Mobile Monitoring and Control System for a Food Industry Development Laboratory

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ABSTRACT
In this demonstration we will show a mobile remote control and monitoring application for a recipe development laboratory at a local chocolate production company. In collaboration with TCHO, a chocolate maker in San Francisco, we built a mobile Web app designed to allow chocolate makers to control their laboratory's machines. Sensor data is imported into the app from each machine in the lab. The mobile Web app is used for control, monitoring, and collaboration. We have tested and deployed this system at the real-world factory and it is now in daily use. This project is designed as part of a research exploration into enhanced collaboration in industrial settings between physically remote people and places, e.g. factories in China with clients in the US.

Author Keywords
Industrial control systems; remote monitoring; mobile collaboration; smart laboratory; laboratory instrumentation

ACM Classification Keywords
H.5.3. Information interfaces and presentation (e.g., HCI): Computer-supported cooperative work.

General Terms
Management, Measurement, Documentation, Design.

INTRODUCTION
Our project is situated at the intersection of mobile, ubiquitous, and social applications for enhancing industrial work environments. Related work in smart laboratory design includes the LabScape project [2] which focused on digitally instrumenting processes and tasks in a cell biology lab. Since this is a food production lab, the tasks are on a different scale of complexity; more closely related work may be found in research on smart homes and kitchens [6] and in factory control environments [8]. We began this project to explore appropriate uses for mobile devices such as cell phones and tablet computers in the context of industrial smart environments. We were already working with chocolate maker TCHO [7] on a different project (involving a virtual "mirror world" of their main factory floor [3] that imported live data and video into a multi-user 3D environment). We looked for other labor-intensive areas where a shared mobile app could be of use in the company,

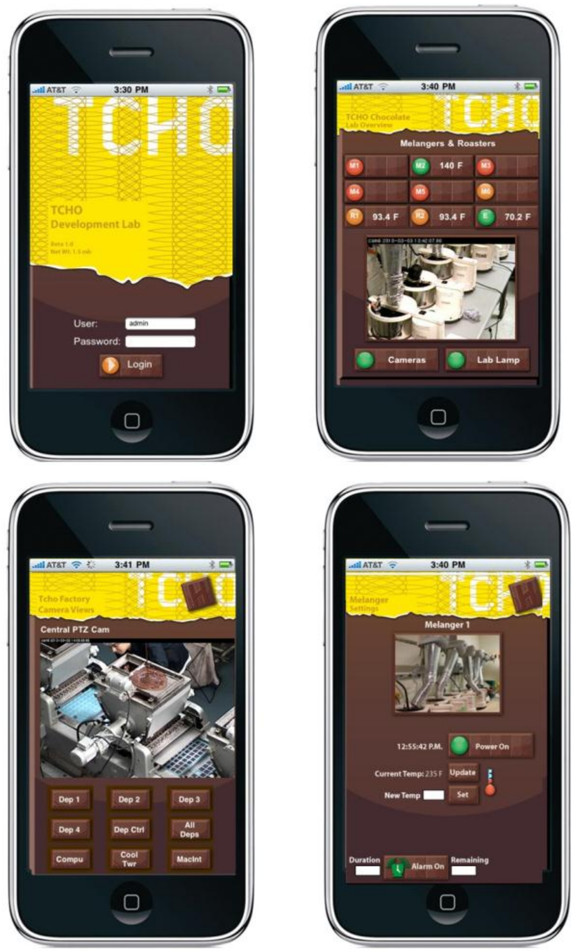

Figure 1. Screen shots from the mobile Web application for controlling machines in the chocolate development lab. In a nod to the company's main business, the UI design has a "chocolate candy bar" theme featuring a torn-off TCHO bar wrapper.

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and fixed upon the development lab, whose users frequently had to come in in the middle of the night for relatively simple tasks such as adjusting temperatures or shutting off machines. In this lab, we found a clear need for mobile control, monitoring, remote collaboration and data capture technologies.

