Analysis of Optical Inspection from AOI and AVI machines

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Abstract:

In PCB industry, Optical Inspection has been grown rapidly in past decades. It is now playing an important role in manufacturing process. Most manufacturers are now using AOI machines to report defects on boards after photo-printing or etching. On the other hand, AVI (Automated Vision Inspection) which sometimes also called FVI (final vision inspection) is growing in a relatively fast pace, but not yet widely used in the industry.

AOI and AVI machines are different kind of machines with different functions, but their working principles are very similar. Many technologies of AVI are built up from AOI.   This paper analyses on the combination factors of AOI and AVI to meet the inspection objective.

There are 3 parts in this paper.   The first part focuses on the application of AOI and AVI and identifies all kinds of defects and boards which they can inspect.   The second part compares the hardware and software of AOI and AVI machines.   The commons and differences are found out.   The third part studies of finding defects under the application and machine issues of AOI and AVI.

The PCB manufacturers are now using AOI and AVI machines to ensure the quality of their boards. Both machines are using cameras to visually find the defects.

What are the differences?

So, we will look into this with the following chapters:

1 – The operation factors of AOI and AVI.

2 – Features of their hardware and software.

3 – How the defects are found

Part 1 – The operation factors of AOI and AVI.

AOI, automated optical inspection is an automated vision inspection of PCB during the manufacturing process.   It is used to scan the inner layers and outer layers of PCB after the processes of etching and stripping.   After scanning by AOI machine, the defects which do not meet the manufacturer's requirement will be identified by the machine. In this way, AOI can detect problems early in the production process, so faults would not be passed to next production process and production cost could be saved.   Therefore AOI can increase the quality of PCBs and reduce the production cost.
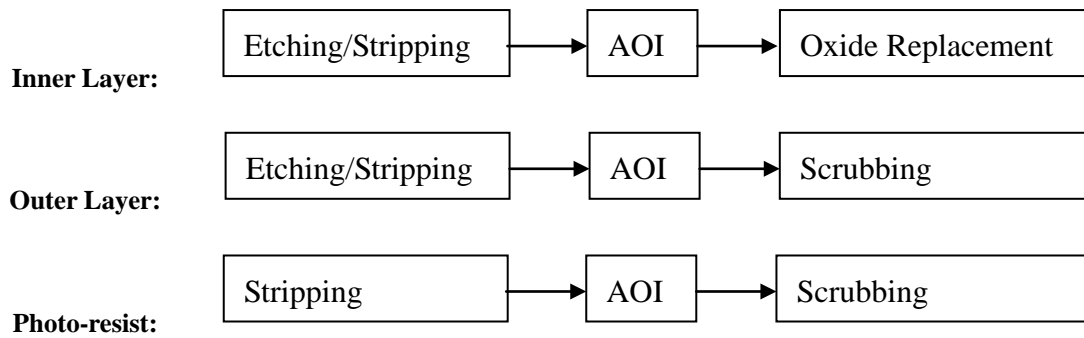
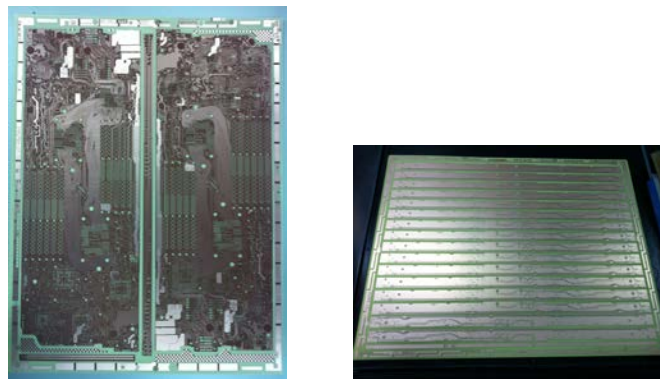**Figure 1 - AOI in manufacturing process**

Figure 2 – INNER PCB

AVI, automated vision inspection is an automated vision inspection on final PCB product. Unlike AOI which is the intermediate inspection process of PCB, AVI is the last inspection process of PCB. Therefore AVI is also called final vision inspection. Before shipping out of PCBs, cosmetic inspection which can identify the defects on the board appearance is very important. These defects were checked by human eyes before. But with AVI technology, many manufacturers use AVI machines to do the inspection automatically now. Compare to human eyes inspection, AVI machines can provide faster and more accurate vision inspection. Therefore, more and more manufacturers use AVI machines to improve the quality of PCB in their productions.

Figure 3 – AVI in manufacturing process

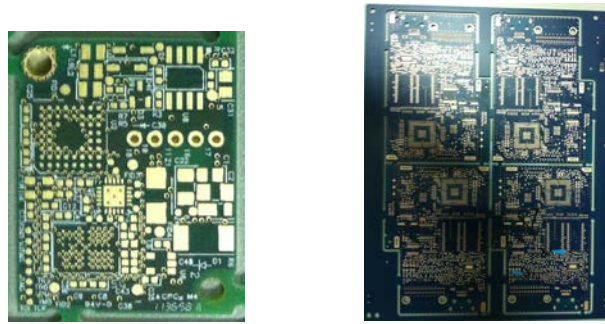**For AVI, the target board is the final PCB product.**

Figure 4 – final PCB

Compare to inner layers and outer layers, there are more features on final PCB. These features are solder-mask, copper under solder-mask, silk screen, golden finger and solder pad. Because there are so many features and each has its own color, AVI machines need more intelligent analysis on color compare to AOI machines.
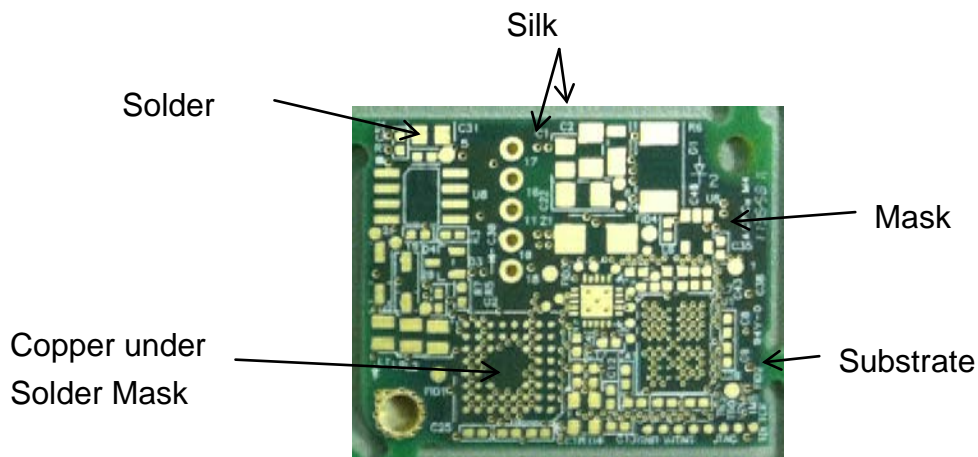

Figure 5 – Features on final PCB

Part 2. Hardware and Software of AOI and AVI machines

Hardware of AOI and AVI machines are very similar. They are both formed by four main parts:

Motion system, lighting system, camera systems, computer systems

I. Motion system:

There are two types of machine for both AOI and AVI machines: manual type machine and auto type machine. For manual type, the boards are loaded and unloaded by operators manually.

The camera and table are moved in x, y-axis when scanning.

Figure 6 – Motion system of manual type machine of AOI

Figure 7 – Auto type machine of AVI

For auto type, the boards are loaded and unloaded by machines automatically.   Some of them also have board flipping over function which makes both sides of the boards can be scanned in one cycle.   The process flow of auto type machine is more complicated than manual type machine.   Here is the process flow of auto type machine of AVI :
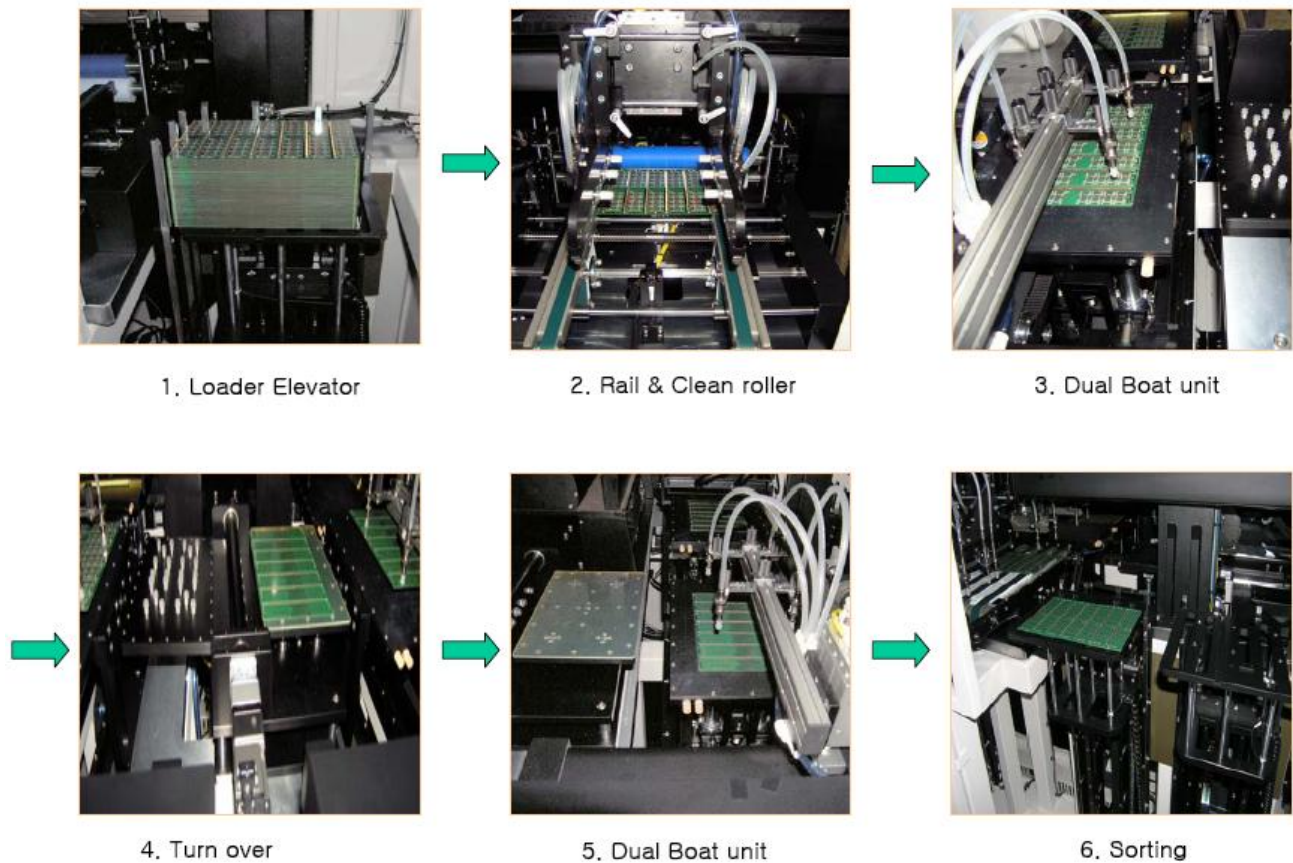
Figure 8 – Process flow of auto type machine of AVI

Table 1 shows the hardware components of motion system of AOI and AVI machines.

