Using Chromo-coded Light Fields for Virtual Reality

Category: Poster

Abstract

The light field, or plenoptic function, is a mathematical construct that describes the complete visual appearance of a scene. It defines the intensity of light traveling through every point in space. The light field provides a unifying construct to describe cameras and displays: pinhole cameras measure the rays passing through one point (the pinhole), stereo cameras capture the light through a pair of pinholes, and systems like the Microsoft Kinect modify the light field in a structured way by projecting light patterns into the scene.

Explicitly manipulating the light field is an approach to changing the world to make it easier to understand. This poster considers opportunities possible with chromo-coded light fields, created by materials like lenticular arrays whose appearance varies by viewing angle.

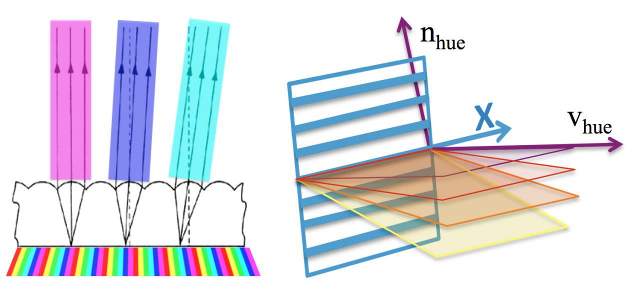
Chromo-coded light fields use color to create additional geometric cues, making it cheaper, faster and more accurate to measure object pose. For high-end applications like image guided surgery, the color-cues make it possible to accurately measure pose of small objects like a scalpel. Because lenticular arrays are cheap and the color cues simplify the computation, they support new possibilities for augmented reality using smart-phones and arbitrary objects.

This poster offers demonstrations of a few augmented reality applications made possible by chromo-coded light fields.

Index Terms: Light Field,Lenticular Array,Augmented Reality

1 Lenticular Arrays

Lenticular arrays are sheets of plastic that are comprised of rows of many thin (0.5mm wide) half cylinders, called lenticules. The lenticules act as lenses that focus parallel rays of light onto the back of the lenticular array. We show this phenomena in Figure 1(a). The roundness of the lenticules are designed such that the focus depth is the thickness of the lenticular sheet.



(a) (b)

Figure 1: a) A lenticular array creates appearances that depend on relative orientation by focusing parallel rays of light onto a pattern on the back of the lenticular array. b) The different appearances lie on planes radiating around the orientation of the lenticular array.

By attaching patterns that interleave different images at the frequency of the lenticules on the back of the array, one is able to generate multiple appearances based on the relative orientation of the lenticular array to the viewer. Commonly, as is the case of children's toys, different images are interleaved to give the effect of an animation while rotating the lenticular array. If the hue color wheel is interleaved, one can create a 1-to-1 relationship between the color and the viewing incident angle of the lenticular array. This enables lenticular arrays to be used for geometric inference.

Others have used lenticular arrays and their 2D counterpart, microlens arrays, for geometric inference. Previous research has used microlens arrays to constrain the relative path of a ray of light for Schlieren photography [6], to reconstruct the surface geometry of a transparent object [7], and to reconstruct the variable refractive index of gases [1]. Other work has used lenticular arrays [5] and microlens arrays [4] to express rotation as a translating bar to augment standard fiducial markers.

2 Chromo-coded Light Fields

In past work, lenticular arrays have been used for rotation estimation using large lenticular arrays [3] and for full pose estimation using small lenticular arrays, called chromo-coded markers [2]. This is possible because the type of lenticular array implemented in these papers creates chromo-coded light fields.

Consider a lenticular array, depicted in Figure 1(b), that is orientated by the length of it's lenticules along the direction $\vec{o}$ in 3D space. For a view rotated around $\vec{o}$, for example $\vec{v}_{hue}$, the lenticular array will appear to have specific hue. In fact, there are a whole set of views of a specific hue that lie on planes radiating out from $\vec{o}$. These planes are defined by the vector $\vec{n}_{hue}$ which is perpendicular to the view direction $\vec{v}_{hue}$ of a specific hue and the orientation of the lenticular array $\vec{o}$.

These planes of colored light create a specific chromo-coded light field. One can calibrate the relationship between the relative rotation around $\vec{o}$ and the hue appearance, and therefore use this light field for geometric inference. Several lenticular arrays oriented in different directions create a more complicated light field which enable better constrained geometric systems. In the next section, we describe the constraints derived from observations of a chromo-coded light field generated from a single lenticular array.

