S8911

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Fujikura Ltd. and *Optenergy, Inc. (Fujikura group)
Today’s Topic: Deep Learning in Manufacturing

Deep Learning (AI)

Service
Agriculture
Retail
Logistics
Manufacturing
Advertise ment
Financial
Medical
Education
Security

Difficulty of DL in Manufacturing
- Few defective images.
- The requirement is quite different from ordinary DL.
  ex. image size, criteria of classification, etc.

We have successfully overcome these.

- The platform of DL visual inspection system was developed to apply to the various production line.
- A visual inspection system has been implemented to actual production line.
1. Introduction of our company
2. Fujikura’s “Monodukuri innovation”
3. Fiber Laser
4. Visual inspection using deep learning
5. Other application, future work.
Fujikura Ltd. corporate profile

- Headquarters
  Tokyo, JAPAN

- Founded
  February 1885 (132 Years)

- Head office and consolidated companies

Fujikura Group: 29 countries, about 140 companies

- 4 business Areas

  - **Power & Telecommunication Systems Company**
    Optical Fiber / Optical Fiber Cable / Equipment & Components/Network Device / Optical Parts / Communication Cable / Power Cables/Industrial wires / Accessories / Bare wires / Aluminium wires / Enamede Wires

  - **Electronics Business Company**
    FPC / Connector / Electronic Wire / HDD Parts / Thermal Product / Sensor

  - **Automotive Products Company**
    Wire Harness / Automotive related Components

  - **Real Estate Business Company**
    Fukagawa GATHARIA
History of our company

1885 Establishment

1923 Restoration after Earthquake and development of Technology

1970 Oil Shock and Fluctuating Market

1890 Starting Operation

1945 From Post-war Recovery to High Economic Growth

1991 Globalization Diversification

Second Industrial Revolution
Electrification, Mass Production, ...

Toward Forth Industrial Revolution (Industrial 4.0)

Third Industrial Revolution
Computer, Robot, Automation...
Industry 4.0 & Smart factory

- Manufacturing Execution System
- Connected Industries
- Big Data
- Cyber-Physical System
- Internet of things
- M2M: Machine to Machine

Key Features:
- Interoperability
- Information transparency
- Technical assistance
- Decentralized decisions

- Highly flexible mass production.
- Condition awareness of machine and process
- Intelligent support of workers
- Product quality
- Just-in-time maintenance and near-zero downtime
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5. Other application, future work.
2.1 “Monodukuri Innovation” in Fujikura

Our main business field is Level 1: Q・C・D Innovation, Level 2A: Creation of new service

“Monodukuri” means production

Level 1 (Q・C・D Innovation)

- Level 1A: Digitization of information
- Level 1B: Aggregation and Manage information
- Level 1C: Analysis using IoT
- Level 1D: Application of IoT in Real World

Level 2 (Create new value)

- Level 2A: Creation of new service using information
- Level 2B: provision of information platform

Solution in real world. Measures by AI and Control of robots by AI

- Construct global ecosystem
- Innovation utilizing the our own strength
- Today’s Talk

Business improvements so far

Business improvements utilizing IoT

Creation of new value using IoT

- AI analysis, Optimization using simulation
- Construction of IT infrastructure
- Digitization using sensors and cameras
2.2 “Monodukuri Innovation” (Level 0)

Kaizen (business improving) process so far
engineer’s insight, intuition, guess etc.
⇒ Total process speed depends on humans processing speed.

Kaizen Process

Grasping the current situation → Identifying the root cause → Testing hypothesis → Countermeasure → Verification

SO far

Insight → Intuition guess → Experience Principle → Conventional technology → Measurement by human

Little & Slow
2.2 “Monodukuri Innovation” (Level 1)

Kaizen process with IoT (without AI)
Human centric process cannot deal a large amount of various sensors data

Kaizen Process:
- Grasping the current situation
- Identifying the root cause
- Testing hypothesis
- Counter measure
- Verification

IoT:
- Sensors
- Cameras
- Intuition guess
- Experience Principle
- Conventional technology
- Measurement by human

Large amount of information

Internet of Things

Data mining, BI tools, etc.
⇒ Human centric result and speed is limited.
2.2 “Monodukuri Innovation” (Level 1)

- Unprecedented speed up, effectivity of countermeasure
  ⇒ AI & IoT is complementary relationship. Promote both as one entity.

Kaizen Process

- Grasping the current situation
- Identifying the root cause
- Testing hypothesis
- Counter measure
- Verification

IoT

- Sensors
- Cameras
- AI Analysis
- AI prediction
- AI Countermeasure

Internet of Things

Artificial Intelligence
1. Introduction of our company
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3.1 Fiber Laser

- A fiber laser has excellent beam quality, high efficiency and high reliability.
- Laser diodes are key components of a fiber laser.