Table 1 – Motion system units

Unit	Description	Manual type	Auto type
Inspection table	Vacuum suction table to hold the boards when scanning	YES	YES
Servo motor	Move the inspection tables and cameras	YES	YES
Loader	Pick up unit to load the boards	NO	YES
Cleaning unit	Usually a clean roller and moving belt	NO	YES
Board handling unit	Using vacuum pick and place robot	NO	YES
Flipping unit	Automatic turn-over unit	NO	YES
Unloader	Unload the boards after inspection	NO	YES
Sorter	Sort the boards to pass, fail	NO	YES

From the table, we can see that manual type machine's motion system is very simple. Its main components are the inspection table and the servo motors which drive the inspection table and cameras. For auto type machines, there are many components and the boards are passed through many stages.

II. Lighting system

For AOI and AVI machines, there are many kinds of light source used in the market.   The most commons are LED, halogen lamp and fluorescent lamp.   Table 2 shows the light source of some AVI machines in market:

Table 2 - Light Source of AOI machines in market

Company	**Brand**	**Light source**
Mania	Autom8tor	Halogen lamp
Orbotech	Discovery	Halogen lamp
Camtek	3G	Halogen lamp
Screen	PI	LED

Table 3 shows the light source of some AVI machines in market:

Table 3 – Light Source of AVI machines in market

Company	**Brand**	**Light source**
Kurabo	BBMaster	LED
Taiyo	TV – Vision	LED, Halogen lamp, fluorescent lamp
ATI	AVIS	LED, Halogen lamp
Camtek	Mustang	Halogen
Utechzone	Skyline	LED

Not only the light sources are different, different AOI and AVI machines use different color light.   Some AOI machines use infra-red light rather than white light.   For AOI machines, the boards just consist of copper and substrate. Infra-red light (wavelength: 700nm~1000nm) are used as it is more response to the copper and less response to the substrate (see Figure 9).   Therefore, machines can distinguish the copper and substrate more effectively when using infra-red light.
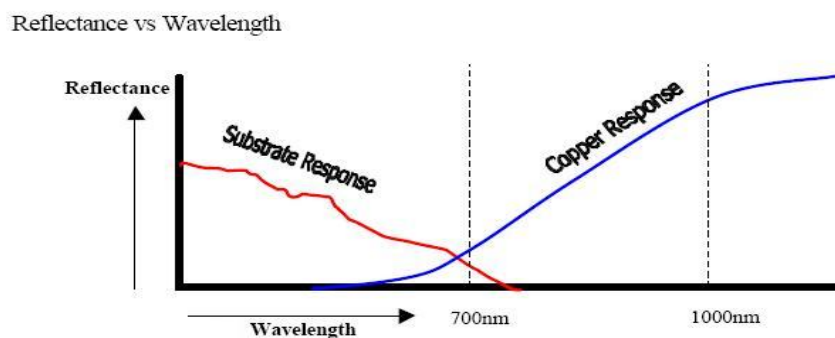

Figure 9 – Reflectance vs Wavelength

For AVI machines, the boards are not just consisting of copper and substrate.   They also need to check the color of many features on the boards.   Therefore, they use white light so that the color of the boards captured will not be affected by the light color.

III. Camera system

The camera system is the most important part of AOI and AVI machines.   The camera system is formed by cameras and lens.
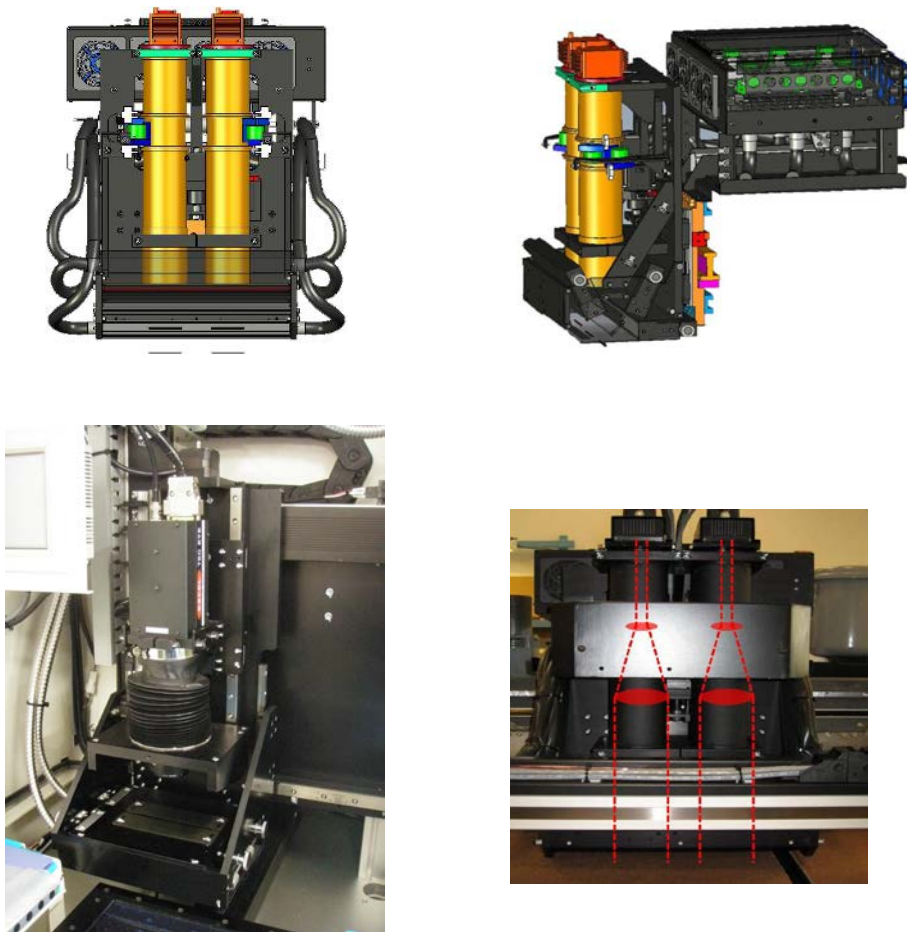

Figure 10 – AOI & AVI Camera system

There are color and monochrome type camera.   For AOI machines, they only need to classify copper and substrate, so monochrome type camera is enough for them.   But for AVI machines, color is an important concern as it is used for cosmetic inspection.   They have to detect some contamination or discoloration on PCBs, so color cameras are more commonly used than monochrome camera for AVI machines.

In digital imaging, a **pixel** (or **picture element**) is a single point in a raster image. The pixel is the smallest addressable screen element; it is the smallest unit of picture that can be controlled. Each pixel has its own address. The address of a pixel corresponds to its coordinates. Pixels are normally arranged in a two-dimensional grid, and are often represented using dots or squares. Each pixel is a sample of an original image; more samples typically provide more accurate representations of the original.

The intensity of each pixel is variable. In color image systems, a color is typically represented by three or four component intensities such as red, green, and blue, or cyan, magenta, yellow, and black.

The number of pixels is also important parameter of cameras.   Larger number of pixels does not mean it can detect smaller defects.   To detect smaller defects, smaller pixel size is required.   Pixel size is calculated by scan width / number of pixels.

For example, the scan width is 2inchs and number of pixels of camera is 2000.   Pixel size = 2inchs/2000 = 1mil.

Some machines use cameras with fewer pixels.   But they can use more cameras to compensate it.   Normally the exposure time for more pixels CCD is longer. So the scanning time of more pixels CCD is longer too.   Therefore, some machines use multiple CCD with less pixels rather than using one camera with more pixels.

IV.   Computer system

When the camera is scanning the PCBs, the image data would be passed to the computer system.   The computer will process the image data at the same time as the PCB is being scanned.   To have high efficiency, the process speed should match the scanning speed.   Otherwise, if the process speed is slower than the scanning speed, then after the board finishes scanning, the operators still have to wait for the computer to process and cannot start to scan another board.   As the computer needs to process large image data in short time, the computer requirement for AOI and AVI is very high. The processer of computer should be fast and the memory should be large.

V.   Software of AOI and AVI

The software is an important part of all AOI and AVI machine.   It provides a graphical interface for the users to operate and perform internal calculation to identify the defects.

VI.   Process Method of the image

It affects the process time as some machines just identify the defects by comparing pixel by pixels.   The processing time would be faster.
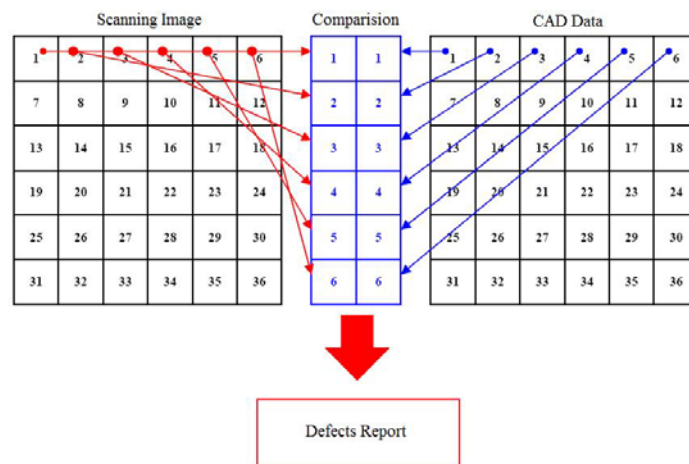

Figure 11 – Detect Defects by pixel by pixel

But some machines use logical method to detect the defects.   They use different method such as some complex contour comparison and design base inspection to detect the defects on different features.   So the process time would be longer.   To maintain short process time, the machine need faster computers and more computers compare to the machine using pixel by pixel method.

The most common operating system of AOI and AVI machines are Microsoft Windows.   The disadvantage is that the computer may get computer virus through network or removable drives.   So some machine use Linux which has fewer viruses.

VII. Verify Station

After the boards are scanned by AOI and AVI machines, user can verify and repair the defects by using verify stations.

