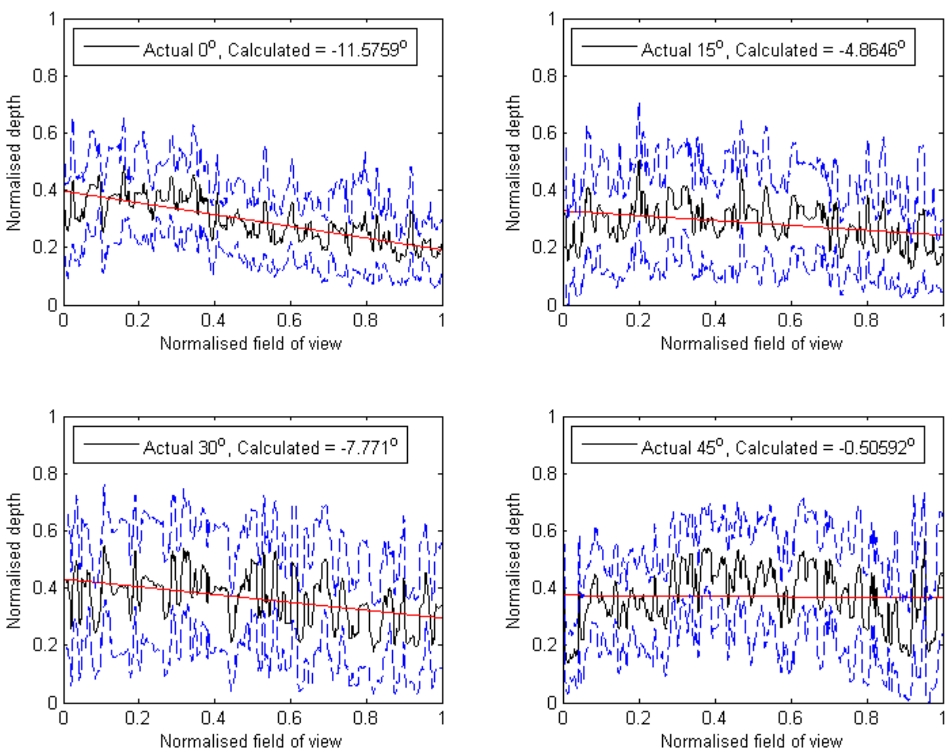

Figure 4. Graphs showing the normalised depth of a point at angles of 0°, 15°, 30° and 45° to the plane parallel to the camera sensor when illuminated with unstructured white light. The results show the recorded data (black), the calculated line of best fit to this data (red) and plus and minus one standard deviation from the data (blue).

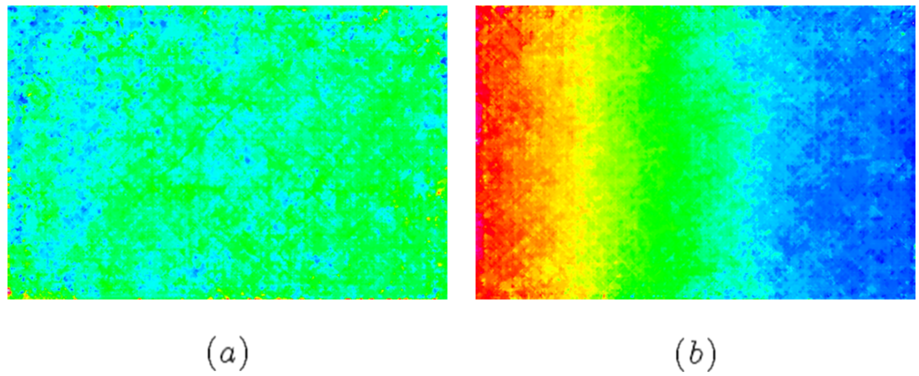

Figure 5. Depth maps produced by Raytrix software when illuminated with regular grid of black dots, as shown in Figure 2(b) at angles of (a) 0 degrees to the sensor plane (x-axis on Figure 2(a)), and (b) 45 degrees to the sensor plane. In these images, the blue end of the visible spectrum represents a distance further away from the camera in comparison to red.

