An Arduino-Based Hardware Lock and Sensor Data Collection System for Cleanroom Equipment

Johansen, Leif; Nyholt, Henrik; Hemmingsen, Jens H.; Eskildsen, Thøger; Hübner, Jörg

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Leif S. Johansen, Henrik Nyholt, Jens Hemmingsen, Thøger Eskildsen & Jörg Hübner

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Brief Introduction to DTU Danchip

- Danish national centre for micro- and nanofabrication, founded 1992
- A unit under the Danish Technical University (DTU)
- 40+ staff
- ISO 9001 certified since 2011
- 14,500 ft² (1,350 m²) class 10, 100 & 1000 space
- 250 registered users at any given time
- Ca. 140 new users per year
- 80/20% academic/commercial use
- From basic research to small-scale production
- 140+ pieces of equipment
- Pieces, 2”, 4”, 6” & 8”
DTU Danchip’s Payment Model

• Payment per cleanroom hour. 20 hours/month cap
• Tool usage payment
  – Class A tools (UV litho, furnaces, plating, etc.): Low fee
  – Class B tools (Thin film dep. and etch): Medium fee
  – Class C tools (DUV stepper, e-beam writer): High fee
  – Class F tools (microscopes, wet benches): Included in access fee
• Cleanroom and tool rates are depending on project type:
  – Academic: No fee
  – Academic with external funding: Reduced fee
  – Commercial: Commercial fee
• Some materials not included in tool rate: Gold, wafers & photomasks
• In the future: Expensive photoresists will be billed by consumption
  (1 G ZEP520: 100 000 $)
• All tool and cleanroom hours are logged via LabManager, our lab usage management system
• LabManager data forms the basis for calculation of hourly rates
LabManager - Architecture

- LabManager: Proprietary lab usage management system
- Gradually developed over 10+ years
- Browser based
  - No s/w installation needed
  - Accessible anywhere (with login)
- Browser interfaces with Apache web server
- LabManager written in PHP
  - Not compiled
  - Easier to change code
LabManager – Functions

- Operator manuals
- Technical documents (user accessible)
- Technical documents (Danchip staff only)
- Maintenance manuals
- Safety instructions
- Contact persons
- Tool status
- Booking calendar
- Start/stop
- Logbooks (partially)
- Web shop (wafers etc.)
- Tool usage statistics
- Uptime analysis
- Bottleneck finder
- Invoicing
- CAPA handling (Danchip staff only)
- Cross contamination (upcoming)
Start/Stop

- Equipment will be put in “in use” mode on the info page
- The chosen project will be billed
- Tool usage statistics can be extracted

Use Equipment

<table>
<thead>
<tr>
<th>Customer</th>
<th>LSJ - lesjo - (Leif Johansen)</th>
<th>Get Last</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customers Projects</td>
<td>Process Develop</td>
<td></td>
</tr>
<tr>
<td>Equipment</td>
<td>DUV Stepper</td>
<td></td>
</tr>
</tbody>
</table>

Start to use
BUT!

- People "forget" to Start/Stop
- No overview over actual tool usage
  - "Comparing log files with registrations made me lose my faith in humanity"
- Unauthorized users accessing tools they are not trained to use
- Impossible to do proper price modelling, bottle neck analysis, etc.
- Funding of DTU Danchip jeopardized
- Unable to troubleshoot breakdowns (who did what, and when?)
- Something has to be done
- **Lock `em up!** (The tools – not the users)
Candidates for Hardware Lock system

- Web IP switches:
The Arduino Microcontroller - Another Good Candidate to Build a Hardware Lock Around

- 8 bit processor
- 35 kB RAM (in flash, SRAM & EEPROM)
- 16MHz
- 14 digital I/Os
- 6 analogue inputs
- Few μW – 2.5W
- Powered over Ethernet (POE)
- Easy to program
- Price 25 USD
- More flexible than ordinary Ethernet switches
- Extra functionality
The LabManager Lock

Arduino UNO

Arduino Ethernet shield

Terminals for relay output

"Traffic light" connection
The LabManager Lock in its Cabinet

- WxHxD: 4x2.5x6 in³ (10x7x16 cm³)
- BOM: >100 $. More expensive than a web switch
- Assembled in house by student helpers
- Easily installable in a service area
- POE: No extra power needed
- Disable/enable
  - Screen power
  - Interlock switch
  - Shutter (aligner)
  - Power (simple tools)
  - Solenoid acuated lock
  - RF generator
Traffic Light

