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Virtual Volumetric Graphics on Commodity Displays Using 3D Viewer Tracking

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Abstract Three dimensional (3D) displays typically rely on stereo disparity, requiring specialized hardware to be worn or embedded in the display. We present a novel 3D graphics display system for volumetric scene visualization using only standard 2D display hardware and a pair of calibrated web cameras. Our computer vision-based system requires no worn or other special hardware. Rather than producing the depth illusion through disparity, we deliver a full volumetric 3D visualization—enabling users to interactively explore 3D scenes by varying their viewing position and angle according to the tracked 3D position of their face and eyes. We incorporate a novel wand-based calibration that allows the cameras to be placed at arbitrary positions and orientations relative to the display. The resulting system operates at real-time speeds (∼25 fps) with low latency (120–225 ms) delivering a compelling natural user interface and immersive experience for 3D viewing. In addition to objective evaluation of display stability and responsiveness, we report on user trials comparing users' timings on a spatial orientation task.

Keywords Volumetric display · 3D graphics · Tracking · Kalman filter · Camera Calibration

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1 Introduction

Three dimensional (3D) displays have emerged as the next generation of viewing technology, exploiting visual disparity cues to create the illusion of depth. Current displays facilitate this illusion through a mechanism to independently control the left and right eye viewpoints. The mechanism is commonly embedded in glasses (e.g. colored anaglyph filters, Sorensen et al. 2004; polarized lenses or shutter glasses, Woods 2009) or through lenticular or parallax barriers built into the screen itself (e.g. auto-stereoscopic displays, Woodgate et al. 2000). Such mechanisms increase the cost of 3D through specialist glasses or display hardware.

In this paper we describe how commodity hardware (a standard flat-screen monitor, with a pair of web-cams mounted on top) can be used to create the illusion of 3D without the expense of specialist hardware. In addition, we move beyond simple depth perception and disparity effects to create a *volumetric* or free-viewpoint display; enabling the user to interactively vary their point of view relative to the scene. This interaction model enables users to "look around corners", to reveal aspects of the scene previously hidden, considering issues such as occlusion and apparent object size (Fig. 1). None of these volumetric attributes are considered in conventional 3D displays, and to the best of our knowledge none have been synthesized on standard 2D hardware in a non-invasive (glasses-free) format.

Our non-invasive volumetric display runs robustly at real-time speeds (25 fps) on an Intel Core i7 1.6 GHz laptop with 18.4 inch flat-panel 2D display using two Microsoft standard definition web-cams.[1] The viewer's 3D position is triangulated and tracked using a Kalman filter supplied with

[1] A video demo of the system is available in the Supplementary Material.