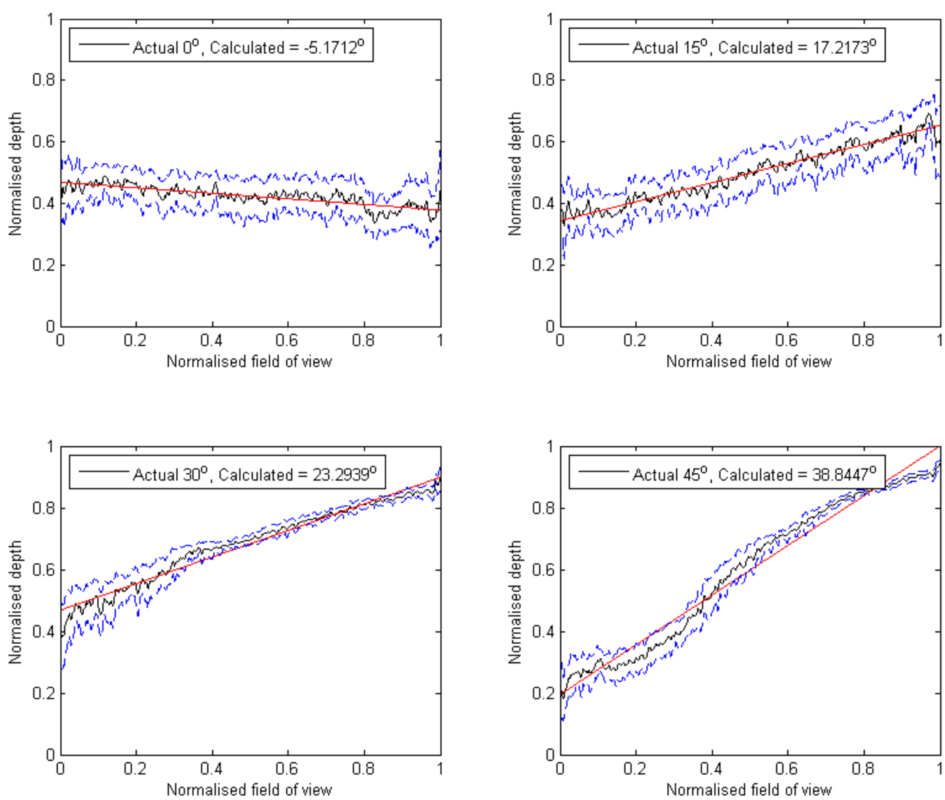

Figure 6. Graphs showing the normalised depth of a point at angles of 0°, 15°, 30° and 45° to the plane parallel to the camera sensor when illuminated with a regular grid of small black circles. The results show the actual data (black), the calculated line of best fit to this data (red) and plus and minus one standard deviation from the data (blue).

3.3 Conclusion

By comparing Figures 4 and 6 it can be seen that when illuminated with unstructured white light, virtually no depth information is present as the calculated gradients are far from the actual physical gradient. However, when illuminated with a pattern, the difference between the actual and calculated gradient is significantly decreased. These results correlate with the initial hypothesis, that the depth calculation in Raytrix R11 plenoptic camera strongly relies on registration between adjacent microimages. If there is no texture in the scene, the depth recovery algorithms produce erroneous results. This work also conclusively demonstrates that depth estimation from a plenoptic camera can be improved significantly with the projection of texture. Future work will involve the optimisation of the illumination pattern, and include an investigation of depth recovery from more complex scenes.

4. VALIDATION OF USING A PROJECTOR TO ADD TEXTURE TO FEATURELESS SCENES

In order to use projected patterns to improve the depth maps from a plenoptic system, it is important to first validate the use of a projector compared to texture being already present in the scene. To investigate its validity, an experiment was designed to explore the differences in calculated depth between a printed and projected pattern onto a plane at varying angles.