- Placed next to tool’s user interface (PC screen, furnace door, loadlock etc.)
Infrastructure Investments: POE Cables

- 140 PDS cables, category 6A
- POE switches
- Price: Ca. 45 000 $
- Not only for LabManager locks
- Also for safety warning signs
- WLAN not preferred
LabManager Lock - Front View

DIN connector: “Traffic light”

POE LAN connector: Power and comm’s

USB connector: Programming
LabManager Lock - Rear View, Relay Type

Relay connection
Rear View – 5 V Control Signal

5 Volt control signal
Rear View, Mains Switch

Mains in

Mains out
Same Platform – CDA Pressure Gauge

- Portable point of use CDA pressure gauge
- CDA readouts are logged in a database via Ethernet
- Also made in a point of use vacuum gauge version
Present Project: Calculation of Resist Consumption

- DUV resist coater
- Expensive resist
- LM Lock analogue input:
  Reading of resist canister weight scale
  1. Read canister weight at tool logon
  2. Read canister weight at tool logoff
  3. Calculate resist consumption
  4. Issue bill for consumed material

- Next project: Automatic status change in LabManager via digital outputs from tool
If the Network is Down...

- Blocked equipment upsets users
- The hardware lock checks the machine’s status in LabManager every 10\textsuperscript{th} sec
- If the lock receives no answer from the software on status, the lock is unlocked (happy hour in the cleanroom)
### LabManager - Competences

#### Competence - Authorized Users

<table>
<thead>
<tr>
<th>User</th>
<th>Trained</th>
<th>Authorized</th>
<th>De-authorized</th>
<th>Resume</th>
</tr>
</thead>
<tbody>
<tr>
<td>elkh - Elena Khomtchenko</td>
<td>✔️</td>
<td>✔️</td>
<td>❌</td>
<td>📜Resumé</td>
</tr>
<tr>
<td>taran - Thomas Aarøe Anhøj</td>
<td>✔️</td>
<td>✔️</td>
<td>❌</td>
<td>📜Resumé</td>
</tr>
<tr>
<td>makei - Matthias Keil</td>
<td>✔️</td>
<td>✔️</td>
<td>❌</td>
<td>📜Resumé</td>
</tr>
</tbody>
</table>

- Only authorized users can start equipment
- Automatic de-authorization after 9 months without usage
- "Bad boys" can be immediately de-authorized

#### Change Log

<table>
<thead>
<tr>
<th>Change</th>
<th>Time</th>
<th>Changed By</th>
</tr>
</thead>
<tbody>
<tr>
<td>authorized:</td>
<td>2013-10-09</td>
<td>elkh</td>
</tr>
<tr>
<td>trainer</td>
<td>16:00:40</td>
<td></td>
</tr>
<tr>
<td>added Training:</td>
<td>2013-10-09</td>
<td>elkh</td>
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<tr>
<td>trainer</td>
<td>16:00:38</td>
<td></td>
</tr>
<tr>
<td>authorized:</td>
<td>2013-10-09</td>
<td>elkh</td>
</tr>
<tr>
<td>user</td>
<td>16:00:37</td>
<td></td>
</tr>
<tr>
<td>added Training:</td>
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<td>elkh</td>
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<tr>
<td>user</td>
<td>16:00:35</td>
<td></td>
</tr>
<tr>
<td>authorized:</td>
<td>2013-10-09</td>
<td>elkh</td>
</tr>
<tr>
<td>maintainer</td>
<td>16:00:33</td>
<td></td>
</tr>
</tbody>
</table>
Results so far

- 48 hardware locks installed 1st half 2014
- Some tools are clearly used “more” (e.g. mask aligners, hot plates, SEMs)
- Usage of some tools fluctuates– difficult to say yet
- We caught a few culprits – including “goldfinger”
Summary

• A hardware lock has been developed – built around an Arduino UNO board
• Controlled (locked/unlocked) from LabManager software
• Can only be unlocked by authorized users
• Different lock versions for different tool types
• Flexible solution capable of also reading sensor data and tool status
• Resilient to network breakdowns
• Not cheapest solution
• Maybe not for everyone
Thanks to the Guys who Did all the Real Work

- Henrik Nyholt. Basic idea concept, hardware design and construction, microcontroller programming.

- Thøger Eskildsen. PHP-programming of LabManager software.

- Jens Hemmingsen. Hardware design and construction.
Thank you for your attention...