

**A Comparison Of
Automatic Optical
Inspection Systems For
Use With Lead-Free
Surface Mount
Assemblies**

M Wickham & C Hunt

July 2002

July 2002

A Comparison Of Automatic Optical Inspection Systems For Use With Lead-Free Surface Mount Assemblies

Martin Wickham & Christopher Hunt

Materials Centre
National Physical Laboratory
Teddington, Middlesex, UK, TW11 0LW

Abstract :

With the move towards lead-free soldering technologies and the effect on joint integrity, there is a heightened interest in the performance of commercial automatic optical inspection (AOI) systems. A particular worry concerned any unforeseen problems in using existing AOI systems to inspect lead-free solder joints. In this NPL-industry collaborative study, a comparison has been undertaken of the ability of six commercial systems to detect known defects in solder joints on specially prepared assemblies. In order to allow each manufacturer to optimise his system for the assembly type used in the evaluation, a single set fifteen defect-free assemblies and fifteen assemblies incorporating defects was made available. Each system was then used in the inspection of ten further test assemblies with lead-free soldered joints containing defects whose numbers and locations were known. The defect types included missing components, misaligned components, components of correct size but wrong value, poor quality solder joints; components with wrong polarity, solder bridges and poor component planarity.

The results clearly demonstrate that all the systems can be used in the inspection of lead-free assemblies, and that AOI of lead-free surface mount assemblies presents no greater challenge than AOI of traditional SnPb soldered assemblies. Indeed, computer programs developed for SnPb assemblies can be adapted for use in lead-free assemblies, albeit with some changes in the accept-reject criteria.

In comparing the various system types (line scanner; vertical or angled camera systems) few major differences were found between their overall capabilities, all performing better at detecting some defects than others. Camera systems did generally out-perform the scanner system for location of misalignments of finer pitch components (the exception being QFPs), whilst angled camera systems did normally perform better with some J-lead defects such as bridges and joints with insufficient solder. In the majority of the defect categories, at least one system achieved a high rating, the exceptions being with R0603 wrong components and SSOP joints with insufficient solder.

Compared with the results of a previous AOI study on boards soldered using SnPb, the systems in this study achieved a greater success rate at locating misalignments and joints with insufficient solder in fine pitch QFPs, and wrong orientation in SOICs and J-leaded devices. The rates of false detection were similar in the two studies.

© Crown copyright 2002
Reproduced by permission of the Controller of HMSO

ISSN 1473 2734

National Physical Laboratory
Teddington, Middlesex, UK, TW11 0LW

Extracts from this report may be reproduced provided the source is
acknowledged and the extract is not taken out of context.

Approved on behalf of Managing Director, NPL, by Dr C Lea,
Head, Materials Centre

CONTENTS

	page
1.0 INTRODUCTION	1
2.0 TEST ASSEMBLY	2
3.0 TEST SYSTEMS	4
4.0 RESULTS	5
5.0 DISCUSSION OF RESULTS	18
6.0 CONCLUSIONS	40
7.0 REFERENCES	41
8.0 ACKNOWLEDGEMENTS	41

1.0 INTRODUCTION

The ever-decreasing dimensions of electronics assemblies and the developments of new interconnection technologies are forcing many electronics manufacturers to move away from manual inspection using microscopes, to automatic optical inspection (AOI) systems. Such a move has received further impetus with the impending introduction of lead-free soldering technologies. AOI systems, and their X-ray counterparts (AXI), have been successfully used for several years in the inspection of joints soldered using traditional SnPb alloys. Indeed in 1999, a previous NPL study was undertaken to assess the ability of AOI and AXI to recognise common surface mount soldering defects (Reference 1).

Since that time there have been significant improvements in these systems and in their abilities to detect such defects, and now with the move towards lead-free soldering technologies and the effect on joint integrity, there is a heightened interest in the performance of commercial automatic optical inspection (AOI) systems. A particular worry concerns any unforeseen problems in using existing AOI systems to inspect lead-free soldered assemblies, and whether or not new algorithms would be required. Many end users are unsure about the capability of AOI equipment and thus may be delaying investment fearing that the equipment will be redundant when lead-free soldering is widely introduced.

Consequently, in this NPL-industry collaborative study, a comparison has been undertaken of the ability of six commercial systems to detect known defects in specially prepared boards assembled using lead-free solder. The project was developed to build upon the experience of the previous investigation, and to benchmark AOI equipment with a range of assemblies soldered with lead-free materials and to assess the current state of the art of AOI systems. Six systems have been evaluated in this study, representing a typical cross-section of the equipment available on the market. Where possible comparisons have been made with the results of the previous study.

