A Personal Projected Display

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ABSTRACT
User interfaces using windows, keyboard and mouse have been in use for over 30 years, but only offer limited facilities to the user. Conventional displays are small, at least compared with a physical desk; conventional input devices restrict both manual expression and cognitive flexibility; remote collaboration is a poor shadow of sitting in the same room. We show how recent technological advances in large display devices and input devices can address these problems. The *Escritoire* is a desk-based interface using overlapping projectors to create a large display with a high resolution region in the centre for detailed work. Two pens provide bimanual input over the entire area, and an interface like physical paper addresses some of the affordances not provided by the conventional user interface. Multiple desks can be connected to allow remote collaboration. The system has been tested with single users and collaborating pairs.

Categories and Subject Descriptors
H.5.2 [**User interfaces**]: graphical user interfaces, input devices and strategies, interaction styles, windowing systems.
H.5.3 [**Group and organization interfaces**]: computer-supported cooperative work, synchronous interaction.
I.3.3 [**Picture/image generation**]: display algorithms.

General Terms
Algorithms, Design, Experimentation, Human Factors.

Keywords
Projected displays, foveal display, person space, task space, videoconferencing, pen input.

1. INTRODUCTION
Since the inception of the personal computer, the interface presented to users has been defined by the monitor screen, keyboard, and mouse, and by the framework of the desktop metaphor. It is very different from a physical desktop which has a large horizontal surface, allows paper documents to be arranged, browsed, and annotated, and is controlled via continuous movements with both hands. The desktop metaphor will not scale to such a large display; the continuing profusion of paper, which is used as much as ever, attests to its unsurpassed affordances [4] as a medium for manipulating documents; and despite its proven benefits, two-handed input is still not used in computer interfaces.

We present a system called the *Escritoire* [1] that uses a novel configuration of overlapping projectors to create a large desk display that fills the area of a conventional desk and also has a high resolution region in front of the user for precise work. The projectors need not be positioned exactly—the projected imagery is warped using standard 3D video hardware to compensate for rough projector positioning and oblique projection. Calibration involves computing planar homographies between the 2D co-ordinate spaces of the warped textures, projector framebuffers, desk, and input devices. The video hardware can easily perform the necessary warping and achieves 30 frames per second for the dual-projector display. Oblique projection has proved to be a solution to the problem of occlusion common to front-projection systems. The combination of an electromagnetic digitizer and an ultrasonic pen allows simultaneous input with two hands. The pen for the non-dominant hand is simpler and coarser than that for the dominant hand, reflecting the differing roles of the hands in bimanual manipulation. We use a new algorithm for calibrating a pen, that uses piecewise linear interpolation between control points. We can also calibrate a wall display at distance using a device whose position and orientation are tracked in three dimensions.

The Escritoire software is divided into a client that exploits the video hardware and handles the input devices, and a server that processes events and stores all of the system state. Multiple clients can connect to a single server to support collaboration. Sheets of virtual paper on the Escritoire can be put in piles which can be browsed and reordered. As with physical paper this allows items to be arranged quickly and informally, avoiding the premature work required to add an item to a hierarchical file system. Another interface feature is pen traces, which allow remote users to gesture to each other. We report the results of tests with individuals and with pairs collaborating remotely. Collaborating participants found an audio channel and the shared desk surface much more useful than a video channel showing their faces.

The Escritoire is constructed from commodity components, and unlike multi-projector display walls its cost is feasible for an individual user and it fits into a normal office setting. It demonstrates a hardware configuration, calibration algorithm, graphics warping process, set of interface features, and distributed architecture that can make personal projected displays a reality.

2. FOVEAL DISPLAY
To create a display that fills an entire desk but also allows life-sized documents to be displayed and manipulated we have created what we call a *foveal display*. One projector fills the desk with a low-resolution display, while a second overlapping projector displays a high-resolution area in front of the user. The optical

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path of the first projector is folded using a mirror above the desk to enable it to generate a display of the desired size without being mounted at an inconveniently high position above the desk surface (Figure 1). Baudisch et al. have combined an LCD monitor and a projector to get a dual-resolution display [2], although they do not address calibration, have used only the conventional keyboard and mouse for input, and get a display with different affordances because of its vertical rather than horizontal placement.

The user can arrange items on the desk, identify them at a glance, reach out and grab them, and quickly move them to the high-resolution region where the text becomes legible and they can be worked on in detail (Figure 2).

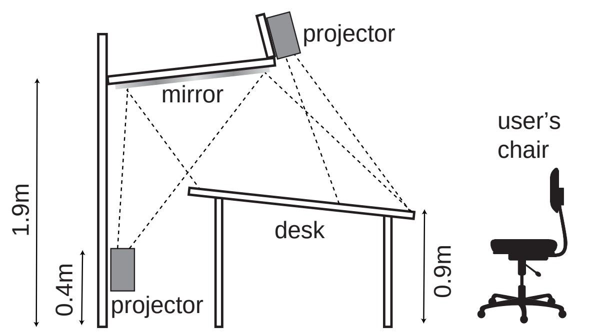

Figure 1. The two-projector configuration of the Escritoire.

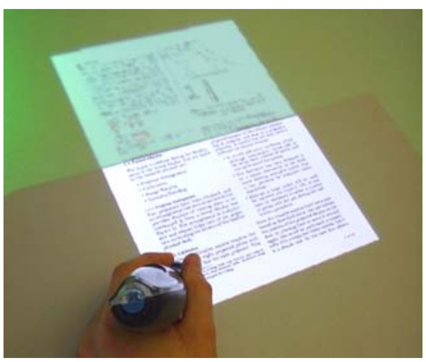

Figure 2. Moving a sheet of virtual paper to the high-resolution region.

3. TWO-HANDED INTERACTION

Bimanual input—using two hands—has manual benefits from increased time-motion efficiency due to twice as many degrees of freedom being simultaneously available to the user, and also cognitive benefits which arise as a result of reducing the load of mentally composing and visualizing a task at an unnaturally low level imposed by traditional unimanual techniques [3].

We have combined a desk-sized digitizer and stylus that provide accurate input for the user's dominant hand, with an ultrasonic whiteboard pen that provides simple and less accurate tracking for the user's non-dominant hand. The non-dominant hand is used to move items around on the desk, setting up a frame of reference for the dominant hand to do its more detailed work such as writing and drawing.

4. COLLABORATION

We have implemented the Escritoire in two parts: a server written in Java that stores the details of the items on the desk , and a client written in C++ that handles the input and output devices. This allows multiple desks to connect to the same server over the Internet allowing geographically separated users to share the desk contents.

We have conducted tests in which pairs of participants converse over a standard videoconference while using Escritoire desks whose contents are shared in a What You See Is What I See fashion (Figure 3). As they talk they can work together to read and annotate documents, gesturing in the shared graphical space as they do so. Systems for remote collaboration often concentrate on optimizing the talking heads model of a standard videoconference but we believe that a shared task space will often be more useful. The shared space provided by the Escritoire is much larger than a monitor screen and supports fast and natural interaction over the whole area, so users share a large visual context while being able to easily refer to and collaborate on specific items.

Figure 3. Augmenting a videoconference with a desk surface that is shared between collaborators.

5. ACKNOWLEDGMENTS

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