Edge AI in Smart Manufacturing: Defect Detection and Beyond

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Wei-Chao Chen, Co-founder of Skywatch & Head of Inventec AI Center
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Speaker Bio

Trista Chen
- Chief Scientist in Machine Learning, Inventec Inc.
- Serial Entrepreneur at the Bay Area
- Staff Research Scientist, Intel Corp.
- Video Architect, NVIDIA Corp.
- Ph.D., CMU ECE

Wei-Chao Chen
- Head of AI Center & Chief AI Advisor, Inventec Inc.
- Co-Founder & CEO, Skywatch Inc.
- Senior Research Scientist, Nokia Palo Alto
- Graphics Architect, NVIDIA Corp.
- Ph.D., UNC Chapel-Hill CS
Smart Manufacturing

https://medium.com/@kenmacken/who-turned-off-all-the-lights-470dc797fd0f
Lights-Out Factory

https://medium.com/@kenmacken/who-turned-off-all-the-lights-470dc797fd0f
Top 12 Industry 4.0 (I4.0) use cases

2023 Market Size ($B)

- Advanced Digital Product Development
- Data-driven Quality Control
- Data-driven Asset/Plant Performance Optimization
- Predictive Maintenance
- Remote Service
- Additive Production
- Human Robot Collaboration
- Everything-as-a-Service Business Models
- Virtual Training
- Remote Asset Testing/Inspection/Certification
- Data-driven Inventory Optimization
- Augmented Operations

CAGR (2018-2023)

Source: IoT Analytics – November 2018
Manufacturing stores more data than any other sector – an estimated two exabytes \((2 \cdot 10^{18} \text{ bytes})\) in 2010.

About Inventec

- Public company (Since 1975; Taipei, Taiwan)
- Tier 1 electronics manufacturer
- Annual revenue USD $16B+ (2018)
- Factories in Taiwan, Shanghai and Chongqing

Personal Computers
- Laptops

Enterprise Computers
- Servers

Solar Energy

Smart Devices
- Medical Devices
AI for Smart Manufacturing

- **Process Automation**
  - Automatic optical inspection
  - Production scheduling
  - Automatic testing

- **Predictive Analysis**
  - Order forecast
  - Production / yield prediction
  - Predictive maintenance
Inventec AI Center

Smart Manufacturing

Automatic optical inspection
Order forecast
Production scheduling
Test automation
...

Future Product

AIOT / Smart City applications
Medical devices
Robotics
Computation Platform
...

Inventec
Why Edge AI?

• Privacy
• Reliability
• Network Efficiency

JETSON TX2 MODULE
• NVIDIA Pascal™ Architecture GPU
• 2 Denver 64-bit CPUs + Quad-Core A57 Complex
• 8GB L128 bit DDR4 Memory
• 32GB eMMC 5.1 Flash Storage
• Connectivity to 802.11ac Wi-Fi and Bluetooth-Enabled Devices
• 10/100/1000BASE-T Ethernet
Laptop Testing Robot

AOI Re-inspection for SMT lines and PCBs

AOI Machine

Laptop Surface AOI

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Laptop Testing Robot

AOI Re-inspection for SMT lines and PCBs

AOI Re-inspection

Laptop Surface AOI
1. Laptop Testing Robot

Background

• Millions of laptops manufactured every month
  – Similar basic design, many different configurations
  – Production tests are *mostly* automatic
1. Laptop Testing Robot

Background

• Product approval is labor intensive
  – Takes weeks to certify for mass production
  – ~1M test assets
  – Hundreds of people running the tests
1. Laptop Testing Robot

Motivation (least -> most important)

• Labor cost and management
• Time-to-market
  – Regression tests take weeks / months to complete
• Increase confidence
  – The management confidence level about manual testing is only around 70%.
1. Laptop Testing Robot

By: Jimmy Ou, Wei-Chao Chen, et al. of Skywatch
Collaboration with Joseph Shi, Jack Hung & Inventec QA Engineers

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1. Laptop Testing Robot

Mechanical / electrical keyboard and mouse

Pneumatic actuators
1. Laptop Testing Robot

Camera with computer vision capability
1. Laptop Testing Robot

• Computer Vision (OpenCV)
  – Perspective correction
  – Edge detection & denoising
  – Template matching

• Tesseract OCR
  – LSTM-based NN OCR engine
1. Laptop Testing Robot

Future Opportunities

• Automatic testing script generation
  – from human-readable to machine-readable test cases
  – Close-loop verification is hard

• Scheduling optimization
  – Reshuffle test levels and orders to speed up process