In the benchmarking the following equipment criteria were assessed:

- machine cost
- ability to locate assembly defects
- amount of false detections made
- speed of inspection

2.0 TEST ASSEMBLY

The test assembly comprised a single-sided PCB containing 87 surface mount (SM) components, as shown in Figure 1 and detailed in Table 1. Twelve different component styles were incorporated with over 1400 solder joints on each assembly.



Figure 1 : Test Assembly

Table 1 : Test Assembly Content

Component	Pitch (inch)	Pitch (mm)	Comp. ID	No. of comp.	No. of joints
QFP256	0.016	0.4	Q	2	512
PBGA256	0.050	1.27	B	1	256
μBGA48	0.018	0.457	FP	1	48
TSOP32	0.020	0.5	T	3	96
SOIC14	0.050	1.27	S	10	140
SOJ20	0.050	1.27	J	4	80
SSOP20	0.025	0.65	SS	6	120
SOT223			SOT	10	40
SOT23			ST	10	30
R0402	0402		R	20	40
R0603	0603		RA	10	20
C0603	0603		C	10	20
Total				87	1402

In total, forty one test assemblies were produced by the National Physical Laboratory. Solder paste printing was undertaken using a DEK 265 printer and a 0.006" (150μm) laser cut stainless steel stencil with metal squeegee blades. The solder paste used was a no-clean product utilising Sn95.5Ag3.8Cu0.7 solder alloy. SM components were placed using automatic placement equipment

or by hand in the case of some components on assemblies incorporating defects. Reflow soldering was conducted in a five zone convection reflow oven. No touch-up of solder joints was undertaken.

All assemblies were manually inspected using a 5x to 30x binocular zoom microscope with ring illumination, and all defects noted. The guidelines used to assess the quality of assembly were those included in IPC-A-610 rev C (Reference 2). The more stringent class 3 criteria for high performance electronic products were used. These guidelines have been incorporated into IEC 61191-2 (Reference 3) and IEC 61191-3 (Reference 4). Level 3 applies in the case of these standards.

Subsequently, fifteen defect-free assemblies and fifteen assemblies incorporating defects were made available to equipment suppliers to aid programming of their own proprietary equipment. Where possible defects were introduced prior to reflow soldering so that the joint characteristics were not unduly affected. However, some defects could only be incorporated after reflow using rework techniques. A further five defect-free assemblies and five defect-containing assemblies were used in the benchmark. The partners did not have access to these latter ten assemblies prior to the benchmark exercise.

The range of defects incorporated in the assemblies included the following :

- Missing components.
- Misaligned components (x and y directions).
- Wrong components (correct size but different value).
- Poor quality solder joints (insufficient or excess solder).
- Wrong polarity components.
- Solder bridges (shorts).
- Poor lead or component planarity including tombstones (component on end) and components on edge.

3.0 TEST SYSTEMS

Six automatic optical inspection systems were evaluated in this project. A brief summary of the systems is given in Table 2. Three basic types of system were included. Sys A was a line scanner based system. This equipment scanned the entire assembly as a single image and then undertook evaluations by defining regions of interest (ROI) in this image and then running algorithms on these ROIs to determine if defects were present. The remaining systems use vertical only, or vertical and angled, cameras to capture a number of images of different areas of the assembly under inspection. ROIs are allocated to these different images and algorithms are then run on these ROIs. A representation of these differences is shown in Figure 2.

Table 2 : Equipment Summary

Machine Identifier	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
Camera Types	Line scanner	Vertical	Angled & vertical	Vertical	Angled & vertical	Vertical
Estimated Programming Time (hours)*	5	16	12	8	12	8
No. of Programming Assemblies Used*	10	30	18	30	30	20
Approx. cost (\$K)*	50	120	120	170	200	120

*based on information given by individual project partners

The programming time and number of assemblies used to assist programming are also given in Table 2 and these are based on information supplied by the project partners. Programming times are similar, varying between 5 and 16 man hours. Half the partners used all 30 programming assemblies available to them, whilst the remainder used between 10 and 20 assemblies. The approximate cost of the systems used during the evaluation are also shown in Table 2.

The same programming assemblies were supplied to all partners approximately one week prior to the evaluation. It should be noted that this allowed limited time for programme development and that this project should be treated as generating a “snap-shoot” of AOI capability. It is general industrial practice to refine test programmes over time as more examples of production defects, typical to the assembly line in which the system is incorporated, are made available. Thus the results reported here could be improved upon with more programming effort and a greater range of production defects.

