The Effect of Eye Position on the View of Virtual Geometry

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ABSTRACT

In this document we discuss a study that investigates the effect of eye position on the apparent location of imagery presented in an off-the-shelf head worn display. We test a range of reasonable eye positions that may result from person-to-person variations in display placement and interpupillary distances. It was observed that the pattern of geometric distortions introduced by the display's optical system changes substantially as the eye moves from one position to the next. These visual displacements can be on the order of several degrees and increase in magnitude towards the peripheral edges of the field of view. Though many systems calibrate for interpupillary distance and optical distortions separately, this may be insufficient as eye position influences distortion characteristics.

1 INTRODUCTION

It is generally understood that optical distortions effect the visible position of geometry presented in most head worn virtual and augmented reality displays. In some cases, these distortions go uncorrected as they may not be seen as critical to the effectiveness of a given application. In other cases, these distortions may be corrected in software by modeling the errors introduced by the display's optical system and pre-distorting the rendered imagery accordingly [1, 7, 8, 9]. However, the latter approach makes several assumptions about the placement of the user's eyes that are typically not correct. One of these assumptions is that the eye of the observer is forward-looking and centered with the viewport. Of course, this is typically not the case, as there is substantial variation in eye separation (roughly 50 to 75mm) and users will move their eyes as they look about a scene [3, 6]. This is well known, but the magnitude of these changes is casually considered to be negligible.

In this document, we detail a series of measurements taken from varying eye positions using a common, off-the-shelf head worn display. These measurements were taken using a modified ACDC calibration method and an off-the-shelf camera and lens [4]. This method provides an approximation of the distortions present in a given display system.

2 METHODS

The measurement apparatus, seen in Figure 1, was an off-the-shelf Logitech HD Pro Webcam C920 with a generic fish-eye lens attachment. The camera rig was then mounted in the chuck of a Rutland manual milling machine. An off-the-shelf display was then rigidly affixed to the mill's moveable stage. This allowed the position of the display, relative to the camera rig, to be moved with 1/1000 inch precision. The display used for this study was an Oculus Rift Development Kit head worn display. However, it is important to note that the basic principles and findings are not limited to this display and are generally applicable to displays of similar design. This encompasses a majority of head worn displays.

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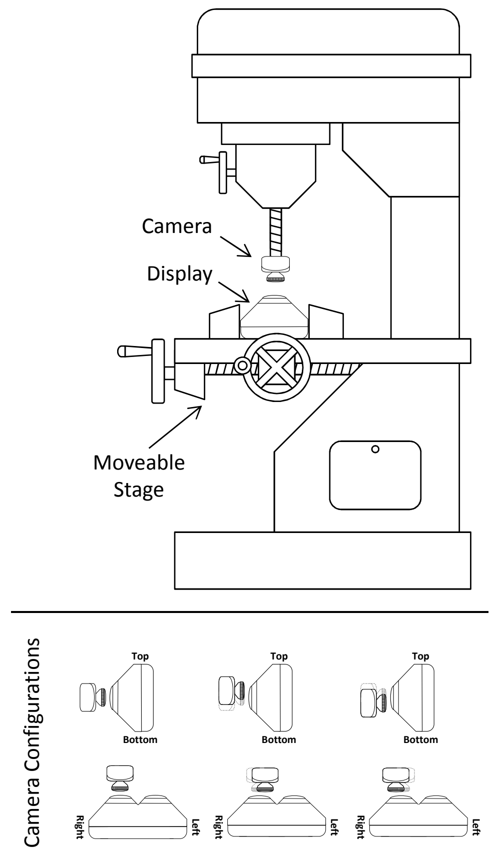

Figure 1: An illustration of the measurement apparatus (top) consisting of a camera, lens, and display mounted in a manual milling machine. The camera positions used for measurement are also depicted (bottom).

The acquisition of measurements was performed with a modified ACDC calibration method. The method characterizes the distortions of a display by comparing a pixel space scan of the display's surface to a previously acquired set of real world sample points. This results in a mapping between the real world sample points and their corresponding pixel space locations. This procedure was modified for our purposes to also capture and store distortion information from a lens-centered point of view and compute the angular difference between it and a subsequent capture positions. A total of five captures were taken: lens-centered, 5mm above center, 5mm below center, 5mm left of center, and 5mm right of center.

