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# What is AOI?

**Automated Optical Inspection** is one of many *manufacturing test methods* common in the assembly of printed circuit boards. This list includes:

Test methods for electronic assemblies:

- **FT** (Functional Test) of finished product
- **ET/FP** (Electrical Test/Flying Probe) of partial assemblies (e.g. PCB's)
- **ICT** (In Circuit Test) of circuits/components on PCB
- **AXI / XI** (Automatic Xray Inspection) for soldering and presence of components
- **AOI** (Automatic Optical Inspection) for soldering and components
- **SPI** (Solder Paste Inspection)
- **OI** (Optical Inspection) by human

Unlike the other test methods, AOI can be applied during any and all steps in the process flow of PCBA (printed circuit board assembly). AOI characteristics include:

- Wide range of Applications
- Principle: An optical defect needs corrective measures
- Contact less measuring device
- Flexible and fast programming compared to electrical test systems
- Detects "un-measurable" RF components
- Quick Return on Investment

Typical limitations of Automated Optical Inspection include:

- Only visible defects can be detected
- False alarms can be triggered by visual differences

There are a variety of technologies employed by AOI machines and systems. They can be divided into the following categories:

- Distinction principles
- Color vs., B/W analysis
- Capturing devices (cameras)
- Optics (Lenses)
- Lighting

Different calculation (distinction) principles are:

- Correlation (picture comparison)
- Vector modeling (threshold rule based)
- Synthetic modeling (image processing based)

**AOI Calculation Principle of Correlation:**

- “Average” picture is created
- Picture comparison using an average picture, based on the “average” pixel-value of multiple digital images of the same component.
- Most commonly found in entry-level camera AOI systems.

Formula for Average Picture:
Image = (Image1 + Image2 + … + ImageN) / N

Correlation offers several advantages in AOI, including

- "Self learning" (by adding a new picture on every false alarm)
- Fast programming
- Flexibility

Typically cited disadvantages of correlation in AOI include:

- Risk of Escapes when operator adds “wrong pictures”
- Alternative components require renewed debugging

**AOI Calculation Principle of Vector Modeling**

- Many inspection fields for each component
- Each field has a ***numerical average*** of pixels
- Judgment by threshold values for each field
- Each field represents a small part of the component, such as only the solder joint
- Usually only Grey-scale analysis
- Both “Self Learning” (via statistics) or “Fixed limits” systems are available

The Advantages of Vector Modeling in AOI include

- Measurements are based on exact numbers
- Rotation measurements are sometimes possible
- Calculations are relatively simple (only grey-scale and small frames)

Vector Modeling also has some inherent disadvantages

- Requires a large library (extensive programming and experience)
- New or Odd components or designs need new modeling (for library)
- Limited flexibility (e.g. low volume-high mix)
- Text cannot be modeled: Additional technology needed

**AOI Synthetic Modeling Principle**

- A synthetic reference picture is calculated
- Calculation starts from a real picture
  - Used in more advanced camera systems, sometimes in combination with vector based models

The advantages of Synthetic Modeling in AOI

- Based on 1 image reference
- Tolerance setting done by modeling (graphical filters)
- Flexible ( well suited to low volume, high mix manufacturing)
- Easy use of alternative components

The disadvantages of Synthetic Modeling in AOI

- Experience & Library required to make modeling easier
- Powerful computer needed

**Color vs B/W in AOI provides significant advantages in performance**

- More powerful detection
- Reducing Escapes (missed defects) by Operator mistakes
- Increased Repair efficiency
- Easy detection of printing problems on OSP or Gold PCB finishes
- Verification of color parameters of components

There are two **Categories of Camera or image capture devices** typically used by AOI equipment design and manufacturers, with their own

- Moving XY Field Camera
- Line Camera or "Scanner"

The Moving XY Field Camera characteristics

- Camera/Light head is moving
- Mixed resolutions possible in one program
- Lighting can be changed per inspection location
- Omnidirectional lighting (360 degrees)
- Larger Field Of View (FoV) increases speed
- Orthogonal camera(s): Top view
  (more cameras = more speed)
- Angled cameras: Side view
  (2.5D gives easier verification on some components; slows down speed and programming time increases)

The Line Camera or Scanner characteristics

- Fast scanning
- Scanning time is independent of component number
- Single resolution per board
- Single direction lighting (no 360 degrees)
- No camera movement routing needed
- Relatively inexpensive

The **lens construction** on cameras is another consideration. Conventional Camera lenses are not ideal for AOI applications because they have

- Diverging view
- Deliver a different view in the center and side of the screen

**Telecentric lenses**, used by AOI equipment manufacturers such as **Marantz Business Electronics**, are ideal for this application.

- The provide a Parallel Optical Path
- This results in a completely flat image over the entire Field of View (FoV)

**Lighting** is another fundamental design component of AOI systems. There are several approaches employed, sometimes in combination with one another.

- ***Top Light*** designs are configured around the lens (70-80 degrees) and are useful for basic inspection requirements
- ***Side light*** design*s* are also around the lens configurations (45 degrees) which can provide improved visibility of text and improved visibility of solder meniscus, an important characteristic of paste pads
- ***Coaxial Lighting*** is designed to go *through the lens* employing a prism construction. It offers significant advantages
    - Light beam lands at 90º to PCB surface
    - It provides a high contrast between flat and non-flat items
    - Excellent visibility of solder defects

No machine is ideal for 100% of all defects, so determining the proportions and types of defects that occur in a particular process, and the required depth of detection required are significant steps to determining the optimum equipment type.

| ***Defect Pareto example*** | ***Frequency*** |
|---|---|
| | |
| ***Solder defect*** | *30%* |
| ***Missing Component*** | *25%* |
| ***Short*** | *20%* |
| ***Wrong Type*** | *5%* |
| ***Polarity error*** | *5%* |
| ***Thombstone*** | *5%* |
| ***Other*** | *5%* |
| ***Lifted Lead*** | *3%* |
| ***Offset*** | *1%* |
| ***Coplanarity error*** | *1%* |
| | |
| ***Total*** | ***100%*** |

There are other AOI machine selection considerations:

- Large or small Batch sizes?
- Is my process stable (False failure sensitivity)?
- Operator time for classification?
- Programming time for new product set up
- Financial: Pay-back time & Budget

**AOI Equipment Performance Indicators**

- Detection ability
  - The balance between real and false alarms
- Inspection speed
  - To match required cycle times
- Process related issues like Manual (desktop), Batch (island) or Continuous (in-line) loading)
- Programmability
  - To match required flexibility and batch sizes
- Financials
  - The Initial investment, Operational Costs (programming + operating) and resultant Beneficial Savings

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