4.1 Method

The imaging system comprised a Raytrix R11 camera and a projector. Initially, the plenoptic imaging system would image a sheet with a pattern printed onto it. After being imaged twice, the printed sheet was then replaced by a featureless plane, onto which the same pattern was projected and imaged twice. Images were taken at angles of 0°, 10° and 20° to the sensor. The chosen pattern can be seen in Figure 2(b), and examples of the depth maps produced via a projected and printed pattern can be seen in Figure 7

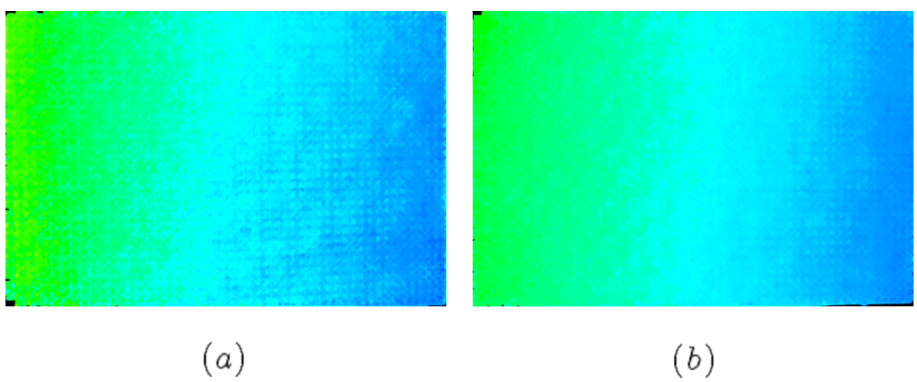

Figure 7. Depth maps produced from the Raytrix camera with a plane at 20° to the sensor with (a) the pattern projected onto a featureless plane, and (b) the same pattern printed onto the plane.

4.2 Results

To evaluate the differences between the projected and printed patterns, the differences in corresponding pixels between different depth maps generated by the Raytrix software (RxLive 2.10) were used. The mean and maximum percentage differences were taken between depth maps from the two printed images, two projected images, and a printed and projected image. The results of this can be seen Table 1. A Paired t-test was also performed on all nine sets of data, which yielded a p-value < 0.001 for all comparisons.

Table 1. Mean and maximum percentage differences between depth values for two images with a pattern printed, two images with the same pattern projected, and one printed and one projected pattern. The plane angle is in reference to the x-axis in Figure 2(b).

Comparison	Plane angle (degrees)	Maximum percentage difference (%)	Mean percentage difference (%)
Printed/Printed	0	3.19	0.39
	10	2.72	0.26
	20	3.11	0.20
Projected/Projected	0	4.16	0.44
	10	6.86	0.65
	20	4.81	0.44
Printed/Projected	0	5.34	0.78
	10	5.37	0.67
	20	5.71	1.19

4.3 Conclusion

Analysing the results in Table 1, it is clear that the differences between generated depth maps are greater between two projected patterns and the projected and printed patterns with relation to the two printed patterns. However, as the maximum percentage difference does not exceed 7% and mean differences are all below 1.2%, this shows that there is very little difference between projecting texture and it already being present on the scene. Along with p-values from a paired t-test of < 0.001 for every comparison, this can validate the use of a projector for producing texture on a scene.

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REFERENCES

[1] Adelson, E. H. and Wang, J. Y. A., "Single lens stereo with a plenoptic camera," *IEEE transactions on pattern analysis and machine intelligence* **14**(2), 99–106 (1992).

[2] Ng, R., Levoy, M., Brédif, M., Duval, G., Horowitz, M., and Hanrahan, P., "Light field photography with a hand-held plenoptic camera," *Computer Science Technical Report CSTR* **2**(11) (2005).

[3] Lumsdaine, A. and Georgiev, T., "The focused plenoptic camera," in [*Computational Photography (ICCP), 2009 IEEE International Conference on*], 1–8, IEEE (2009).

[4] Georgiev, T. G. and Lumsdaine, A., "Resolution in plenoptic cameras," in [*Computational Optical Sensing and Imaging*], CTuB3, Optical Society of America (2009).