AOI Verify Station   AVI Verify

Figure 12 – Verify Station

Part 3 – How the defects are found

I. Reference image

For all kind of AOI and AVI machines, there must be a reference image in order to find out the defects on the boards. It is used to compare with the scanned image to identify the defects. This reference image can be either a CAD data or a golden board image. A CAD data is a Computer-aided design data of PCBs which includes much information such as the circuit layout, solder mask layout, etc. These CAD data are created by CAD software. All regions are classified for a CAD data.
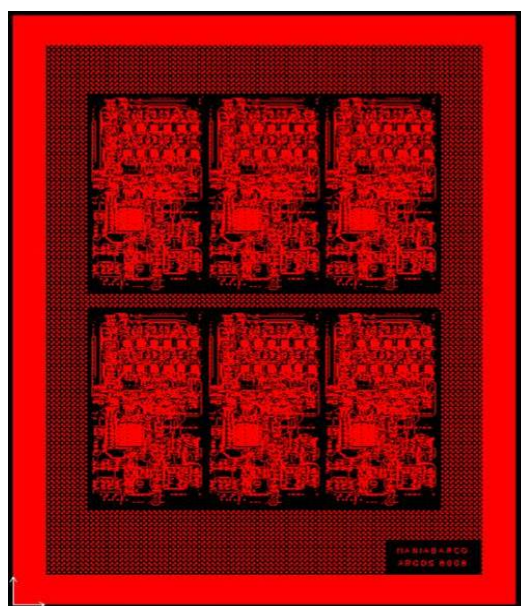
Figure 13 – CAD data

Another kind of reference image is the golden board image.   A golden board image is an image of a good board.   To ensure the board is a good board, it is normally checked manually by some magnifying devices first.   After that, it will be scanned by AOI/AVI machines and the image captured will be the golden board image.   Sometimes, the golden board image is created by scanning a number of boards and using the average image of these boards as the golden board image.
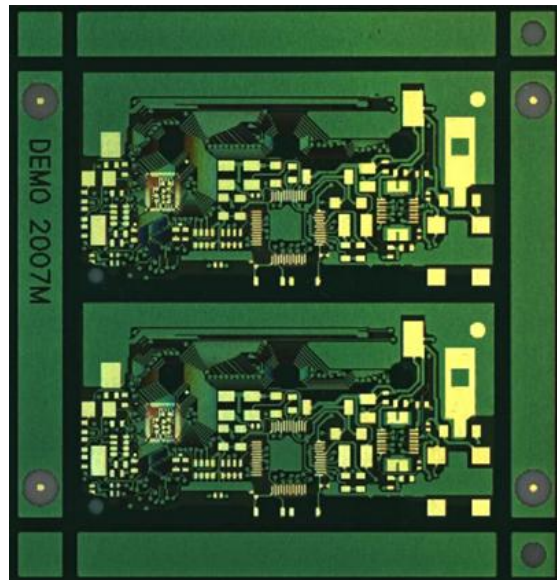
Figure 14 – Golden board image

If the reference image is CAD data, the CAD data is classified while the scanned image is not classified.   Therefore, the scanned image needed to be classified before comparing with the CAD data.
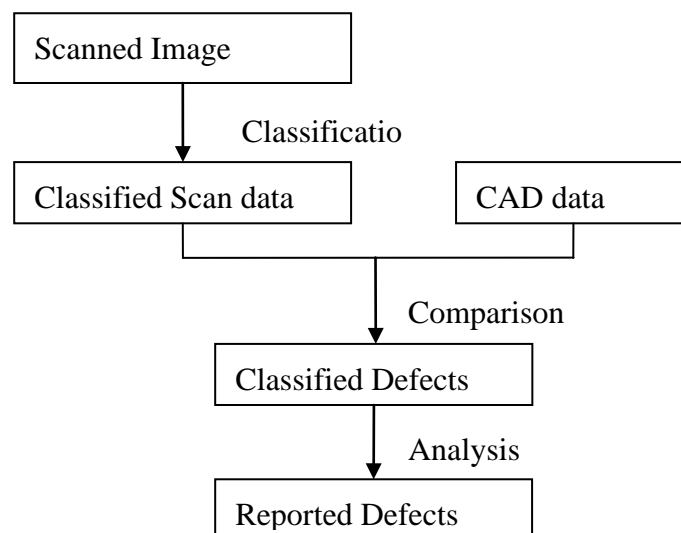
Figure 15 – Process of reporting defect using CAD data as reference image

If the reference image is golden board image, both scanned image and golden board image are not classified. Therefore, the scanned image can be compare directly with the golden board image to get the image difference.   The

golden board image is classified for analyzing with the image difference.
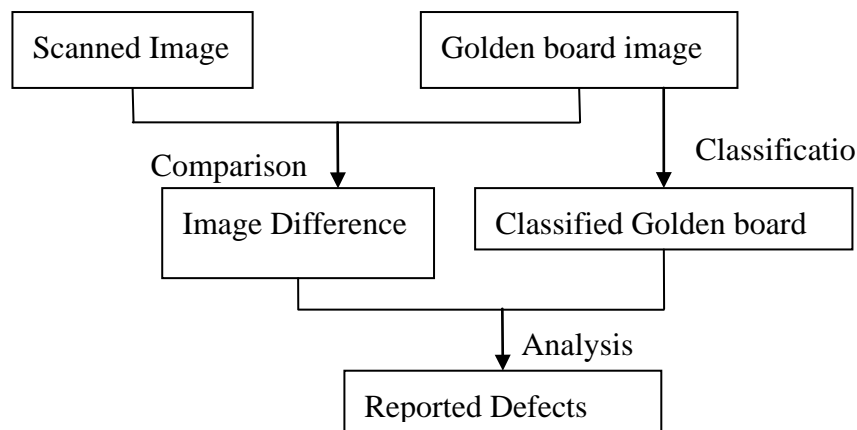
Figure 16 – Process of reporting defect using golden board image as reference image

II. Classification of image:

It is an important process.   For AOI, all regions of the image will be classified to copper, substrate.   For AVI, the classification is more complex.   The regions are classified to solder mask, silk printing, golden finger, solder pad, etc. These classifications are based on the brightness or color of the image.   For example, an AOI machine using monochrome type camera, the scanned image will be a gray image.   The brightness of grey image will be represented in a histogram.   A threshold value will be auto-calculated by the machine.   For regions which the brightness is higher than the threshold, they will be counted as copper.   For regions which the brightness is lower than the threshold, they will be counted as substrate.
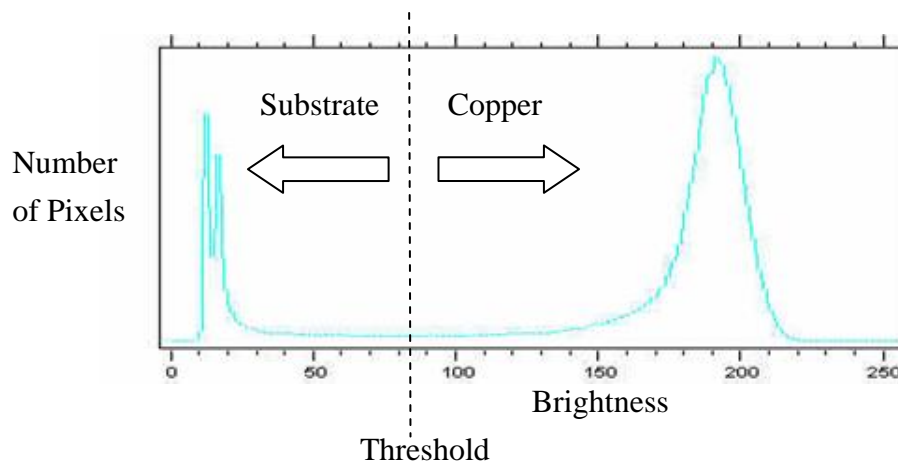
Figure 17 – Histogram

By using the threshold value, the gray image will be classified to copper and base and become a binary image. The white color region represents the copper and the black color region represents the base.

Board   Grey image   Binary
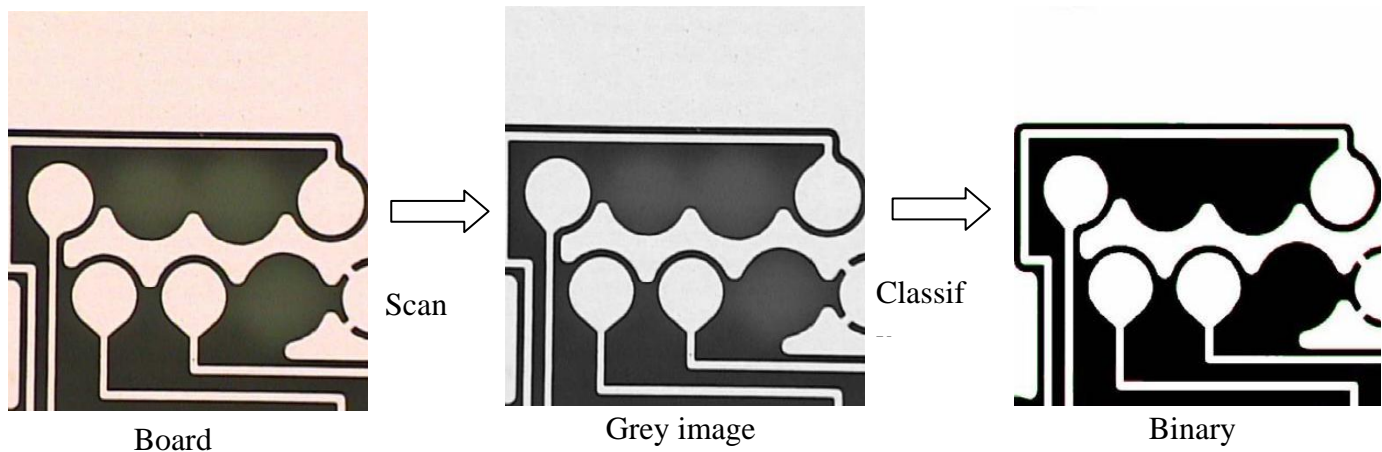
Figure18 – Scan and Classify image

If the original position is not copper but it is classified as copper, then there will be a false defect after comparison with the reference image.   Therefore, the classification process is very important and needs to be very accurate.