DEVELOPMENT LAB CONTEXT

The development lab is called the Flavor Lab, as it is the place where TCHO develops its proprietary methods for creating unique chocolate flavors. Cacao beans from different growers and geographic areas are analyzed and new recipes developed for each of them. Each new harvest or type of cacao bean may require different treatment, such as a longer, slower roast, a longer grind, or a higher grind temperature. TCHO's aim is to create chocolate with identifiable flavors such as nutty, citrus, or fruity without adding any such flavors to the chocolate. Rather, they are looking for cacao beans with these flavors inherent in them, and then searching for the right process to enhance the bean's native flavor most fully. (See Figure 2 for TCHO's flavor wheel.) Accurate tracking and control of time and temperature are essential.

Figure 2. The development lab aims to find flavors inherent in cacao beans from varying sources like Peru and Ghana.

The Flavor Lab's mobile control and monitoring app is now in daily use at TCHO. Screenshots from the current version can be seen in Figure 1. Using the app, lab personnel can start or stop lab machines and control temperature and set power-down time from wherever they are, via iPhone, iPad, or Android devices. Alarms can be set for push notifications to remind users when needed. The app also gives the user a real-time view into the lab (via pan-tilt-zoom camera) for visual confirmation.

Understanding lab tasks: observation and interviews

During our development period, the six users of the lab ranged from expert to novice, with three experts overseeing the work of three trainees. We interviewed lab users and observed their work process over a period of several weeks. Many tasks were primarily manual, such as sorting, slicing, and picking over the cacao beans, and testing them for humidity and quality of fermentation. (Due to variation in the beans from harvest to harvest, each new batch, even from the same source, requires testing.) After these tests, the beans went through a complex and ever-varying cycle of roasting and grinding, where a typical run might include the following steps: pre-roast, roast 1, pre-roast 2, roast 2, coarse grind, then a longer melanger grind, X hours at Y temperature. A melanger is a heated mixer/grinder; the TCHO lab has six. A melanger grind could run anywhere from 14 - 26 hours. Often there would be five or six simultaneous runs with different timing and temperatures. This extended time period means at least two people would be involved, usually more. Every step and its variables are recorded; this body of data is a vital part of TCHO's intellectual property.

Supporting common procedures

We looked for specific, situated tasks or processes with spatial, temporal, and/or environmental components that could usefully be controlled remotely. Use parameters developed from the interviews and observation found the following tasks that could be supported:

- Monitor and control power, temperature and duration for melangers (heated grinders)
- Monitor and control temperature and duration for roasting ovens
- Capture temperature data over time to database
- Video of lab to confirm control
- High-definition video of notes on whiteboard and temperature gauges

Remote status and control of the melanger and roaster cycles and general awareness of the lab were the primary needs that came out of the observation and interviews.

App design

The UI is custom designed with a somewhat whimsical chocolate candy bar theme, complete with half-torn-off wrapper. Although this is a Web application, it is developed to work and behave like a native app, with a screen designed and matted for iPhone and iPad, and a general format for all other mobile devices (e.g. Android). It is also completely functional on regular desktop browsers. It can easily be ported to other mobile platforms with minor CSS and JavaScript provision to give it a different skin and native behavior on those platforms.

In the app itself, each machine has a dedicated page, accessible from a main overview page. Controls on that page are specific to that machine (machines are assigned to "zones" so that where they are physically plugged in assigns the machine ID). The lab camera also has a control page, so people can move the PTZ camera around to see what is happening in the room. The PTZ camera is configured with presets to focus on various work stations and workbench areas in the lab, with zoomed-in views available for some. These allow remote users to confirm their control settings, and, in cases where a batch job goes wrong or needs fine-tuning, the users can recall the video to see what happened. For example, when (rarely) the melanger's turnbelt (that controls the drum speed) gets jammed up or does not turn smoothly, the viscosity of the chocolate mixture does not come out right even though the temperature and duration settings were correct. An RPM sensor was considered too expensive, but a video zoom can show a remote user that the problem is occurring and they can correct either through a remote stop/start or by alerting an onsite co-worker.

User authentication

The lab is the generator of much of the chocolate company's proprietary information; it is constantly developing new recipes for the roasting and grinding of cacao beans for chocolate making. User authentication had to be built into the web app to ensure appropriate levels of access and control to the lab's cameras, materials and machines. For example, a guest or client might be allowed temporary view-only access, with no machine control, while the lab users might simultaneously use the machine controls to start and stop machines and monitor or change temperature settings.

