Using deep learning technique to automate banknote defect classification\(^1\)

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\(^1\) This presentation was prepared for the Workshop. The views expressed are those of the authors and do not necessarily reflect the views of the Bank of Italy, the BIS, the IFC or the central banks and other institutions represented at the event.
Using Deep Learning Technique to Automate Banknote Defect Classification

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To increase the efficiency of our banknote printing operation

- By reducing defect rate with real-time banknote printing quality inspection
- By reducing human effort involved in the inspection process

Motivation

To expand ML applications into central bank operations (BAU) especially for more automation & lean processes

- Statistical compilations, e.g. government spending, entity-resolution/disambiguation
- Human Resources
- Communications
- Banknote printing works
Banknote Printing Process

1. Simultan
2. Intaglio
3. Quality
4. Number
5. Cut-pack

- Offset printing machine
- Number printing machine
- Intaglio machine
Quality Inspection

Number of defects from the note printing process contributes to the cost of cash.

Feedback info. to previous steps for quality improvement.

Quality Inspection Machine

90% of the errors/defects occur in the “simultan” and “intaglio” steps.

1% defect target

0.95% actual defect percentage

Simultan | Intaglio | Quality | Number | Cut-pack
require human inspector to manually classify and collect statistics of defect types to inform operators in previous steps
Automatic Defect Classification

1. Real-time feedback to operators of the printing process, which will result in faster fixes
2. Reduce the human manual work-load in the process

QIM

Defect target: 1%

Reduction of defect: 20%

simultan\intaglio\quality\number\cut-pack
Examples: Banknote Defects

- **Dot/Ink Spot**
  - Defect
  - Normal

- **Wiping**
  - Defect
  - Normal

- **Set-Off**
  - Defect
  - Normal
Methodology
Automatic Defect Classification

Model: ResNet-101* + 3FC
[one shared model for 5 banknote denominations]

Input: image pair (defect banknote + standard banknote)
Output: 7 defect classes

Training (1,659 banknote defects)

Test Accuracy
(Out-Of-Sample)

97%

Operational Accuracy
74%

<table>
<thead>
<tr>
<th></th>
<th>Dot (Front)</th>
<th>Dot (Back)</th>
<th>Wiping (Front)</th>
<th>Set Off (Back)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Baht</td>
<td>467</td>
<td>461</td>
<td>99%</td>
<td>366</td>
</tr>
<tr>
<td>50 Baht</td>
<td>438</td>
<td>392</td>
<td>89%</td>
<td>184</td>
</tr>
<tr>
<td>100 Baht</td>
<td>947</td>
<td>946</td>
<td>100%</td>
<td>231</td>
</tr>
<tr>
<td>500 Baht</td>
<td>247</td>
<td>229</td>
<td>93%</td>
<td>184</td>
</tr>
<tr>
<td>1000 Baht</td>
<td>123</td>
<td>123</td>
<td>100%</td>
<td>59</td>
</tr>
<tr>
<td>Sum</td>
<td>2222</td>
<td>2151</td>
<td>97%</td>
<td>1024</td>
</tr>
</tbody>
</table>

Acc = Accuracy

99%

Training (1,659 banknote defects)

Test Accuracy
(Out-Of-Sample)

97%

Operational Accuracy
74%


20 Baht 467 461 99% 366 330 90% 1066 1023 96% 327 306 94%
50 Baht 438 392 89% 184 102 55% 1416 692 49% 252 186 74%
100 Baht 947 946 100% 231 229 99% 575 543 94% 612 564 92%
500 Baht 247 229 93% 184 145 79% 1319 177 13% 627 525 84%
1000 Baht 123 123 100% 59 54 92% 433 163 38% 654 592 91%
Sum 2222 2151 97% 1024 860 84% 4809 2598 54% 2472 2173 88%

Acc = Accuracy
Future Work

Improving performance on all 7 types of defects (90% coverage), currently work best only on the 3 biggest defect types

- Increase accuracy to 90%+, via more training data
- Expanding to front & bank variations (certain error types occur mostly only on one side)

Expanding to the automatic quality inspection to the cut-pack step