For AVI machine, there are more features on boards, so the histogram is more complicated.   The regions are classified to several areas such as solder mask, solder pad, golden finger, silk screen, etc.   Also many AVI machines use color camera.   So multiple histograms of different color (ex. Red/Green/Blue) are used and classifications are done by many parameters.   Therefore the classification process is more complicated.
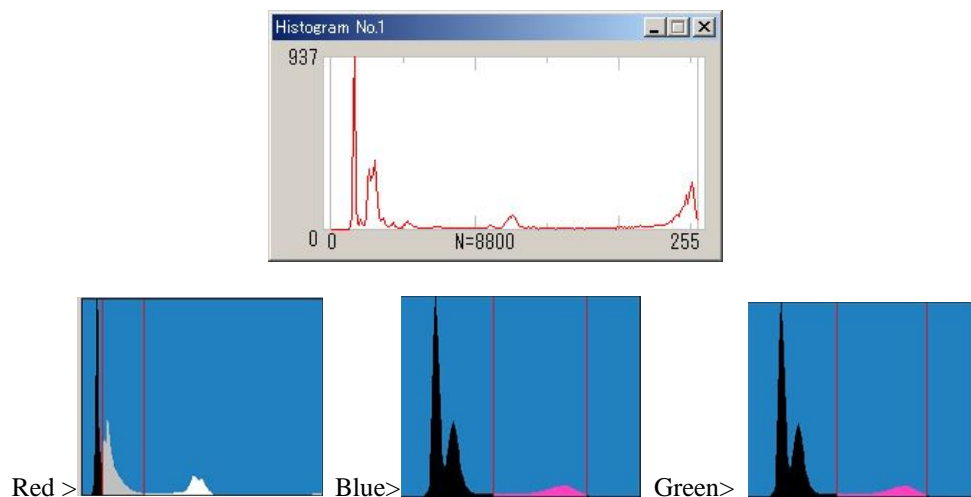
Figure 19 – Histogram of AVI machine
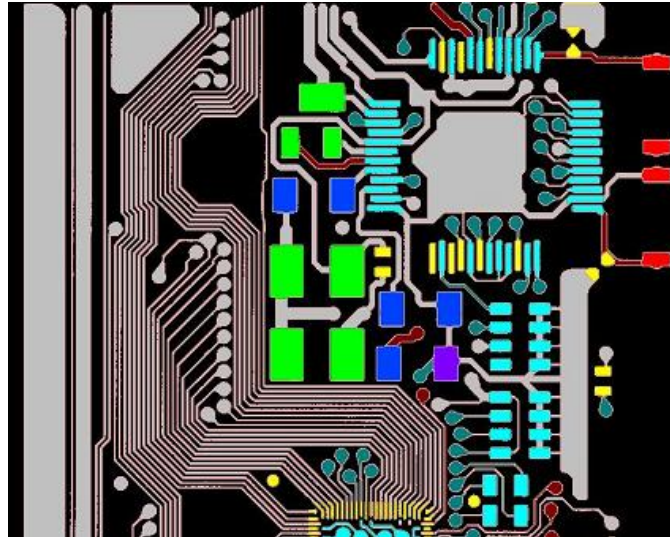
Figure 20 – Classified Image of AVI machine

As the classification is more complicated and more difficult to be accurate, most AVI machines use golden board image as the reference image because the scanned image can be compared with golden board image directly without classification.

For AOI machines, they inspect inner layers and outer layers which are just formed by copper and substrate, so the classification is easier.   Therefore, CAD data are commonly used.

After the defects are identified, they will be analyzed based on some factors such as the size of defect, position of defects to decide whether they are critical defects and are reported to user.
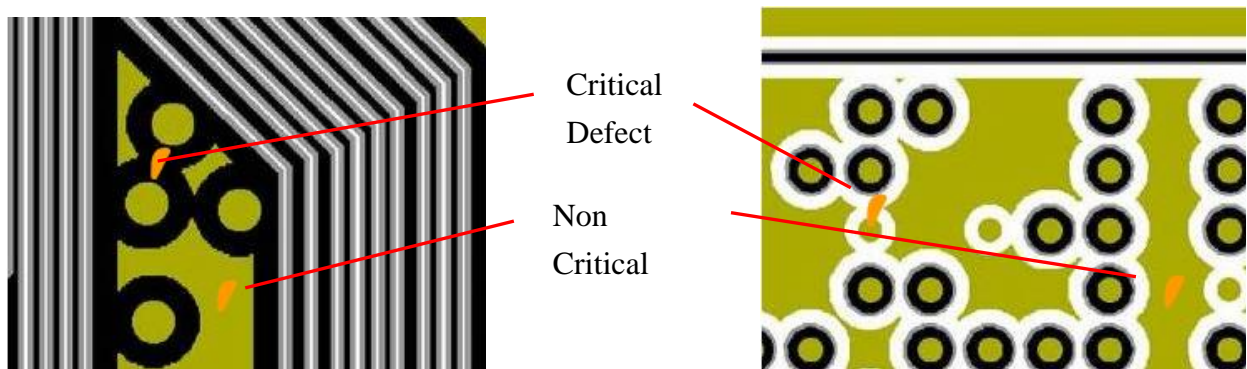
Figure 21 – Critical defect and non critical defect

From the figure 21, the two defects are same size, the defects which near the pads may cause short circuit.   Therefore they are counted as a critical defect and reported by machine.   For the defects which are far from the lines and pads, they are counted as non critical defect and not reported by machine.   The software will analyze whether the defect should be reported based on users' setting.

After analyze the defects are critical or not, the software will classified the defects as short circuit, open circuit, etc.   The software can also do the statistic on number of different defects.   So the users can use these statistic results to find out the production problem and improve their production process.

III.   Defects finding in AOI and AVI

For AOI and AVI, the main two factors determine whether the defects can be identified are the size and brightness/color of defects.   The pixel size of the AOI and AVI machines determine the minimum size of defects it can detect.   The pixel size can be seen as the basic unit of the scanned image.   Therefore, the minimum defect size detectable must be larger or equal to pixel size.   But even if the defect size is same as the pixel size, the defect might be very difficult to detect.   For example, in the following case, defect size is same as pixel size.

For case A, it is the best situation where the defect is inside the pixel, so the defect is easily detectable.   For case B, it is the worst situation as each of the four pixels can only see the 25% of the defect, so it may not detect the defect. Therefore, if the defect size is very small and is close to the pixel size, then it may not be detected by the machine.
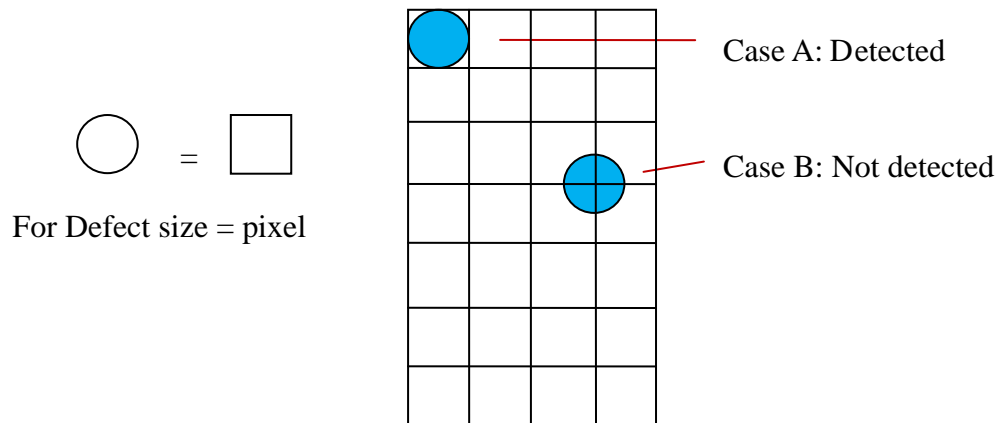
Figure 22 – Case for defect size equal to pixel size

Another factor which makes the defect difficult to detect is brightness/color of defect.   If the brightness/color of the defects is closed to normal area, then it will be difficult for machine to detect the defects.   The common missing defects on AOI and AVI are scratches and dents.
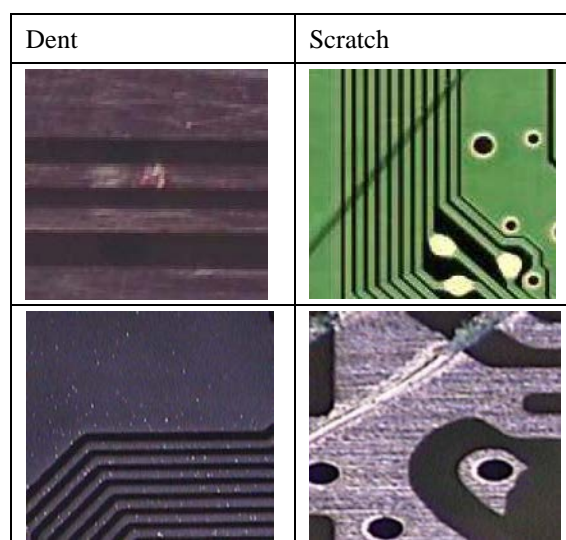
Figure 23 – Case for defect size equal to pixel size

The light of AOI machines and AVI machines are consist of specular and diffuse light.
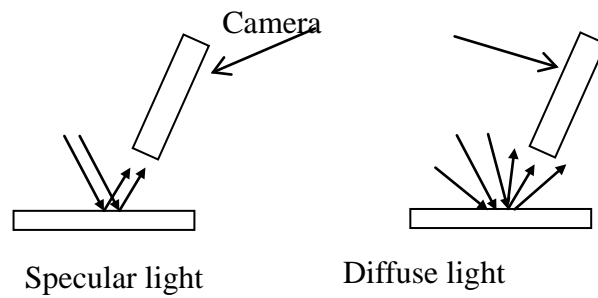
Figure 24 – Specular light and diffuse light on flat surface

For specular light, light ray incident on the surface in single angle and reflected into a single direction by the surface like mirror-reflection.   For diffuse light, the light incident on the surface from many directions and reflected in many directions.

Consider a dent on a line, the surface of the dent is not flat, most of the specular light will not be reflected to the camera. But diffuse light will be less affected by the surface and there will be some part of diffuse light being reflected to the camera.
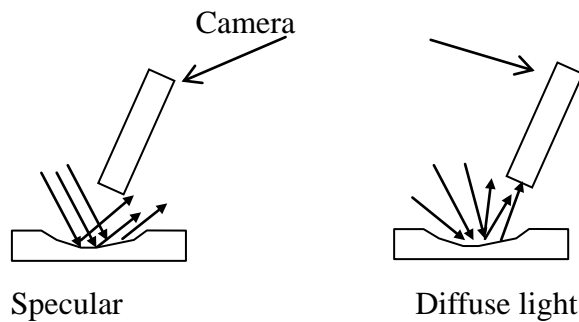
Figure 25 – Specular light and diffuse light on a dent

If the diffuse light intensity of the dent is high enough, the brightness of dent will be similar as the brightness of flat surface.   This small brightness difference may cause the machine unable to detect the dent.

On the other hand, if the intensity of diffuse light is reduced, then it may cause some false catching, such as oxidation, dust, oil stain, etc.

position and does not need to move.   But for AOI machine, the board sizes are larger, so the inspection table and the scan area are larger.   If the camera's scan width is shorter than the width of inspection table, then the camera need to be moved when scanning.

The motion system components of universal machine are similar to AOI and AVI machine.   The universal machine can use the motion system design of AOI or AVI machine with just little modification.

IV.   Camera system

There are color type and monochrome type camera for AOI and AVI machines respectively.   For AVI machines, color type camera performs better because it needs to detect the discoloration, contamination, etc.

For AOI machine, monochrome type camera is enough as it only needs to identify copper and substrate.

