Information-Preserving Imaging for Heterogeneous Networked Displays

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Abstract

Networked display systems facilitate collaboration between remote participants. However, display and network limitations can lead to information loss that can jeopardize the shared context essential for effective collaboration. Our goal is to preserve the fidelity of visual information transmission in heterogeneous, networked display systems. We are developing **information-preserving imaging algorithms** that explicitly model the performance characteristics of displays, networks, and human observers. We use novel image representations to compensate for potential information loss. The goal of our work is to enable reliable, interactive, visual communication among collaborators and improve the effectiveness of remote communication in critical tasks.

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Introduction

Over the past decade dramatic advances in networking and electronic display technologies have led to the emergence of visually-based digital communication systems. These distributed systems allow geographically dispersed teams to work collaboratively on critical tasks. These systems support a wide range of collaborative applications such as emergency response, tele-medicine remote maintenance and repair, reconnaissance, and command-and-control. They often incorporate a wide variety of display devices that are used under varying environmental and network conditions.

To achieve effective coordinated action in critical applications, the users of such systems need reliable and appropriate information about the situation at hand. However, a major obstacle is that users may see different versions of the image and video data because of display, network and environmental limitations. This lack of shared context between collaborators can result in miscommunication, confusion, and error.

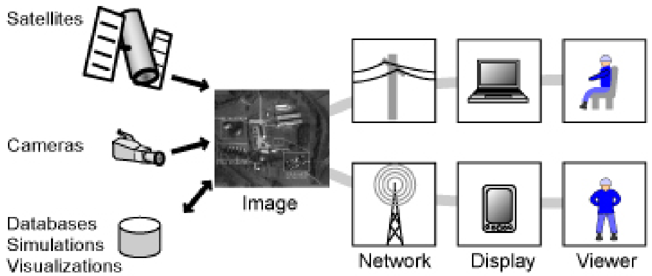

Figure 1. In heterogeneous networked display systems participants collaborate using systems that include four components: images captured from different sensors, networks, displays and viewers.

Figure 1 shows a heterogeneous networked visual communication system consisting of multiple users viewing electronic displays connected by a network. The system incorporates a range of displays, including mobile PDAs, laptops, display walls, heads-up displays, and immersive virtual environments, which connect over wireless and high-bandwidth networks. The system incorporates multiple information sources including cameras, sensor arrays, and satellite feeds, as well as computer databases, simulations, and data analyses. The visual data displayed in such systems include video data (live and archived), satellite images, 3D simulations, terrain models, and abstract information visualization such as maps and graphs.

Our approach

We are developing **information-preserving imaging algorithms** to support **effective visual communication in heterogeneous networked display systems**. Our approach is to model the network, displays and human users together in a common framework to understand end-to-end constraints, and use these models to create image encodings and display algorithms that preserve information fidelity for each user's display configuration.

A framework for understanding visual communication systems

Visual communication systems consist of four components: images, networks, displays, and viewers (see Figure 1). Images code information into patterns of light. They can be powerful vessels for information, but like the proverbial tree falling in the forest, images require displays and viewers to be meaningful. The performance characteristics of the displays and viewers can be understood in terms of four *channels*: space, time, color and intensity.

CHARACTERISTICS OF DISPLAYS

Spatial characteristics of displays include physical size, aspect ratio, and spatial resolution; temporal characteristics include update rate, refresh rate, and response time; chromatic characteristics include gamut, and bit depth; and intensity characteristics include range, bit depth, and gamma. Mismatches between image content and display capabilities in any of these characteristics can result in degraded quality.

CHARACTERISTICS OF VIEWERS

The performance characteristics of human vision can also be described with respect to space, time, color, and intensity, allowing direct comparison of display and visual capabilities and limitations. The spatial response properties of human vision include acuity and contrast sensitivity; temporal properties include flicker fusion, temporal contrast sensitivity, and motion perception;

color properties include trichromacy, color discrimination, and color naming; and the intensity response of the visual system can be described by two factors, luminance range and adaptation.

CHARACTERISTICS OF NETWORKS

Besides displays and viewers, networks can also be a source of information loss in multi-user visual communication systems. For example, users connected by a low-bandwidth, wireless network might not receive rapidly varying data and they would thereby lose the shared context necessary to achieve coordinated action. Network performance is typically modeled along three axes: bandwidth, latency, and reliability. Each of these axes can be characterized in terms of the limitations it imposes on the spatial, temporal, color, and intensity properties of image transmission.

Information-preserving imaging algorithms

Ideally a visual communication system would display image information to all participants with perfect fidelity; however, in reality there are always limitations in the system. We are working to develop adaptive image transforms to preserve the fidelity of visual information in real-world visual communication systems.

One example is tone mapping algorithms that compress high dynamic range images for display on low dynamic range devices [2,3,4,6,7]. Because the algorithms are based on advanced models of human vision they produce images that are faithful visual representations of scene appearance. Figure 2 shows one of these algorithms applied to a high dynamic range image of an outdoor scene.

Figure 2. Tone-mapping of a high dynamic range image with a 10,000-to-1 intensity range. Linear mapping (left) clips the range and loses detail. The visual mapping (right) compresses the intensity range and accurately represents the scene's true appearance.

We are also exploring feature-based imaging algorithms that preserve image information [1,5] (see Figure 3). Standard image representations are purely pixel-based and are targeted for particular display characteristics (e.g., resolution, frame rate, dynamic range). By explicitly capturing features that are perceptually important like edges, patterns, and object silhouettes, image fidelity can be preserved on different displays.

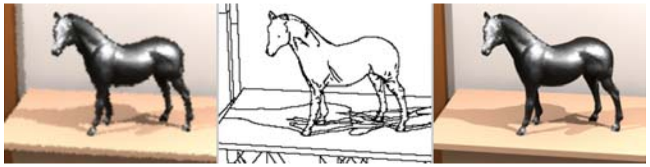

Figure 3. Feature-based image representations. Image quality reconstructed from features and sparse data (center, right) is superior to image (left) generated using standard techniques.

Impact

We are developing information-preserving imaging algorithms for high-quality, interactive, visual communication in heterogeneous networked display environments. To achieve this goal the impact of all system components on performance needs to be quantified. The four-channel framework outlined above allows us to formally characterize and model the capabilities and limitations of electronic displays, networks, and human display viewers and their impact on information transmission in visual communication systems. By preserving information fidelity across a wide variety of display, network, and viewing conditions, this research will improve the efficiency of remote task collaboration in a range of applications.

Citations

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