**Fiber laser products**

- Pulse
- Single mode
- kW Hi-power

**Fiber laser Application**

- Cutting
- Welding
- Surface processing

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**Fiber Laser Basic Configuration**

- Combiner
- Pump light
- Oscillator
- Laser beam ($\lambda 1.1 \mu m$)
- Output 6 kW

**High-power semiconductor Laser**
3.2 Pumping LD for Fiber Laser

\[ \lambda:900\text{nm} \]
Output power:10~20\text{w}
3.3 Manufacturing process of LD for fiber laser

Pre process
- Crystal growth
- Electrode process
- Die cutting

Visual inspection by humans ➔ AI

Post process
- Assembly
- Measurement & Evaluation

Characteristics inspection

LD-Chip
Au wire
Sub-mount
3.4 Visual inspection Criteria of LD chips

1. LD chips are classified into 5 categories (A-E) depending on their defects.
2. "Others (defects) mode" needs to be treated and they are classified into different categories depending on their size and position.
3. For multiple defects in an LD chip, it is classified according to a priority of category classification.

<table>
<thead>
<tr>
<th>Occurrence position</th>
<th>Defect modes</th>
<th>Others mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mode1</td>
<td>mode2</td>
</tr>
<tr>
<td>Area 1</td>
<td>Category B</td>
<td>Category C</td>
</tr>
<tr>
<td>Area 2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Area 3</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

"Others mode" category classification

- For multiple defects in one chip, categorized accordingly to the prioritized category.
  - Category C > Category D > Category E > Category B > Category A
- A LD chip with no defect is categorized into A

This classification was done by skilled workers.
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4.1 Overview of visual inspection

**Purposes**
1. Promotion of automatic inspection
2. Accumulation of knowledge and skills of AI

*Improve competitiveness of manufacturing company (Monodukuri Innovation)*

3. Productivity and quality improvement of semiconductor lasers

*Improve competitiveness of Fiber Laser products*

**Organization of Project Ai**
1. **User (Image preparation)**
   - Optenergy, Inc. (Fujikura group)
   - Fujikura Ltd. R&D dep.

2. **AI technology development**
   - Fujikura Ltd. Production facilities dep.

3. **System development**

**Process overview**
- Setting a Wafer
- Taking an image
- Cutting out chip images
- Inspection with DL
- Output results
4.2 System development process

- Construction of AI
  - Preparation
    - 4.3 Requirement definition
    - 4.4 Computer resources
    - Data preparation
  - Learning
    - 4.5 Model tuning
    - Parameter tuning
    - 4.6 Data tuning
    - 4.7 Verification of learning
  - Validation
    - 4.8 Inference accuracy

- Presentation scope
- Construction of Interface
- 4.9 System reliability

- Production facilities (Hardware)
- Production facilities (Software)

- Beginning of use in production line
## 4.3 Requirement in visual inspection system

The special requirement of our DL system different from ordinary DL is shown.

<table>
<thead>
<tr>
<th>No</th>
<th>Special requirements</th>
<th>Action, issue</th>
<th>Slide</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The large ratio of chip size to defects size (1:500000) Size is 30 times larger</td>
<td>Pixel size</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Computer resources</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Deep learning model for large image</td>
<td>4.5</td>
</tr>
<tr>
<td>2</td>
<td>There is “Others” mode</td>
<td>“Others” modes is classified into sub modes.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Defects is classified into different class depending on the size and position</td>
<td>Create data base to manage image data</td>
<td>4.6</td>
</tr>
<tr>
<td>4</td>
<td>There are few images in some failure categories.</td>
<td>data augmentation</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Explanation for AI classification</td>
<td>heat map</td>
<td>4.7</td>
</tr>
<tr>
<td>6</td>
<td>Implementation in production line</td>
<td>High reliability</td>
<td>4.9</td>
</tr>
</tbody>
</table>
4.4 Pixel size and computer resources

- Pixel size ⇒ minimum defects: 2x2 pixels, the whole chip: 2 million pixels

- Minimum defects 2x2 pixels ⇒ Minimum size
- The whole chip ⇒ 30 times large size (typical case: 256x256 = 65 thousands)

- DGX-1 with Tesla V100
  - Performance (GPU FP16): 1 peta FLOPS
  - System memory: 512GB
  - GPU memory: 16GB/GPU

Graphs showing:
- Number of training images vs. Capacity of Main Memory (GB)
- Size of mini-batch vs. Capacity of GPU memory (GB)

- 5000 images
- MAX 9 images
- Capacity of GPU memory ranges from 0 to 16 GB
- Capacity of Main Memory ranges from 0 to 6000 GB
4.5 Tuning the network model

- General deep learning model doesn’t work → Network model is build from scratch

General model (ex. VGG) → NG

- Varying the layer, filter size, etc.
- Checking Training log & heat map

Select the best network config.