If the universal machine has both color type and monochrome type camera, then it can change different camera type for scanning different boards.   But the cost will be higher, the machine size will be larger and the complexity of machine will be higher.

Some AVI machines also use the monochrome camera.   The time to process the data captured by color type camera is longer than the monochrome type.
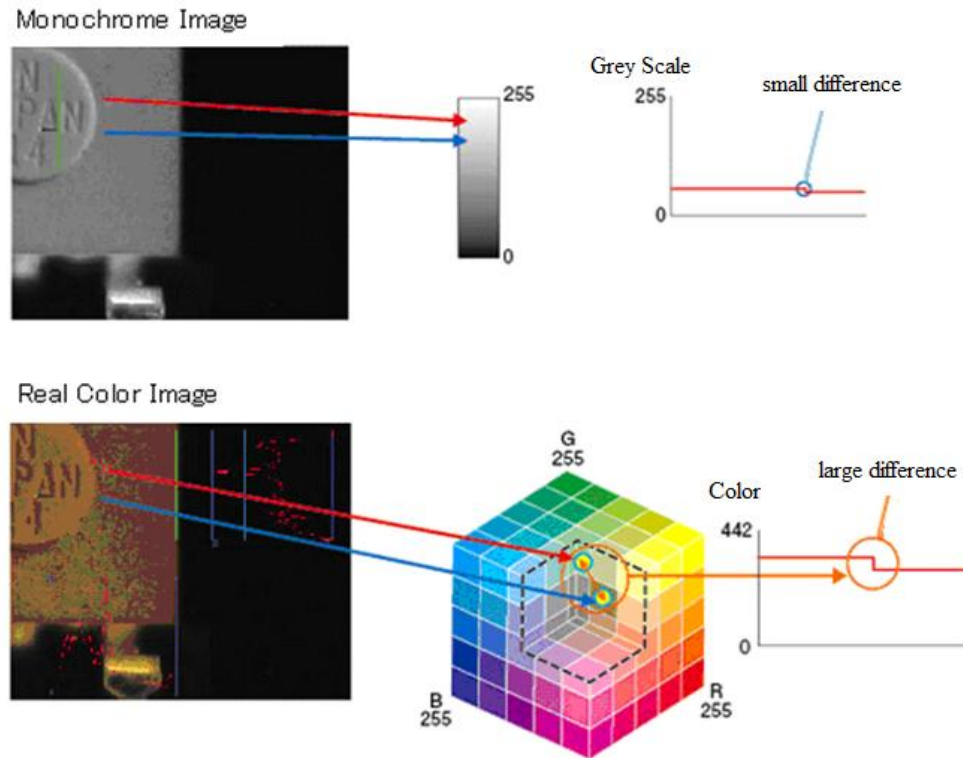

Figure 26 monochrome and color difference

V. Lighting system:

For light source, many AOI machines use halogen lamp.   The advantage for it is the light intensity is strong.   But the disadvantages are the life cycle is short and power is large.   For AVI machines, many use LED.   The advantage of it is the life cycle is much longer and power is small.   Some also has hybrid light source, for example, with halogen lamp and LED together.

Many AOI machines use red light to scan inner layers and outer layers.   It is because red light is more sensitive to copper. For photo-resist, they use different light color such as the yellow light.   It is because different light color has different wavelength.   The reflectance of copper and substrate are different for different wavelength.   Different wavelength may be more sensitive to some defects or some materials.
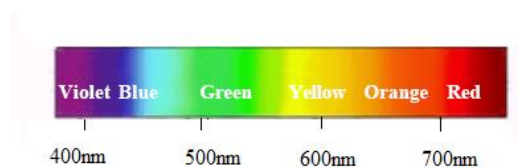
Figure 27 wave length for different light color

As mentioned earlier, under AVI machines, those boards are not just consisting of copper and substrate. They also need to check the color of many features on the boards. Therefore, they use white light so that the color of the boards captured will not be affected by the light color.

**** End of the paper

About Gardien

The Gardien Group is the world's largest provider of independent testing services to the PCB manufacturing industry. From small batch testing in one of the company's 25 facilities located throughout Asia and North America, to fully integrated inspection within a PCB production environment, Gardien's 500 employees serve customers supplying the automotive, defense, telecommunications, computer and industrial markets. For additional information about Gardien, please visit the Company's website at www.gardien.com

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Agenda

- The operation factor of AOI & AVI
- Hardware and Software
- How the defects are found

The Operation of AOI & AVI

- AOI for PCB Inner/Outer Layer
- AVI for finished PCB with solder resist
- The different light sources used on different board types
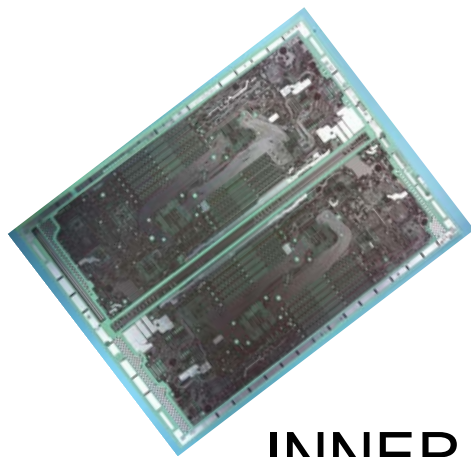
INNER LAYER
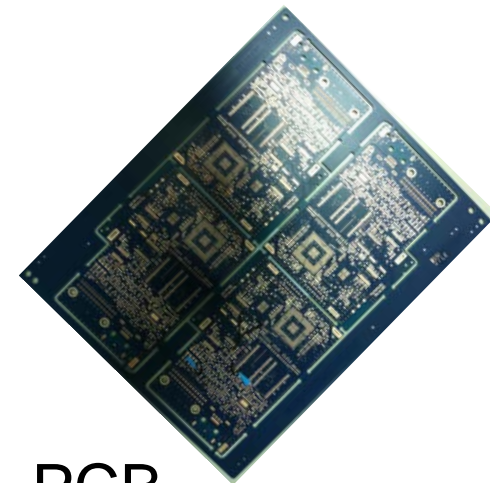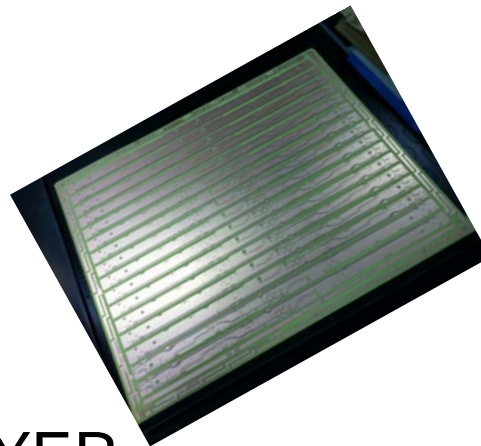
PCB

