Gaze-Contingent Spatio-Temporal Filtering in a Head-Mounted Display

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1 Introduction

The spatio-temporal characteristics of the human visual system vary widely across the visual field. Recently, we have developed a display capable of simulating arbitrary visual fields on high-resolution natural videos in real time by means of a gaze-contingent spatio-temporal filtering [1]. While such a system can also be a useful tool for psychophysical research, our main motivation is to develop gaze-guidance techniques. Because the message an image sequence conveys depends on the exact pattern of eye movements an observer makes, we propose that in future information and communication systems, images will be augmented with a recommendation of where to look, of how to view them. Ultimately, we want to incorporate gaze guidance technology into mobile applications; such technology, integrated into a head-mounted display (HMD), could use computer vision techniques to enhance human visual performance.

In our demonstration, we will show a first implementation of such a device in the form of a system that implements our gaze-contingent spatio-temporal filtering algorithm in an HMD with video-see-through. Subjects will be able to walk around, seeing their natural visual environment inside the HMD. We will demonstrate that we then can manipulate what the subjects see in real time.

2 Gaze-Contingent Spatio-Temporal Filtering

Visual acuity is highest only in the very centre of the human retina, the fovea, and drops off sharply towards the periphery. This variable-resolution effect has been simulated on image sequences in a gaze-contingent manner, e.g. [2].

Such "foveation" has typically been used to reduce the bandwidth required for video transmission or to improve the perceived video quality at a certain bandwidth [3]. Another application has been the simulation of visual field defects, e.g. to educate students or relatives of patients suffering from such defects. For an overview of applications of gaze-contingent displays in general, see e.g. [4].

Our work, however, focuses on the guidance of eye movements [5], and so we are interested in the effect that foveation has on the observer's eye movements. Based on the observation that movement or change in the visual periphery is a

Fig. 1. Example of our spatio-temporal filtering algorithm. The effects in the middle and the right pictures can be combined in an arbitrary manner. Gaze position is indicated by the little white square to the left (below the white sail). Left: Still shot of the original movie. Middle: Spatial blur that is increased towards the visual periphery. Right: Temporal blur. Note the disappearance of the little girl to the right.

strong cue for eye movements, we have extended the techniques used by [2] such that they also filter in the temporal domain.

In the spatial case, the video sequence is filtered using an arbitrary two-dimensional map that specifies the desired spatial resolution at each pixel location relative to the direction of gaze. This is achieved by blending between levels of a multi-resolution pyramid computed for each frame in the video. The extension to the temporal domain is conceptually simple, but computationally challenging, because ultimately, each video frame that is displayed is a weighted sum of more than 250 high-resolution video frames surrounding it.

In experiments with our gaze-contingent system, we have indeed been able to show that eye movements are influenced by a temporal foveation. Furthermore, if the strength of the effect is kept below a certain threshold, it is not detected by the observer [6].

3 Head-Mounted Display

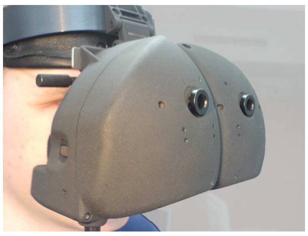

Fig. 2. Picture of our head-mounted display. Note the two scene cameras facing forward; two gaze cameras are integrated into the case.

Our HMD is a custom-made model manufactured by a company that also sells off-the-shelf head-mounted displays (Trivisio), with eye-tracking capabilities fitted in collaboration with the SensoMotoric Instruments GmbH. For each eye, the HMD has a separate VGA input connected to a microdisplay with 800x600 pixels spatial and 60 Hz temporal resolution. Because our work focuses on the effect of visual stimulation in the periphery, the optics were chosen so that the field of view spans a wide 50 degrees of visual angle diagonally (40x30 degrees). Furthermore, four cameras are attached to the display. Two digital scene cameras (640x480 pixels spatial, up to 48 Hz temporal resolution) face forward, covering the field of view of the display. They can be connected to a computer via USB to enable a so-called "video see-through" mode, where the image sequence recorded by the cameras is immediately fed back to the displays. This setup allows us to perform arbitrary manipulations on the visual input in a highly natural environment. Two further cameras are placed in-between the microdisplays and the user's eyes and record the eye movements. Their analogue outputs are digitized using a framegrabber box connected to a computer via firewire and they allow for gaze tracking at 50 Hz with an accuracy of better than 1 degree.

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