Training log

Original image

with feature heat map

Accuracy

Typical number of layers

Number of layers

2 6 12 100
4.6 Data tuning

- Create data base to manage image data and utilized for improvement.
- For insufficient image data sets, data augmentation (LV1, 2) is performed.

Data base item (example)

<table>
<thead>
<tr>
<th>Chip ID</th>
<th>Lot No.</th>
<th>Defect mode</th>
<th>Defect Sub mode</th>
<th>Defect Position</th>
<th>Defect size</th>
<th>Augmentation</th>
<th>Inference results</th>
<th>...</th>
</tr>
</thead>
</table>

Image DB

- Training, inference results

Defect modes

- mode1
- mode2
- **Others mode**

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<th>Occurrence position</th>
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<th>Area 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
<td>Category B</td>
<td>Category C</td>
<td>Category D</td>
</tr>
<tr>
<td>Large</td>
<td>Small</td>
<td></td>
<td></td>
</tr>
<tr>
<td>More than 10 Sub modes</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area 1</th>
<th>Area 2</th>
<th>Area 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category E</td>
<td>Category A</td>
<td></td>
</tr>
</tbody>
</table>

More than 10 Sub modes
4.6 Data tuning

- Create **data base** to manage image data and utilized for improvement.
- For insufficient image data sets, data augmentation (LV1, 2) is performed.

**Data base item (example)**

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<th>Defect size</th>
<th>[Augmentation]</th>
<th>Inference results</th>
<th>...</th>
</tr>
</thead>
</table>

**Image DB**

- **LV1:** General data augmentation (Rotation, up-down, Left-Right inversion, etc.)
- **LV2:** Synthesized image data is used.

Original → Synthesized + heat map

Confirm **No adverse effect** due to synthesis images
4.7 Verification of learning

- Not only the judgment of classification accuracy confirm that the heat map shows the correct position.
- Improve accuracy by eliminating discrepancies one by one

1. Human Judge = X

2. DL inference = X

Completion
4.7 Verification of learning

- We check the heat map for consistency during the inspection.
- Improve accuracy by eliminating discrepancies one by one

1. **Human Judge = X**

2. **DL inference = X**

3. **Feature map**

   **Discrepancies**

   DL focuses on a different point from the human's judge point.

4. **Improvement**
   - Inferring what kind of error occurs from feature map
   - \( \Rightarrow \) Increase the similar images (including synthesized images)
   - \( \Rightarrow \) Confirm the effect

**DL judge this cat. X by chance based on different point.**
4.8 Inference results

- The 98% high accuracy has been achieved. That exceeds human accuracy (95%).
  ⇒ Pass-Fail classification: 98%, Category classification: 95%

- Pass/Fail accuracy

<table>
<thead>
<tr>
<th>Test data Pass: 47% Fail: 53%</th>
<th>DL system</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pass</td>
<td>Fail</td>
<td></td>
</tr>
<tr>
<td>Answer Pass</td>
<td></td>
<td>46%</td>
<td>1%</td>
</tr>
<tr>
<td>Answer Fail</td>
<td></td>
<td>1%</td>
<td>52%</td>
</tr>
</tbody>
</table>

Total: 98%

- Category classification accuracy

<table>
<thead>
<tr>
<th>category</th>
<th>Pass accuracy</th>
<th>Fail accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>97%</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>95%</td>
<td>86%</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td>88%</td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Consider actual occurrence distribution

Weighted accuracy 95%
4.9 System design for reliability, extensibility, etc.

- Implementation in production line

- Loose coupling
- High reliability
- System extensibility
- Failure recovery
- Traceability

FA Process
- LD wafer
- Imaging Devices, etc.

Interface Process
- Message check
- Multiple start up prevention
- Pixel size check
- Message edit
- Abnormality notification
- Failure information
- Trace information

DL process 1
- DL process N
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5.1 Robot picking with AI

The robot autonomously obtains the image of the objects, recognizes the image by deep learning, judges based on the recognition result, and decides the next action.

With 300 picking, more than 95% of success rate is achieved.

Future application of robot picking technology
- Motion capturing, autonomous robot
5.2 Summary

● Fujikura is pushing forward “Monodukuri Innovation”
● Case study of AI
  ① Visual inspection systems of LD with deep learning
    • Deep learning with large-scale images
      - The limitations of computer resources.
      - Model tuning for the original image dataset
    • Efforts to improve the accuracy
      - Managing the training image data by Database
      - Use of synthesized images for too little sub category.
      - Data tuning with feature heat map
  ② Robot picking with AI
    • For future applications
      - Motion capturing, autonomous robot
Thank you for your kind attention

We are recruiting colleagues to work together with us!!

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