AOI in Process

AOI in Process

- Image Transfer

Inner or Outer

AOI

- Verify Defect

- Repair Defect

Lamination

AVI in Process

PCB
Product

AVI

Shipping
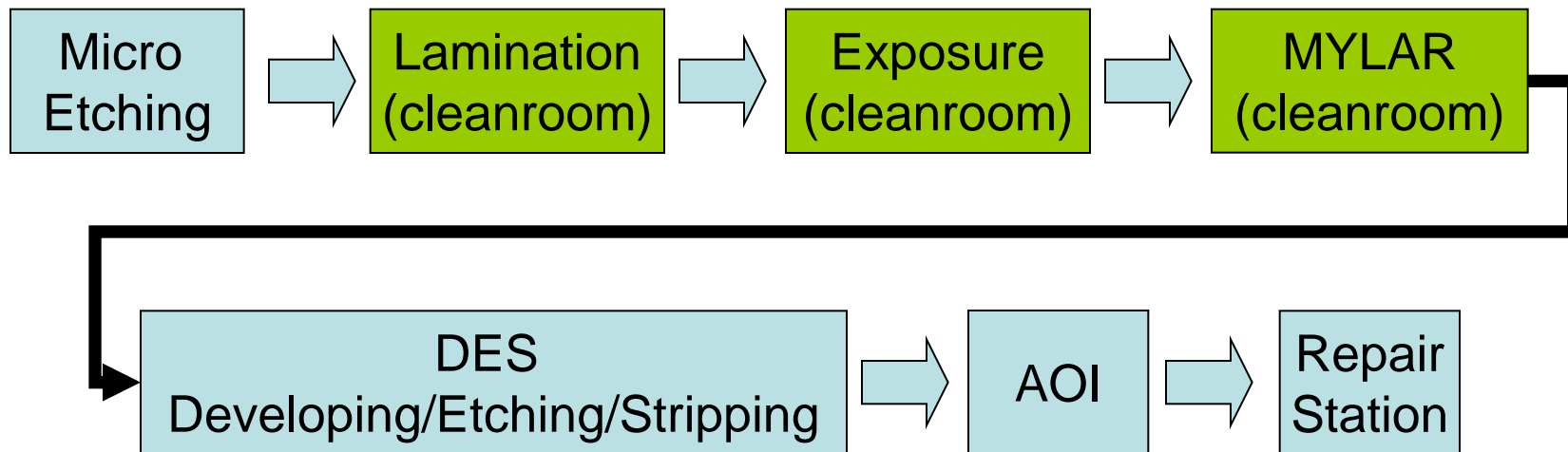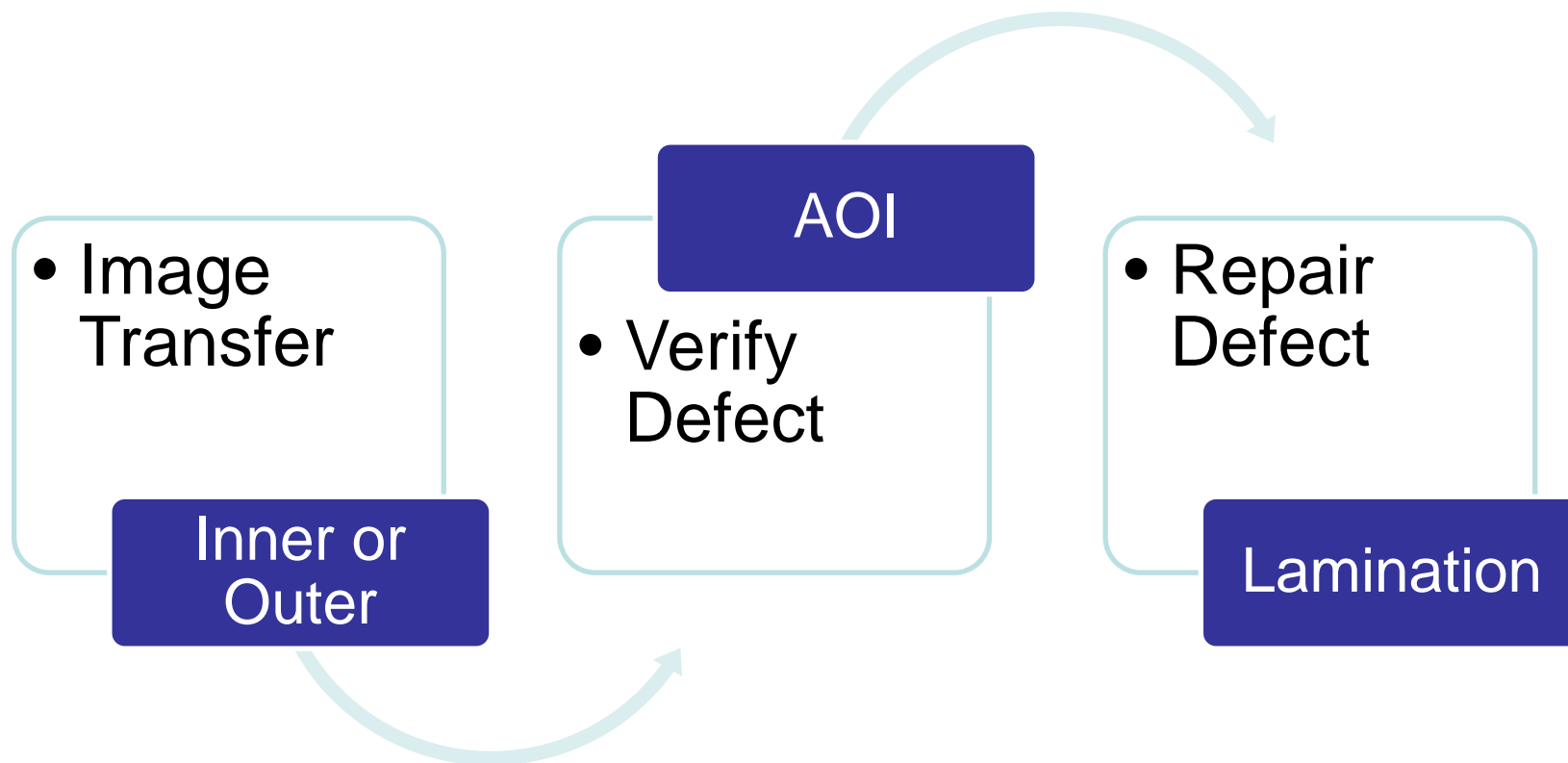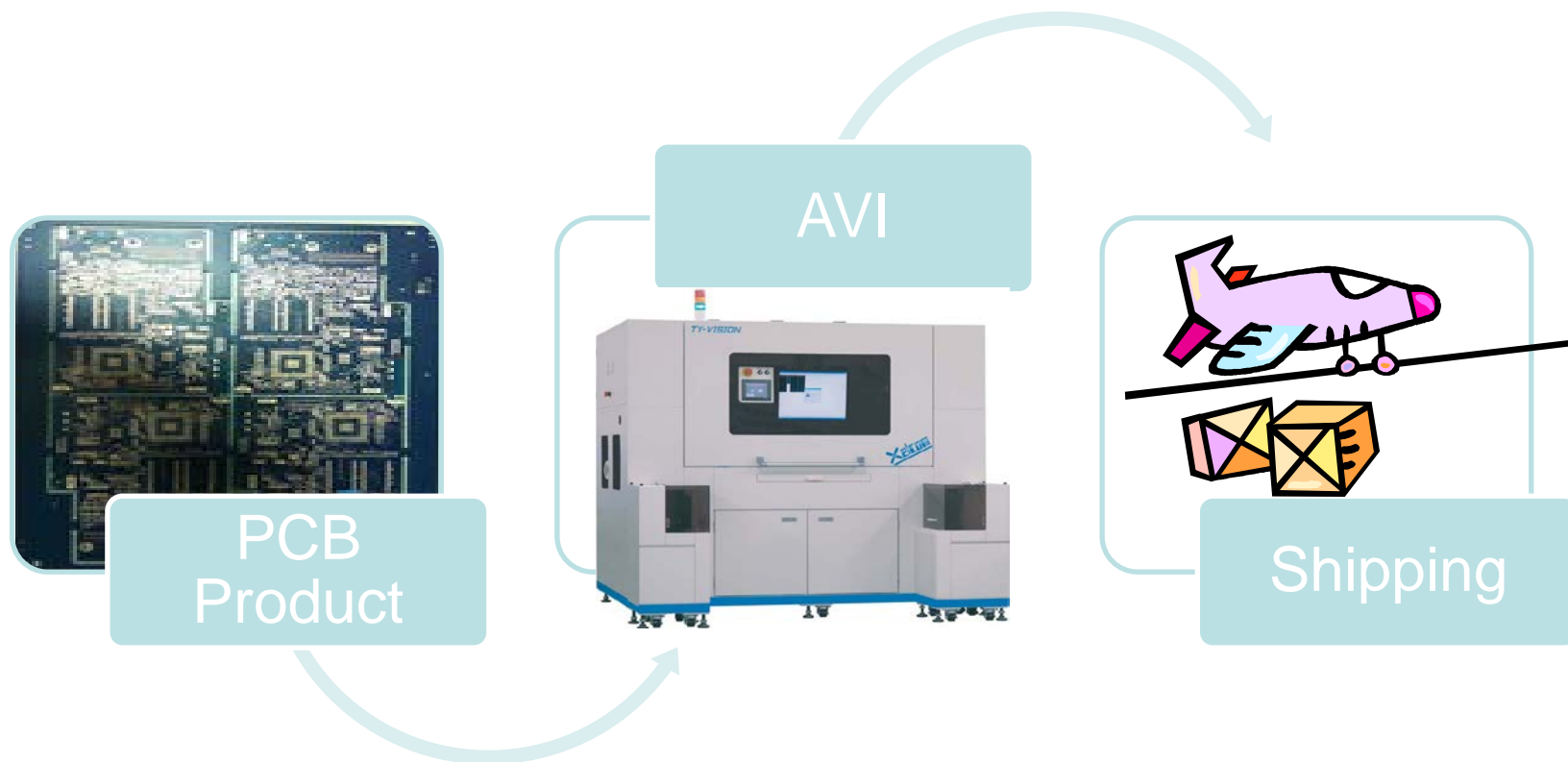
Inspection Features with AVI

SILK

SOLDER

MASK

Copper under
Solder Mask

SUBSTRATE
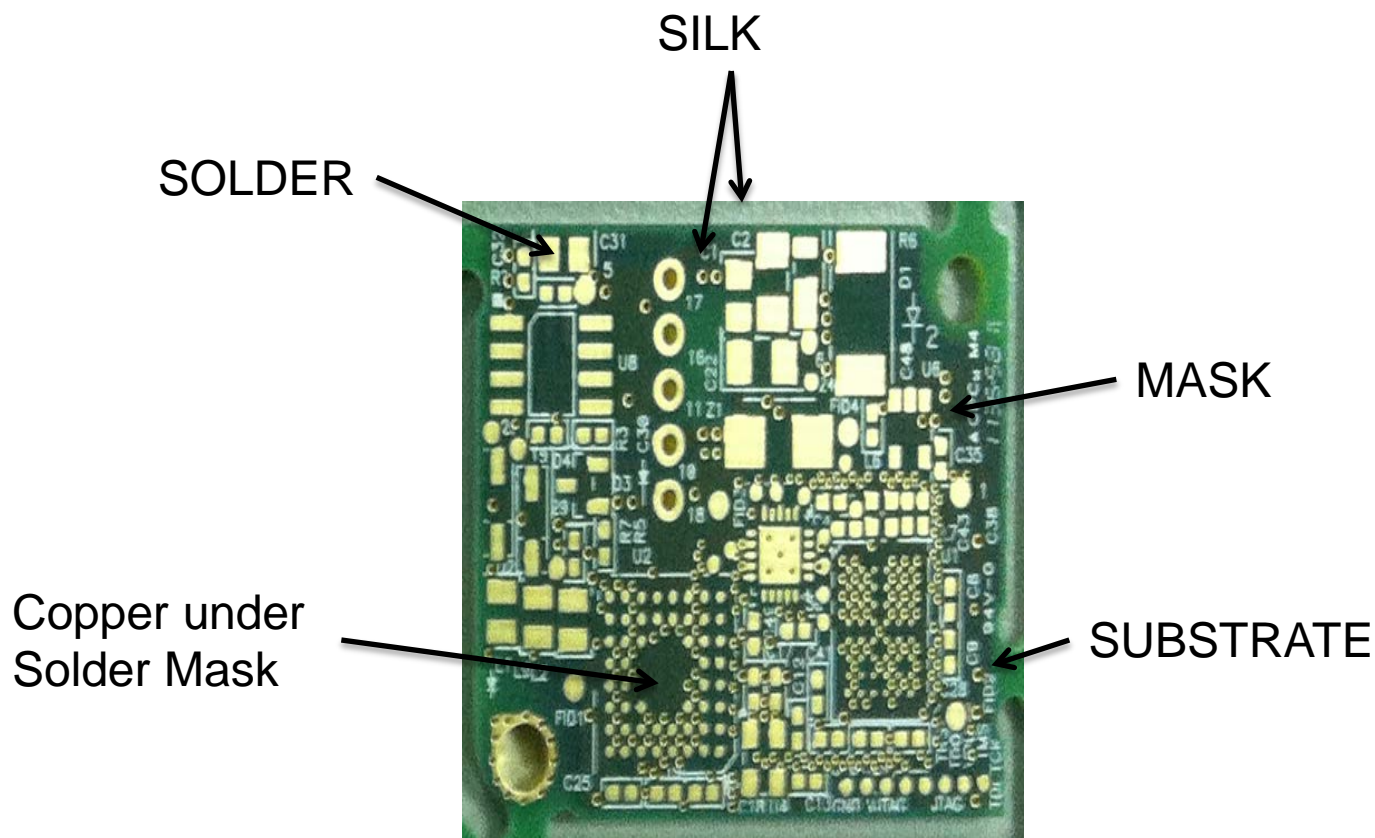
Hardware of AOI & AVI

AOI monochrome type camera

Company	Brand	Light source
Mania	Autom8tor	Halogen lamp
Orbotech	Discovery	Halogen lamp
Camtek	3G	Halogen lamp
Screen	PI	LED

AVI color type camera

Company	Brand	Light source
Kurabo	BBMaster	LED
Taiyo	TV – Vision	LED, Halogen lamp, fluorescent lamp
ATI	AVIS	LED, Halogen lamp
Camtek	Mustang	Halogen
Utechzone	Skyline	LED