• Monkey testing?
Laptop Testing Robot

AOI Re-inspection for SMT lines and PCBs

AOI Machine

Laptop Surface AOI
2: AOI Re-inspection

Common SMT defects
2: AOI Re-inspection

High false positive
Low first-pass yield

AOI Machine

Pass

Fail

Re-inspection by human

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2: AOI Re-inspection

AOI Machine

High false positive
Low first-pass yield

By: 許正翰, 呂明峻, 張文于 of NTU & advised by Wei-Chao Chen of Skywatch & NTU & Trista Chen of Inventec
Data & domain knowledge provided by Jessie Huang, Peter Chu @ TAO, among others

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2: AOI Re-inspection

Traditional Computer Vision defects w/ well-defined rules

Deep Learning defects w/ intuitive descriptions
2: AOI Re-inspection

0. Excess Solder (true)

1. Excess Solder (false positive → pass)

2. Insuff. Solder (true)

2. Insuff. Solder (false positive → pass)
Laptop Testing Robot

AOI Re-inspection for SMT lines and PCBs

Laptop Surface AOI
3. Laptop Surface AOI
## 3. Laptop Surface AOI

### Human readable rules

<table>
<thead>
<tr>
<th>Defect type</th>
<th>Class A spec</th>
<th>Class B spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scratch</td>
<td>Length: 12mm</td>
<td>Length: 20mm, Acceptable: 2 lines</td>
</tr>
<tr>
<td></td>
<td>Acceptable: 2 lines</td>
<td>Acceptable: 3 points</td>
</tr>
<tr>
<td>Dent</td>
<td>0.5 mm² &lt; size &lt; 0.7 mm²</td>
<td>0.5 mm² &lt; size &lt; 1 mm²</td>
</tr>
<tr>
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<td>Acceptable: 3 points</td>
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3. Laptop Surface AOI

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Human readable rules
3. Laptop Surface AOI

Training data

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3. Laptop Surface AOI

Surface defect classification

AIMobile M1 (Nvidia TX2)

By: Benson Lin of Skywatch, Trista Chen and Irene Chen of Inventec, Wei-Chao Chen of Skywatch & Inventec
In collaboration with Steven Wang, Sing-Wang Chen, Alfa Shih & Tim Zhang et al @ ICC
Machine manufactured by Jerry Tseng @ Leh-Yeh; Edge machine provided by Mark Lu @ AIMobile
3. Laptop Surface AOI

AIMobile M1 (Nvidia TX2)

Pass/Fail Classification

Pass

Fail

DL detection
3. Laptop Surface AOI

**Stage 1:** Explainable

**Stage 2:** Adjustable

Pass/Fail Classification

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3. Laptop Surface AOI

Stage 1: Explainable
Stage 2: Adjustable

Pass/Fail Classification

DL detection

Pass

Fail
3. Laptop Surface AOI – Explainable

Why did it pass/fail?

- Defect type
- Defect count
- Defect size

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Defect class cluster analysis

Defect types:

\[
\begin{array}{ccccc}
\text{s1} & \text{s2} & \text{s3} & \text{s4} & \text{s5} \\
\text{a} & \text{b} & \text{c} & \text{a} & \text{b} & \text{c} & \text{a} & \text{b} & \text{c} & \text{a} & \text{b} & \text{c} & \text{a} & \text{b} & \text{c}
\end{array}
\]

15 classes ?

5 classes ?

Stage-1 multi-class detector
Defect class cluster analysis

Defect types: s1, s2, s3, s4, s5

Laptop categories: a, b, c

Defect types: s1, s2, s3, s4, s5

Output

Input

15 classes

5 classes
3. Laptop Surface AOI

Stage 1: Explainable

Stage 2: Adjustable

Pass/Fail Classification

DL detection

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3. Laptop Surface AOI – Adjustable

Class A
2 lines 2 dots

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3. Laptop Surface AOI – Adjustable

Class B
3. Laptop Surface AOI – Adjustable

Class C
3. Laptop Surface AOI – Adjustable
3. Laptop Surface AOI – Adjustable
3. Laptop Surface AOI – Adjustable

Class A++
3. Laptop Surface AOI

Stage 1: Explainable

Stage 2: Adjustable

Pass/Fail Classification

DL detection

Fail

Pass
3. Laptop Surface AOI – Factory Prototype
Benefits of AI for Manufacturing

• The Obvious
  – Accuracy
  – Labor Saving ROI

• The Big Scope
  – Consistency
  – Trustable digital record
  – Industry 4.0

Source: Taiwan’s Institute for Information Industry (III) 2017
Benefits of AI for Manufacturing – I4.0

Production Efficiency

Peak Productivity

Identified Problem

Process chain

Productivity Detraction by Tool Failure

System Halt and Resume

Mfg TSUNAMI (Domino Effect) as Mfg Fluctuation Propagation

Image source: Hitachi “Factories of the Future”, NEXT 2019
Unexpected Bonus:
to do well while building your AI engine

We’re on a mission to connect 60,000 residential disabled in Taiwan to join AI work by providing high-quality data fuels to your AI engines.
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Innovation Quality Open Mind Execution