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Towards Plenoptic Multi-View Imaging

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Abstract: Plenoptic imaging provides 3-D data in a single acquisition. Combining a plenoptic camera and mirrors to create a plenoptic multi-view system is explored. Results show the benefit of post-acquisition refocusing and 3-D reconstruction.

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1. Introduction

There has been a recent surge in the popularity of plenoptic camera technology, especially from commercial companies [1], due to the unique user experience it provides. From a single plenoptic raw image, a user can change focus, viewpoint, aperture, and depth of field all in post-processing. This results in the ability to reconstruct a depth map of a 3-D scene from a single acquisition. Of course, the information available is limited by the field-of-view, and hidden surfaces cannot be reconstructed. One method of increasing coverage is to move either camera or object and acquire another image. This takes time and is not always practical in dynamic or high-throughput situations. An alternative is to use multiple cameras to acquire several views simultaneously. For plenoptic imaging, this would incur a high cost both financially and computationally. A more economical solution is to use a single camera with mirrors to increase coverage, with each mirror acting as virtual camera. A problem that arises with using mirrors for multi-view imaging is managing the system focal planes; careful calibration is needed to ensure that a subject is captured in focus for each view. Situations where not all views are in sharp focus occur, and although calibration can help alleviate the problem, subject-specific calibration is time-consuming and tedious. In this preliminary study a new method of plenoptic multi-view imaging is investigated to allow for more robust multi-view imaging whilst simultaneously enhancing the 3D reconstruction capability of a plenoptic system.

2. Basics of plenoptic imaging

An ordinary camera system can be described simply in terms of a lens and an imaging sensor. In order to change the viewpoint, aperture, focus, or depth of field of an image the system must be physically changed and another image acquired.

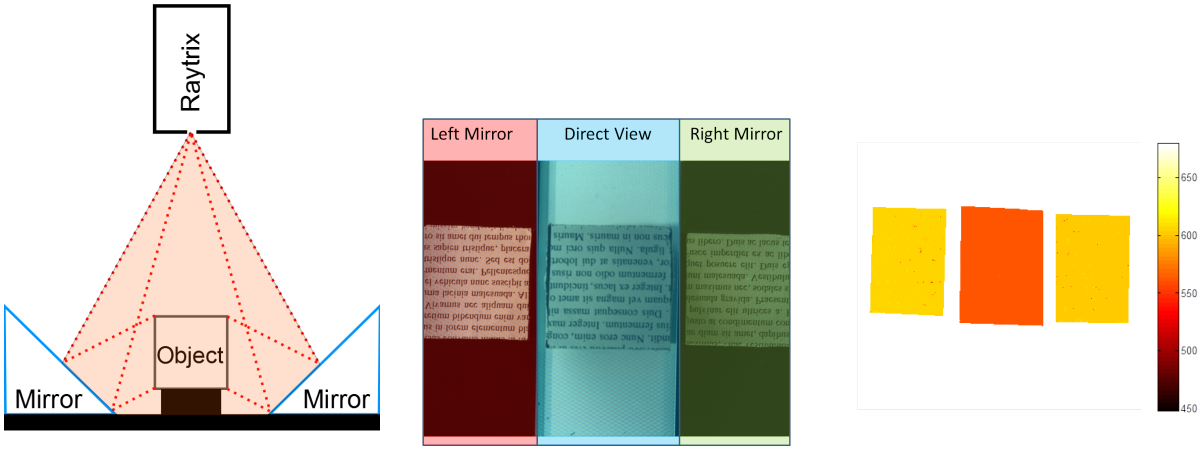
The directional information of rays in a conventional camera is lost. Plenoptic cameras preserve the directional information of rays at the expense of spatial resolution. They do this through placing a microlens array between the main lens and sensor of a traditional camera. The placement and characteristics of this microlens array dictate the final resolution of the system [3].

Since the direction of rays is known, digital refocusing can be achieved through tracing captured rays to a different *virtual sensor* plane [2]. Therefore a focal stack can be produced and in focus information pieced together to extend the depth of field. A simpler way to achieve this is to digitally stop down the aperture, however this negates the benefit of maintaining a large aperture main lens.

3. Application to multi-view imaging

As introduced previously, multi-view systems require information from multiple focal planes to be captured in order to provide useful information. In many applications which require larger aperture systems, this is exacerbated by a shallower depth of field. Calibration techniques are available, however these are dependent on the size and placement of the imaging subject and thus must be done on a per subject basis to be effective. The ability to digitally refocus

post-acquisition with plenoptic cameras means less dependence on the scene-subject geometry. Depth maps can also be generated for the different views. By transforming mirror views using knowledge of mirror positions, depth maps can be combined in 3-D space giving potential for a snap-shot plenoptic multi-view 3-D reconstruction.



(a) Experiment Schematic (b) Multi-View Image (c) Block Depth Map

Fig. 1: Experiment Set-up: (a) shows a schematic of the experiment, with the Raytrix R11 mounted above a textured object, and two mirrors placed at an angle of 45 degrees. The field of view of the camera is ensured to cover the direct and mirror images of the object. (b) depicts how the multi-views are captured on a single sensor image, and shows how these images can be interpreted. The depth map in (c) is the result of RxLive rendering, region of interest segmentation, and back-projection through an image using values calculated in RxOptics. The colour bar shows distance in mm from the camera.