Camera of AOI & AVI
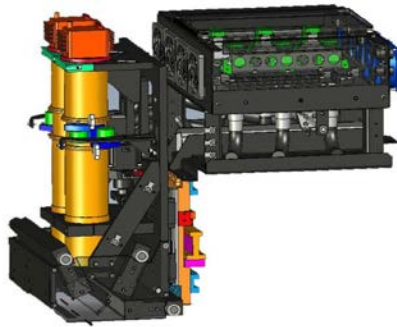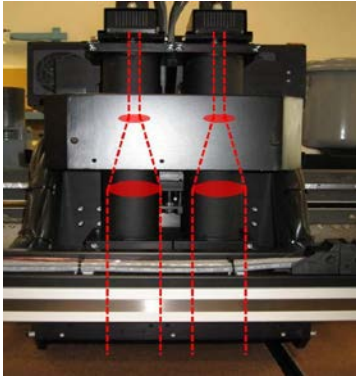
Camera System of AOI
monochrome type
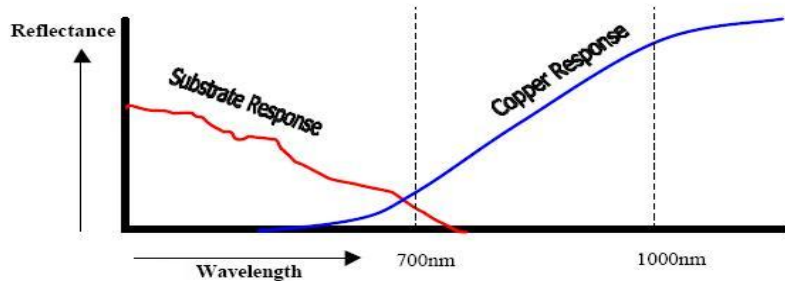
Reflectance vs Wavelength

Camera System of AVI
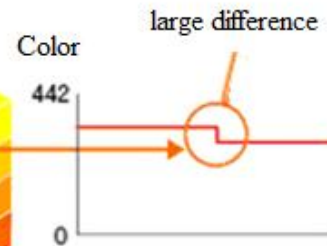color type

Monochrome and Color difference

Specular and diffuse light of AOI

Light on flat surface

Specular light · Diffuse light

Camera

Light on a dent surface

Specular light · Diffuse light
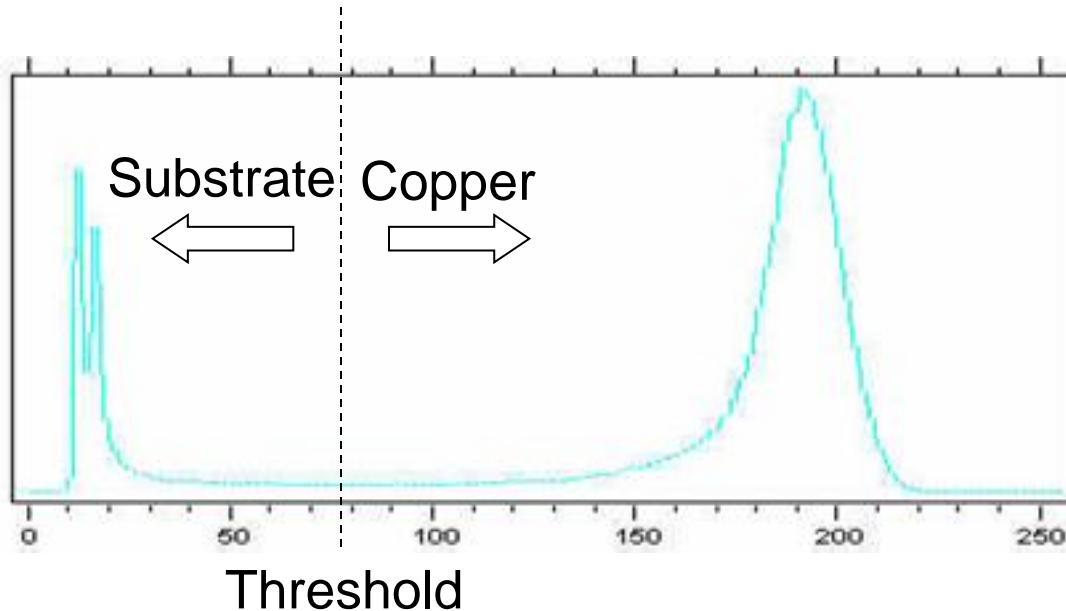
Camera
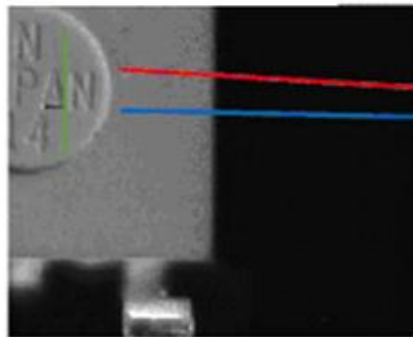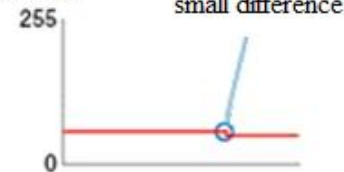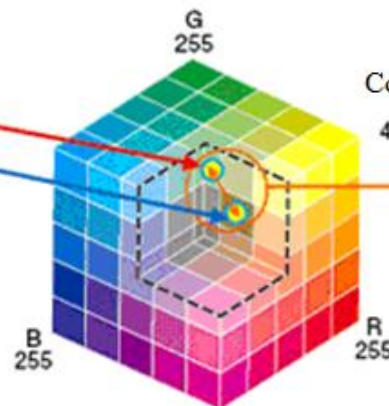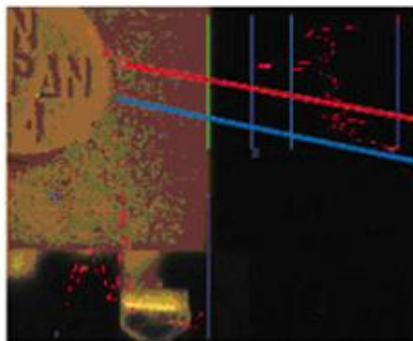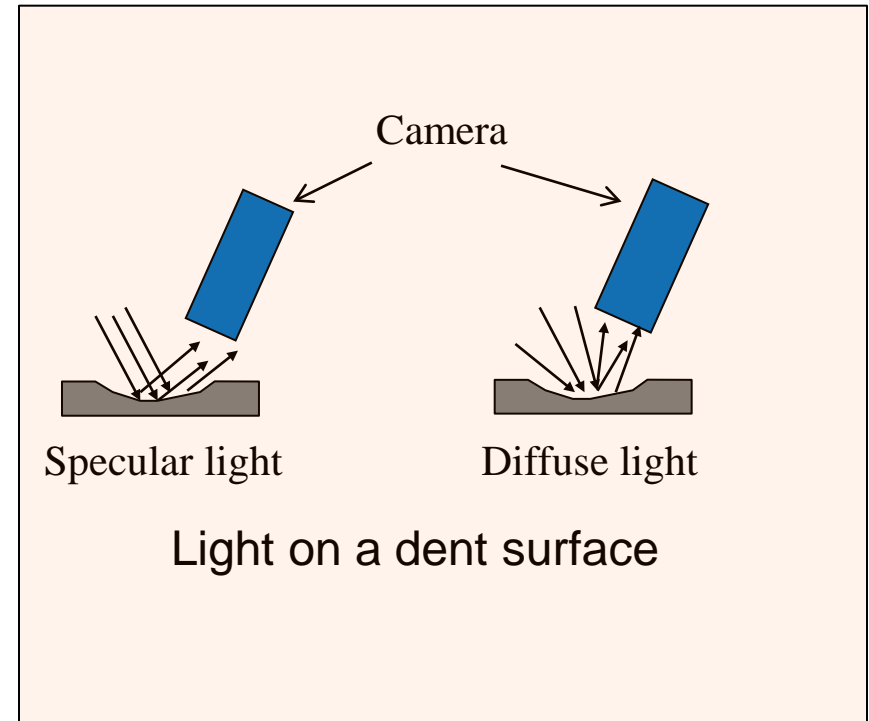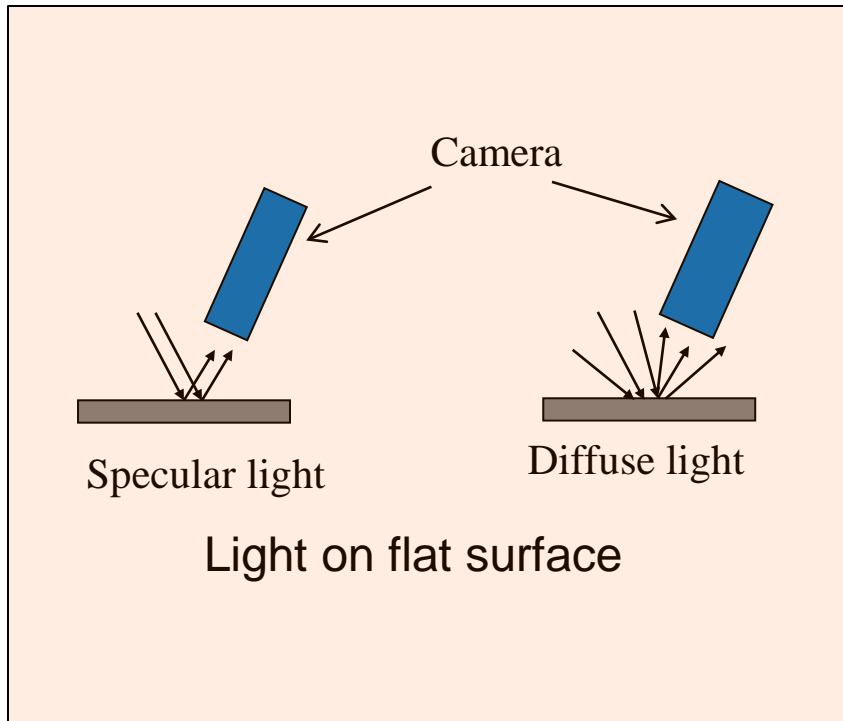
Scan & Classify Image of AOI
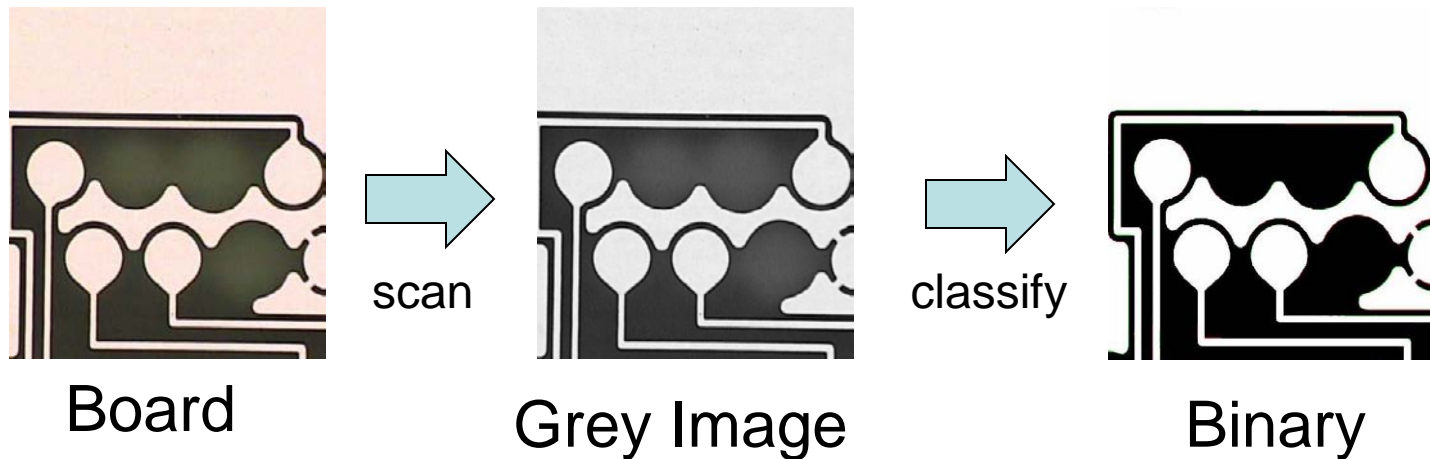
Board

scan

Grey Image

classify

Binary

If the original position is not copper but it is classified as copper, then there will be a false defect after comparison with the reference image. Therefore, the classification process is very important and needs to be very accurate.

