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Tele-Graffiti: A Pen and Paper-Based Remote Sketching System

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Tele-Graffiti is a system allowing two or more users to communicate remotely via hand-drawn sketches. What one person writes at one site is captured using a video camera, transmitted to the other site(s), and displayed there using an LCD projector. See Figure 1 for a diagram of one site:

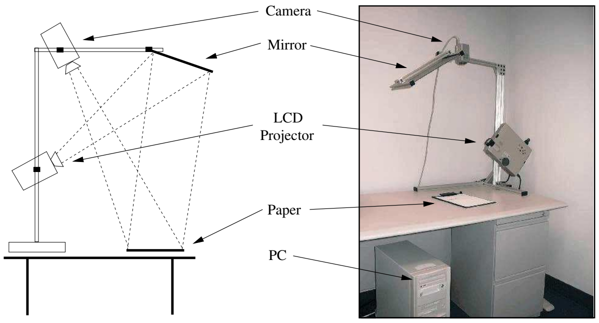

Figure 1. Left: system diagram. Right: real system.

Such a system has a variety of applications in teleconferencing and remote education. It also has potential applications in human-computer interaction, using the paper as a combined display and input device. See Figure 2 below:

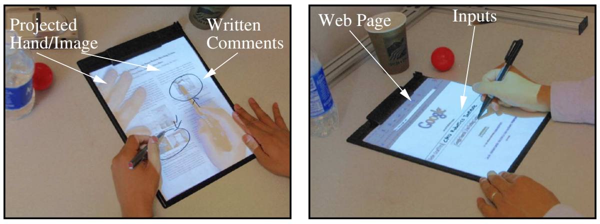

Figure 2. Example applications. Left: Remote education. An instructor interacts with a student. Right: Human-Computer Interaction. A user provides input to a Web page.

The advantage of our system over other intelligent desktops [2] and white-boards [1] is that the users are free to move the pieces of paper on which they are writing. In Tele-Graffiti, paper detection and tracking is based on real-time paper boundary detection. In the applications mentioned above, this step needs to be robust to the occlusions caused by the user's hands and the distractions caused by printed or hand-written material on the paper. As the paper may move during the time lag between image projection and capture, we also need to disambiguate the paper from the projected image at previous time-step. Finally, the two-fold ambiguity in the paper orientation has to be resolved. See Figure 3.

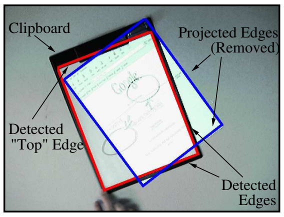

Figure 3. Paper detection. (1) The camera sees the paper and the projected image from the previous step. (2) The orientation of the paper is ambiguous without the clipboard.

To solve these problems we have developed a paper detection algorithm that takes advantage of the facts that (a) the paper is bounded by four long edges roughly perpendicular to each other, (b) we know the approximate location of the projected image from the previous time-step and therefore its edges can be removed, and (c) the asymmetry between the top and the bottom of the clipboard can be used to resolve the ambiguity in the paper orientation.

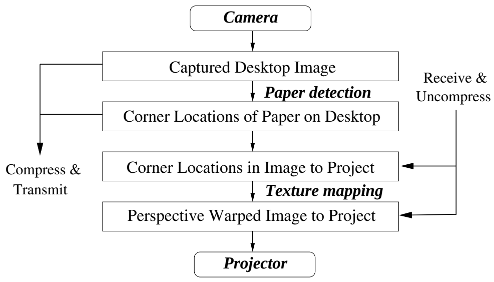

Figure 4. Simplified Tele-Graffiti system architecture.

A simplified system architecture is shown in Figure 4. Paper detection runs in 15 milli-seconds per frame on a PII-450MHz machine and the paper is tracked accurately even with almost complete occlusion and misleading projected texture. Currently the communication link between the two sites has a delay of around 70 milli-seconds, which is partly due to the image compression algorithm. Overall the end-to-end system runs at 15 frames per second on dual PII-450MHz machines connected by 100 Base-T Ethernet.

References

[1] D. Hall, C. L. Gal, J. Martin, T.Kapuscinski, and J. Crowley. MagicBoard: A contribution to an intelligent office environment. In *Proc. of the 7th Intl. Symp. on Intell. Rob. Sys.*, 1999.

[2] P. Wellner. Interacting with paper on the DigitalDesk. *Communications of the ACM*, 36(7):86–96, July 1993.