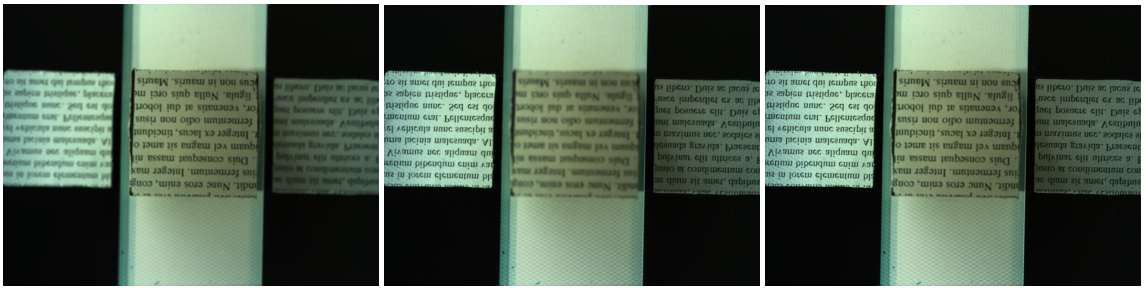
4. Methods

A Raytrix R11 (Raytrix GmbH) with a 100mm lens (Makro-Planar T* 2/100, Zeiss) was mounted into a vertical system with two mirrors (75K00ER.3, Newport Corporation) placed on a stage a distance of 600mm from the camera standing at an angle of 45 degrees. A custom object was created using a 5mm×5mm×5mm cube with text on each side. This object was placed on the stage between the mirrors so that the camera field of view contained both the object and its virtual images (reflections through the mirrors). The object was slightly raised (1cm) to ensure total coverage in the mirror views from the camera perspective. The camera was focused so that the point of furthest refocusing was 650mm from the camera to ensure all views would be captured correctly. This set-up produces the images shown in Fig. 1. The results of multi-view refocusing are shown in Fig. 2. This demonstrates that with plenoptic imaging the focus is more flexible, allowing a more robust method of collecting in focus information from a subject.

The Raytrix generated depth map (produced by RxLive (v2.10, Raytrix GmbH) gives a relative measure of virtual depth, which can be converted to an estimate of object-space depth by back-projecting through the optical system. This can be done using system parameters and the thin lens equation, or RxOptics software (v2.10.6, Raytrix GmbH). The result of this back-projection can be seen in Fig. 1c. Perspective effects must also be accounted for, and so position in the *xy* plane are scaled by the field of view at a given depth.

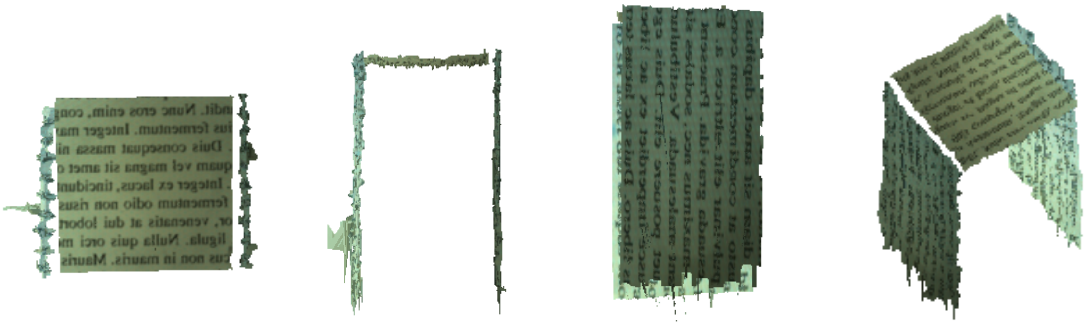
Raytrix depth mapping can also be used to calculate mirror positions. The method used for this calibration step is to place paper onto the mirrors providing an opaque surface to estimate. The surface should contain detail, in order to gain a good depth estimate, which can be printed or projected onto it.

Once this mirror position is calculated, system geometry can be used to transform the multi-view depth maps into a combined 3-D model. Since virtual depth points have been transformed into object-space, we can use the mirror position to transform the mirror views from reflected image depth to real object position. Since the mirrors are known to be at 45 degrees, this value is used in reconstruction to alleviate the Raytrix inaccuracies in slope calculation. The results for the complete plenoptic multi-view reconstruction are shown in Fig. 3. A median filter has been applied to the reconstruction to remove outliers within the positional calculations.



(a) Top Focus (b) Mirror Focus (c) All In Focus

Fig. 2: Raytrix Focus Results: The effect of depth of field on multi-view imaging is simulated by the Raytrix refocusing in (a) and (b), which shows blurred information in the mirrors and in the direct view respectively. The all in focus image (c) shows the Raytrix extended depth of field.



(a) x-y View (b) x-z View (c) y-z View (d) 3D View

Fig. 3: Reconstruction Results: (a-d) show different view-points of the 3-D reconstruction data.

5. Discussion

It has been shown that combining plenoptic imaging with mirrors in a multi-view system can benefit both the multi-view approach, with post-acquisition refocusing, and the plenoptic technique, with multi-view 3-D reconstruction. Plenoptic imaging allows systems to extend their depth of field, which is highly important for large apertures which are needed in applications such as non-contact luminescence imaging [4]. Plenoptic multi-view 3-D reconstruction is promising for the application of snap-shot 3-D scanning for 3-D printing. Now that this method and work-flow are established, quantitative experimentation will determine the accuracy and limitations of the technique, and more complex target objects are required for validation. Future work will include optimising and automating the system and the reconstruction process. An important step here is to gain the most accurate estimate of mirror angle as possible, which will mean a more robust and automated system for reconstruction. Further investigation and the implementation of a system for specific applications are exciting prospects.

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