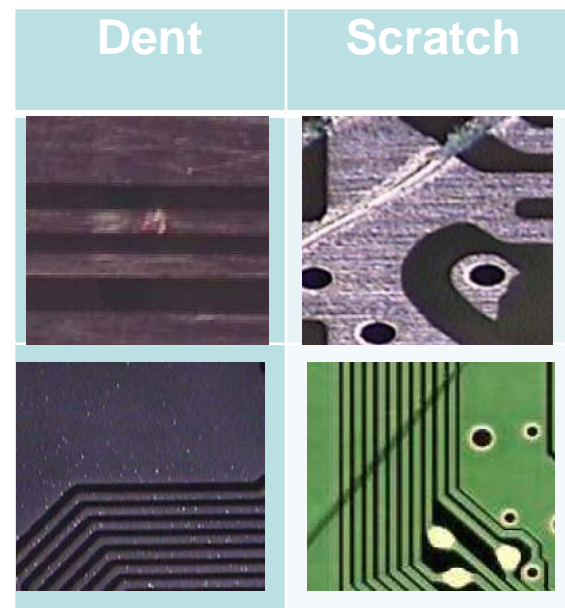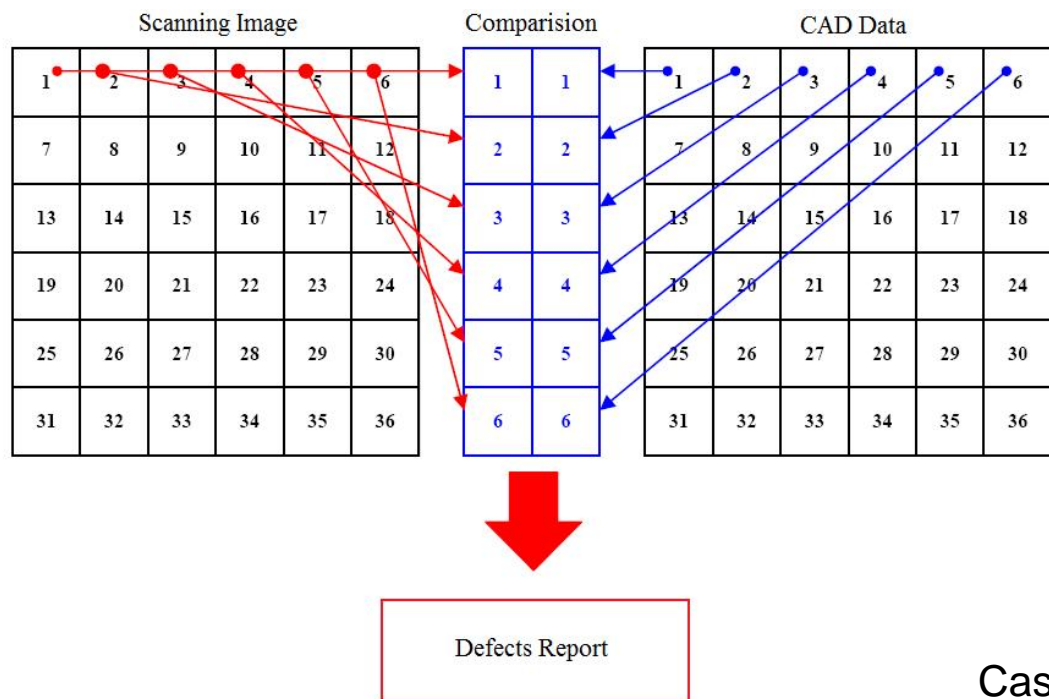# Threshold Histogram of AOI

Substrate ⟵ Copper ⟶

Threshold

- For regions which the brightness is higher than the threshold, they will be counted as copper.   For regions which the brightness is lower than the threshold, they will be counted as substrate.
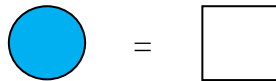
How the Defect are Found

Detect Defects by pixel from Graphical Interface
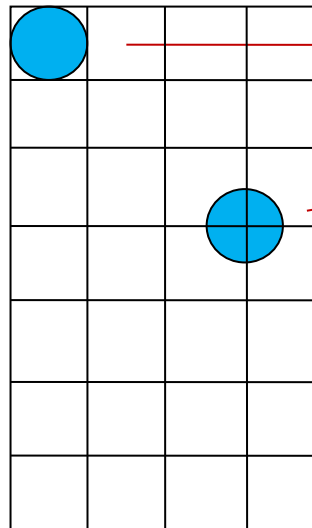

Case for defect size equal to pixel size

Finding Defect

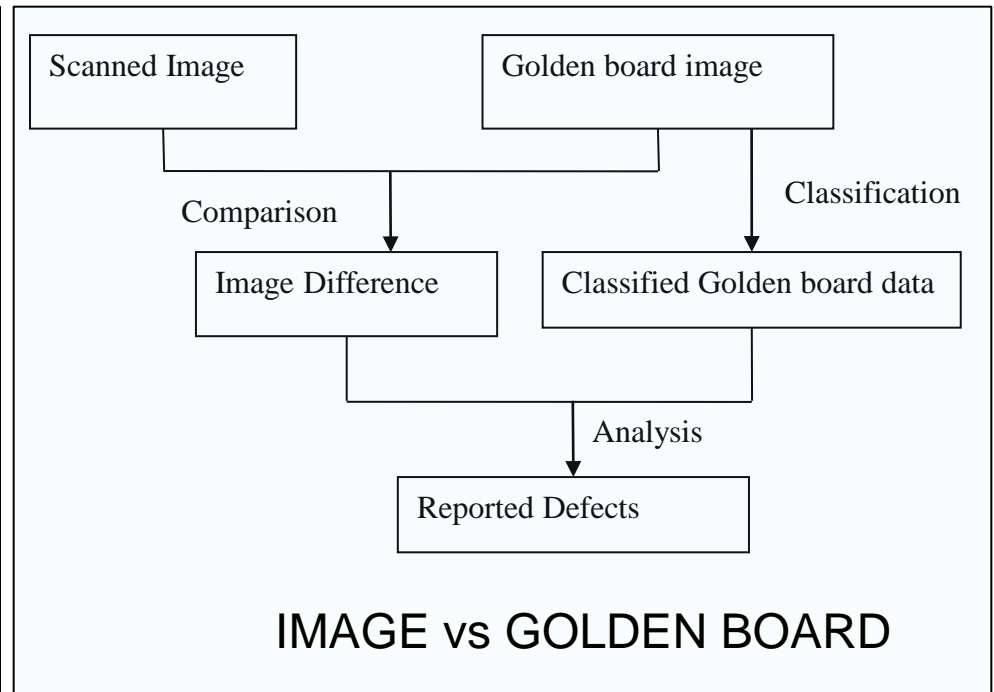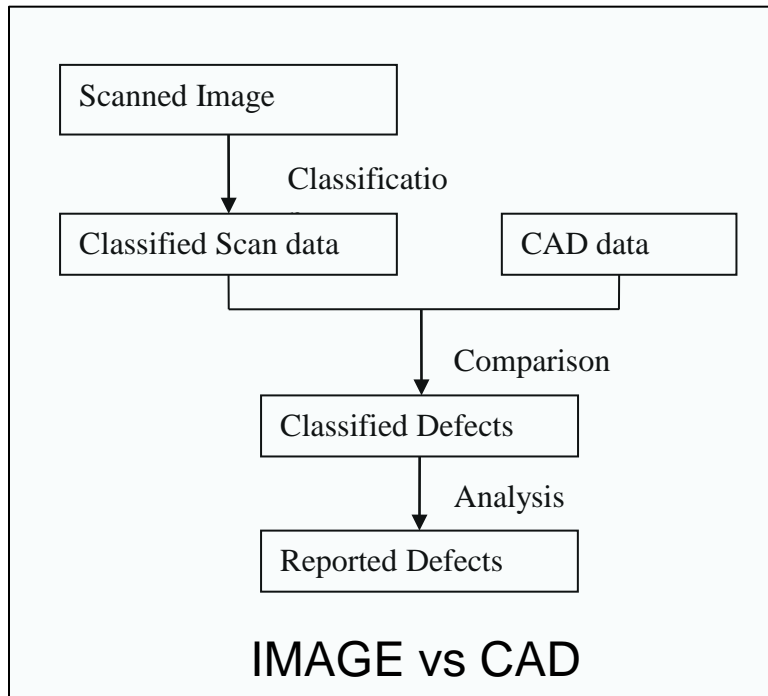For Defect size = pixel size,

Case A: Detected

Case B: Not detected

For case A, it is the best situation where the defect is inside the pixel, so the defect is easily detectable. For case B, it is the worst situation as each of the four pixels can only see the 25% of the defect, so it may not detect the defect. Therefore, if the defect size is very small and is close to the pixel size, then it may not be detected by the machine.

CAD Image with PCB Comparison

Scanned Image

Classification

Classified Scan data   CAD data

Comparison

Classified Defects

Analysis

Reported Defects

IMAGE vs CAD

Scanned Image   Golden board image

Comparison   Classification

Image Difference   Classified Golden board data

Analysis

Reported Defects

IMAGE vs GOLDEN BOARD

Considerations

- The need of Optical Inspection is a must in the PCB world as to ensure the high quality requirement.

- In order to make the effectiveness of space use and carbon reduction, the combined function machine will be one of fairly ideal approach to the user.

Thank You