3 RESULTS

For each sampled point, the angular difference between the point's lens centered position and each offset position was calculated. This difference between the central position and the offset positions will simply be referred to as angular displacement. Changes in angular displacement result in apparent changes in the visual location of

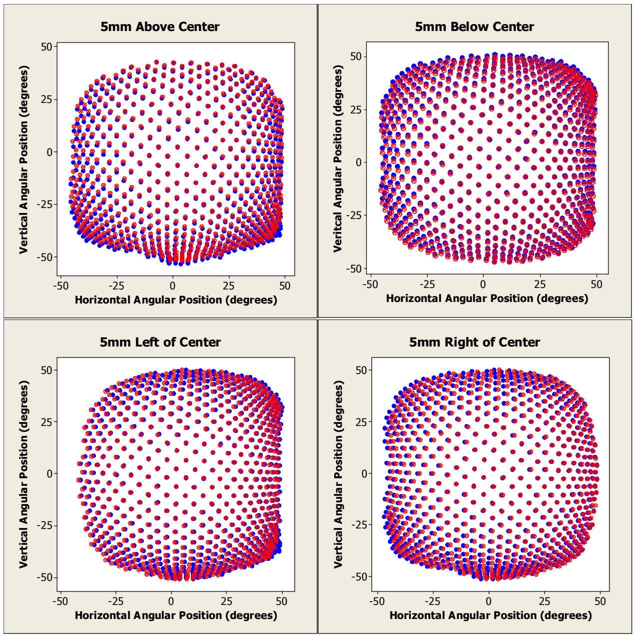

Figure 2: Sample positions acquired by the measurement method. Filled circles indicate the sample's position as measured from the center of the lens. Open circles indicate the sample's position as measured from the designated offset. Note that the two correspond closely in the center but diverge as samples move toward the edges.

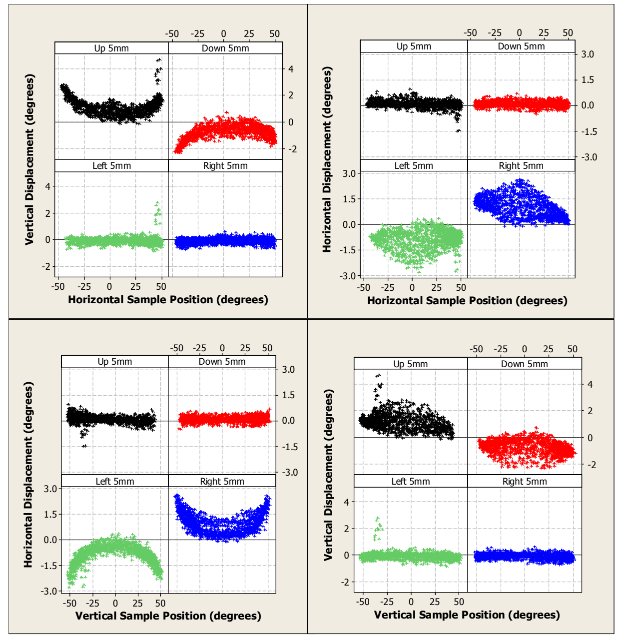

Figure 3: Per-axis angular displacement for each of the eye positions.

a given point. Figure 2 shows the raw positions of lens centered and offset sample points. Even when presented in this manner, angular displacement is apparent. These errors become even more obvious when examining per-axis angular displacement, depicted in Figure 3. The majority of the angular displacement occurs in the periphery of the field of view, approaching as much as 3° of displacement. Generally, displacement errors stay somewhat closer to zero along the center of the axis of translation, but can still reach roughly 2°. To add perspective to these errors, a 3° change in position is roughly equivalent to an object located at 10 feet moving by 6 inches to the left or right (or roughly 16cm at a distance of 3m). The magnitude of these errors, of course, is highly dependent on the optics used in the display and will undoubtedly be different from one display to the next.

The offsets we used for our measurements were not arbitrary as they cover the typical range of pathologically normal humans. Even when interpupillary distance is used to render a scene from the correct camera separation in the virtual environment, these errors will persist if the distortion correction method does not also account for the eye's position relative to the lens center. This can naturally lead to incorrect vergence information in stereoscopic scenes and, subsequently, incorrect judgment of depth. Another important factor that must be considered is that the optical center of the human eye is not coincident with its rotational center. The consequence of this is that the optical center of the eye translates on the order of roughly 1mm as the eye rotates in the socket. This is troublesome as the rendered geometry will inevitably appear to shift slightly as the observer looks about a scene. Though it is not investigated directly by this work, one could reasonably speculate that such shifts could potentially induce motion related sickness or disorientation. Similar problems have been indicated by related work investigating head worn displays and usability issues[2, 5]. This possibility necessitates future research that incorporates the current findings with studies of user susceptibility to this phenomenon.

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