3 Geometric Inference with Chromo-coded Light Fields

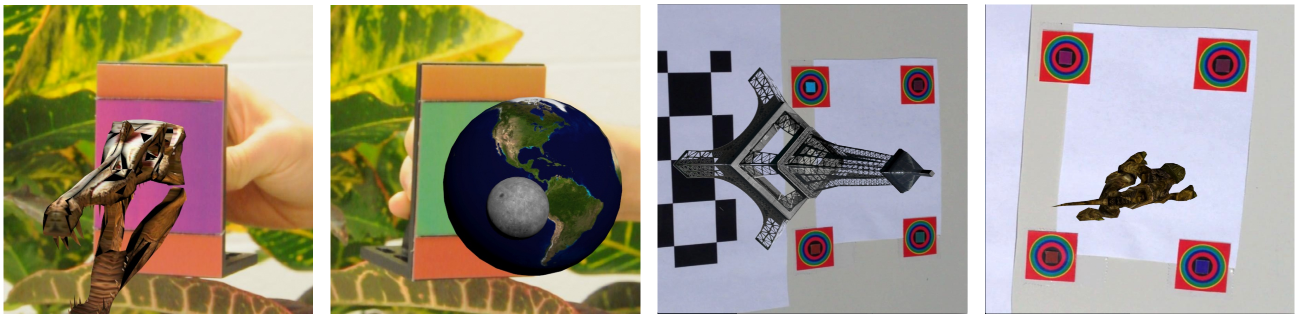
In the next section, we recap how one can use lenticular arrays for geometric inference, but leave out many of the details found in previous work [3, 2]. The imaging system is modeled as a pinhole camera and is defined by the intrinsic parameters captured in the matrix K. In this system, a pixel p captures a ray $\vec{r}$ defined as:

$$\vec{r} = K^{-1} p \tag{1}$$

Therefore, if we image a lenticular array at location p, then the lenticular array must lie along the ray r.

As described earlier, the observed color of the lenticular array may differ depending on the relative angle between the incident viewing angle and the orientation of the lenticular array. If the lenticular array appears blue, for example, the incident ray must lie in the plane $\vec{n}_{hue}$ that corresponds to the particular orientation around $\vec{o}$ where the lenticular array appears blue.

Rotational Constraint Given the pixel location and hue of a chromo-coded light field in an image, we can solve for the rotation relating the camera and the lenticular array reference frames. The ray $\vec{r}_i$ observing some lenticular array must lie on the plane $\vec{n}^i_{hue}$ defined by the hue seen along $\vec{r}_i$, therefore, $\vec{r}_i$ must be perpendicular to $\vec{n}^i_{hue}$. If we rotate $\vec{r}_i$ into the reference frame of the lenticular array, than we get the following constraint on rotation R:



(a) (b) (c) (d)

Figure 2: Lenticular arrays enable Augmented Reality applications, where 3D models are rendered into a camera feed, giving the appearance that the model is in the real scene. In a) and b), we show educational demos where users look at different angles of a dinosaur skull and the earth. In c and d, we show transplanted and synthetic scenes put into the real world.

$$\vec{n}^i_{hue} \cdot R\vec{r}_i = 0 \tag{2}$$

We know $\vec{r}_i$ from the pixel coordinates and a pre-calibrated K. In addition, we are able to find the direction of $\vec{n}^i_{hue}$ as we know the relationship between the color and incident viewing angle for each lenticular array. For additional lenticular arrays in the same reference frame, we get additional constraints on rotation from the same equation.

In addition, the relative observed locations of two lenticular arrays gives another constraint on R. Let two lenticular arrays be at positions C_i and C_{i+1} in their local reference frame. Three rays must be co-planar: the displacement between the two arrays in their local reference frame and the two rays observing the two lenticular arrays. This constraint is written as:

$$(C_i - C_{i+1}) \cdot R(\vec{r}_i \times \vec{r}_{i+1}) = 0 \tag{3}$$

Therefore, the chromo-coded light field created by two differently oriented arrays gives three constraints which allows one to solve for all three free variables in R.

To create the light fields necessary to constrain R, one may use large or small lenticular arrays. Large lenticular arrays actually provide a rotational constraint for each individual pixel across a lenticular array, as a camera may see many angles of a chromo-coded light field due to perspective.

Translational Constraints Besides the relative orientation of a lenticular array (R), one is also able to solve for the relative position T of a set of lenticular arrays in reference to the camera. Details about the constraints necessary to do this can be found in previous work [3, 2].

4 Augmented Reality Application

Imaging at least two lenticular arrays gives us enough information to infer about the relative orientation and translation of a plane relative to the camera. This enables many different applications, but is particularly well suited for Augmented Reality (AR). Using the pose information, we can project 3D models onto frames of a video. When deployed in a real-time camera feed of a mobile displays, such as a smart phone, a user gets the illusion that the 3D model is in the real-life scene. To demonstrate this, we show frames from two different video datasets, each with 2 different models. We include the full videos in the supplementary material.

In the first video dataset, we use three large lenticular arrays to estimate the relative orientation and position of a moving object. To demonstrate the potential for AR use in education, we render a dinosaur skull in one version of the video, and the earth and its moon in a second version. We show a frame from these two videos in Figures 2(a) and 2(b). The precise orientation estimations allows a user to explore the different view points of the model.

In the second video dataset, we use 4 lenticular markers to estimate the relative orientation and position of a plane. On that plane, we project the Eiffel tower. Because of the model's height, we can quickly see any small errors in orientation estimation. In another version of the video, we project an animated monster running in a circle. Frames of each of these demos can be seen in Figures 2(c) and 2(d). With these two demos, we show that we can immerse a user in transplanted and imaginary scenes, through a screen.

5 Conclusion

The chromo-coded light fields created by lenticular arrays, enables the inference of the relative orientation and position of a plane or object relative to a camera. As a result, one is able to realistically render digital models over images of the real world, augmenting the experience of a user.

References

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