Each user account is assigned one of the three roles: guest, admin or super-admin.

- Guest users have access to video browsing and simple remote control, e.g. turning the lab lamp on/off.
- Admin users are authorized users of the lab, typically TCHO employees that run its daily operations. They have complete control and access to all the devices, e.g. turning on/off the melangers, setting new temperatures, setting timers, setting alarms to trigger push notifications.
- Super-admin users have system-level control in addition to device control, e.g. creating new user accounts, access to database and the web and video servers. These users maintain the daily system operation and development of the mobile control system/software.

Iterative design

We created several iterations of the mobile app over a period of about eighteen months. One of the surprises we found from ongoing user interviews is that although an early version of the UI had built-in texting and note-taking, users preferred to use either physical notes and the whiteboard in the lab, or standard phone texting. They did not want to have "another place to look" for notes. We also:

- Moved from read-only status (for initial testing) to full control mode for most machines, including temperature setting and machine control
- Redesigned architecture to focus on machine zones rather than on individual machines. To support this we also revised the software driving the mobile web pages, and hardened the software underlying the sensor database.

Figure 3. Tasks in the development lab include sorting (top), and melanging (center). At bottom, a look inside a melanger midway through its run.

- Refined the UI, developed it for more devices, and enabled new features including remote temperature control and timer settings
- Updated Web application for onsite control (non-iPhone based, in a standard browser)

SYSTEM DESIGN

The mobile app is a Web application that is hosted on an Apache web server running on Linux and available around the clock. It was developed using a combination of PHP, HTML, CSS and Java Script, and JQuery. Data is organized and stored using a mySQL database, which also acts as the Job queue container. The video server uses server push to push video to the web pages. Python scripts control and query the relays connected to the devices as well as updating the database. Web pages query the database and display the corresponding status of each device. For device control, we have two kinds of Control Request: synchronous and asynchronous. An example of a synchronous request is turning the lab lamp on/off; it is executed instantly by the python script. An asynchronous control request such as "turn mixer on/off" is sent to the web app asynchronously, queued at the database and executed by a python script in a FIFO order, so that the last command sent – from anyone – is the executed command. Device status is then updated at the database. Since there are only a few users that have control of the lab devices currently, this approach is low cost and low risk. Should the number of users increase, a more sophisticated approach can be designed to handle the job queue. The system also implements a timer with an alert option for operating the mixers and roasters. With the alert option, a push notification is sent to the user as a reminder. Users can use this mechanism to set alerts at various time intervals, to check or adjust parameters like temperature and grind time.

Machine Control

For monitoring and controlling the power and temperature on melangers and roasters, we created a custom hardware control and relay box, run by custom python scripts, that integrated Omega Engineering's CN7500 series temperature/process controllers and software, with RS485 communication, a dual LED display, and built-in alarm functions [5]. For networked device control, we used Comtrol's DeviceMaster Ethernet to serial device server [4**].**

Video network/server architecture

Three PTZ cameras and seven standard network video cameras [1] are installed around the factory and lab. The system supports server push for Windows IE, Safari and FireFox browsers. A dedicated acquisition server streams and stores the video data. The PTZ cameras are configured with a number of preset views for users to select. Video data is saved and available for later review. The system also supports Web-based search and annotation of video.

INDUSTRIAL SOCIAL MEDIA

Both the mobile app and the virtual mirror world at TCHO are designed for lightweight social interaction as well as data and machine management. In the mobile system, for instance, users can see if someone else is already in the lab when a machine times out or otherwise needs attention. Workers can remotely check on tasks, and communicate via text message (texting is not inside the app, as noted earlier) to update each other on task status. Expert chocolate makers can "look over the shoulder" of a novice without having to be physically present every moment. Though these seem like small conveniences, they create cumulative efficiencies both in employee time and in reduction of error (especially the common error of leaving the melangers or roasters heating for too long, resulting in a ruined batch).

Conclusion

We see a number of options for expanding this app, like binding the video data with the device data and labs environment parameters to form a complete, integrated log of all operational data for each batch; and extending the informal note-taking aspect of the system to include voice.

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