**INVENTION DISCLOSURE FORM**

**Southern Methodist University**

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| **Invention Title:** | | Method and apparatus for all-in-focus image capture using lens swivel. | | | | **Date:** | **02/03/2016** |
| **Abstract** (type, purpose, and primary uses): A camera can only focus on a single plane, which is at a precise distance from a camera. Consequently, objects in front of and beyond the plane that is in sharp focus appear blurry in a photograph. The ability to capture a sharp image of objects at multiple depths is highly desirable in several applications including optical microscopy, machine vision, and surveillance imaging. The invention described herein proposes a new method for creating an all-in-focus image, by processing images acquired as the lens is swiveled about a pivot point in the camera. The principal advantage of our invention over prior art is the reduced number of images needed to assemble an all-in-focus image, especially in scenarios wherein the scene depth is infinitely large. | | | | | | | |
| **To This Cover Sheet Please Attach:** (1) A description of the invention; (2) A short description of any prior art; and (3) Any other pertinent information. | | | | | | | |
| (**Chronology of Development:** 1) Date of conception: | | | 12/13/2015 | | | | |
| (2) Date of first written description: | | | 01/15/2016 | | | | |
| (3) Date of first test: | | | 12/13/2015 | | | | |
| (4) Disclosures to non-University personnel (date, place, and nature of disclosures): | | |  | | | | |
| (5) Prospective and actual publications (date, title, publisher; include thesis or dissertation): | | | “All-In-Focus image capture using swiveling lens,” prospective paper submission to Topical meeting on Computational Optical Sensing and Imaging, 2016. | | | | |
| **External Support** of work leading to this invention (agency names, award numbers, and SMU project numbers): | | | | | | | |
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| **Commercial Potential:** List experts who may be consulted (under a Non-Disclosure Agreement) to determine value and potential (this is optional). List companies with known commercial interests. List foreign countries where protection should be sought. | | | | | | | |
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**Brief Description of the invention**

It is physically impossible for a camera to simultaneously focus on all objects at different depths in a scene. A conventional camera produces a sharp (focused) image of a planar object only if the object is at a precise distance from the lens governed by the Gaussian Lens Formula. However, obtaining an image having equal sharpness for objects at varying depths (i.e. large depth-of-field) is highly desirable in both commercial and scientific imaging applications such as macro photography and light microscopy. Several computational approaches to produce an all-in-focus image have been proposed. For example, in a technique known a focal stacking, multiple images that are captured while focusing the lens at several multiple depths are combined to form a single image with all objects in focus. In this work, we present a novel technique to produce an all-in-focus image by a weighted combination of images captured while rotating the lens about a pivot point. Figure 1 shows the result of a simulation using our technique. In this simulation, three playing cards were placed at depths of 800 *mm*, 1000 *mm* and 1200 *mm* from a 24 *mm* focal length lens. We generated 9 images that simulate the effect of imaging the scene while rotating the lens between -6° and 6° (w.r.t. the vertical axis). Figure 1a. shows one of the images in the stack. It can be seen that different portions in each of the three cards are in focus. This is because the plane of sharp focus angularly sweeps across the scene as lens is tilted (see Figure 2). In addition to the spatially varying defocus, as a consequence of the lens tilt, each image of the scene also experiences a shift across the sensor. This shift needs to be corrected before combining them into a single all-in-focus image as shown in Figure 1b. The recipe to correct the image filed shift (and distortion) that are a result of lens tilt/swing depends on the intrinsic parameters of the optics. We have also derived the exact mathematical expressions that describes the nature of this shift (and distortion) which is essential for the reconstruction step.



The main advantage of our method over the existing focal stacking method is that it requires far fewer images for scenes consisting of objects whose depths vary from very close range to infinity. This is because while the plane-of-sharp-focus in the focal stacking method sweeps the object space linearly across the depth, in the proposed lens swiveling method the plane-of-sharp-focus sweeps the object space angularly as shown in Figure 2.

Since we collect a stack of images with differential focus, we can also do selective focusing *after-the-fact* similar to lightfield cameras such a Lytro in addition to generating an all-in-focus image. Also, we envision that same apparatus will allow us to generate a 3D depth map of the scene.

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| **Figure 1a.** One of the images from the stack of 9 images showing the regions that are in and out of focus. In the simulations the three cards are at 3 different distances—800 *mm*, 100 *mm*, 1200 *mm*—from the lens. The region within the green dash lines is in relatively sharp focus. The bands between the green and blue dashed lines is the transition region. | **Figure 1b.** Reconstructed all-in-focus image showing that the 3 cards are rendered sharp in the image. |
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| **Figure 2.** Line drawing showing the orientations of the plane-of-sharp-focus for different amounts of lens tilts (between 0° and 20°). The plane-of-sharp-focus sweeps the object space angularly when the lens is swiveled about a pivot point. | |