Design Evolution of a Mixed Reality Factory System

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ABSTRACT
We will demonstrate successive and final stages in the iterative design of a complex mixed reality system in a real-world factory setting. In collaboration with TCHO, a chocolate maker in San Francisco [1], we built a virtual "mirror" world of a real-world chocolate factory and its processes. Sensor data is imported into the multi-user 3D environment from hundreds of sensors and a number of cameras on the factory floor. The resulting virtual factory is used for simulation, visualization, and collaboration, using a set of interlinked, real-time layers of information. It can be a stand-alone or a web-based application, and also works on iOS and Android cell phones and tablet computers. A unique aspect of our system is that it is designed to enable the incorporation of lightweight social media-style interactions with co-workers along with factory data. Through this mixture of mobile, social, mixed and virtual technologies, we hope to create systems for enhanced collaboration in industrial settings between physically remote people and places, such as factories in China with managers in the US.

Author Keywords
Mixed reality, 3D applications, data visualization, remote collaboration, virtual worlds, pervasive computing, mobile mixed reality, collaborative tools.

ACM Classification Keywords
H.5.1. [**Information Systems**]: Artificial, augmented, and virtual realities.

INTRODUCTION
Mixed reality (or cross-reality) systems are those where ubiquitous sensor/actuator network infrastructures in the real world and augmented or virtual world systems interact, creating a "seamless electronic nervous system that extends across people, things, and places" [2]. Mixed reality systems have diverse uses for data visualization and remote collaboration in industrial settings, such as factories. We are interested in understanding appropriate methods for communicating and collaborating in these environments, and, to aid this kind of collaboration, in importing real-world sensor data (such as temperature controls, machine state, and environmental status) and multi-camera imagery from the real factory floor. This research is facilitated by an ongoing collaboration between our research lab in Silicon Valley and a local company that runs a real-world chocolate factory. TCHO, the chocolate company, is a start-up focused on creating "high-tech chocolate" by applying new technologies and high replicability at every step from cacao bean sourcing through chocolate production, shipping, and marketing. As such, they are open to the shared experiment of inventing and installing mixed-reality systems for factory applications.

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DESIGN CHALLENGES
Our first design challenge was to identify what data in and around the factory was important (and to whom), and to design an infrastructure to capture and deliver this data as needed. We currently work with four input data streams, and have identified several others for future incorporation. Our system uses:

- data from the machines in the production line and the chocolate molding line on the factory floor
- data from machines in a smaller laboratory setup
- video data from a multi-camera video capture network we installed around the factory, and
- environmental data, tracking temperature and humidity in the factory and its associated laboratory.

We experimented with many possible applications and display types as mixed reality system outputs. Currently we can access the factory world on iOS and Android phones and tablets, as well as via stand-alone or Web-based applications. Another challenge we faced was practicality: how to create systems that could reasonably be deployed and maintained in a factory setting. For example, the costs associated with high-end virtual environments are prohibitive for most companies, especially start-ups. We were interested in finding a low-cost or open source virtual environment platform that could meet our requirements for a secure, collaborative online workspace. Finally, we needed to be sensitive to the needs of our collaborators in the chocolate factory, who were in start-up mode. Additional work for them caused by our presence on-site could disrupt vital company timelines. Our designs are based on observations and interviews with factory

personnel, and are meant to possess low learning curves and high usefulness to accommodate busy factory employees.

DESIGN REQUIREMENTS

A primary design question was the appropriate spatial distribution and representation of video and live data. We use a combination of embedded and live video around and about the factory, and the data from the sensors and controllers that run the machines on the main factory floor. Embedded videos are short explanations of machine functions designed as aids for visitor tours; the videos are high definition and pop up upon an avatar's approach to the virtual model of the machine the video is about. Live video is available in-world from fourteen Axis network cameras we installed around the factory floor [3]. Seven of these network cameras are pan-tilt-zoom cameras; these are configured with a number of preset views that users can access in-world and via iPhone or tablet. Several cameras are actually installed inside factory machines, for close-up views of factory processes. The video from all cameras is recorded to and stored on an onsite digital video recorder, for more manageable access to multiple streams.

Figure 1. The TCHO factory floor and its "mirror" in the current web-based 3D factory world.

For the live data streams, most of the machines in the TCHO factory are controlled through the commercial industrial control software called Wonderware, which is in widespread use in factories around the world [4]. We read data from TCHO's Wonderware system via the custom system architecture we developed. The resulting data stream is distributed into the virtual factory world. Sensor data appears in floating text against a transparent color cloud, called a "Data Spot." The Data Spots are animated sensor display indicators showing such data as hot water temperature, chocolate temperature, or machine state. This design allows live sensor data to be easily read in-world, while not blocking visibility of the machine model. For a professional version, we are experimenting with more complex DataTab designs that allow in-world users to access more detailed information, such as text explanations or graphed sensor histories. DataTabs also incorporate live video controls.

Virtual world platforms

Mixed reality systems use virtual worlds for representation and visualization. To create the mixed reality system, we needed both a virtual world and sources of real-world data to bring into it. The machine models and building model were developed by a digital artist from measurements and photographs, not from CAD models (which typically have too high a polygon count for usefulness in a multi-user world). Virtual world platform features we looked for included enterprise-level security, robustness and stability with many users, a rich API and community support, and a sophisticated media environment including animations, live audio/video, physics modeling, and social systems support (avatars, chat). Though we were able to build reasonable representations of the Virtual Factory in several of the virtual platforms we tried, we have settled on Unity 3D [5], a multi-platform game development platform, as the most practical for enterprise needs.

CONCLUSION

The mixed reality factory system we have developed informs an ongoing design study in mixed reality systems for the enterprise.[6] Finding a robust virtual platform for mixed reality data delivery was key to finally releasing the system for use. This mixed reality system is now in daily use at TCHO.

ACKNOWLEDGMENTS

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