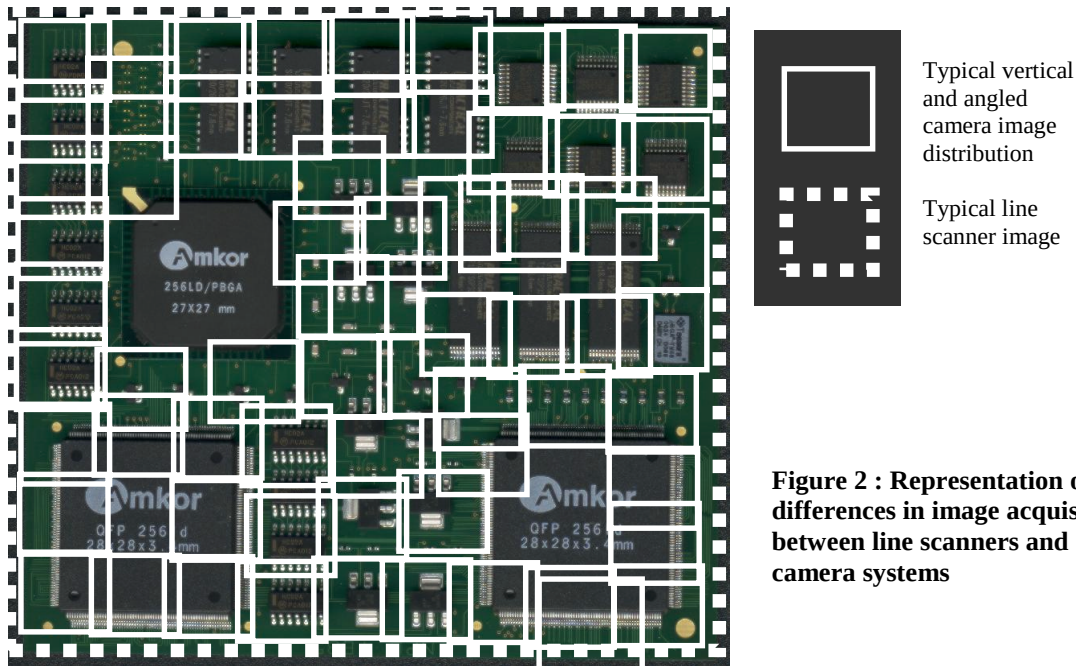


Figure 2 : Representation of differences in image acquisition between line scanners and camera systems

4.0 RESULTS

After programming and debugging, each of the AOI systems was used to inspect the ten previously unseen defect-free and defect-containing benchmarking assemblies. The results are based on detection of errors from the initial run of the five defect-containing assemblies through the systems.

The test times for each equipment trial are shown in Figure 3. The test times fall into two broad groups. The majority of the camera systems have test times of around 14 to 20 seconds. The test times for the line scanner system and one of the camera systems were longer at around 50 seconds, although the suppliers of this latter system believe that with a better camera, the 50 second test time could be brought down to less than 15 seconds.

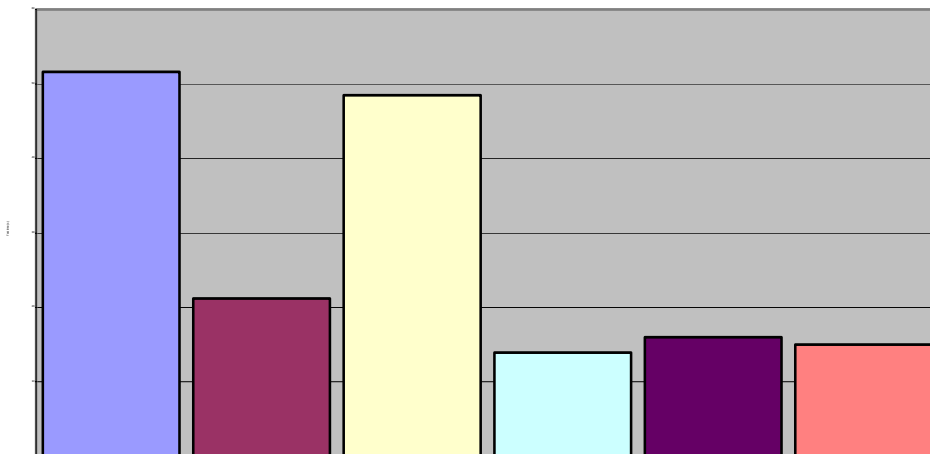


Figure 3 : Comparison of Assembly Test Times

False detect rates (i.e. detecting a non-existent defect) were calculated from the results for the five defect-free benchmarking assemblies. The false detect rates are summarised in Tables 3 & 4. No IC-pin-level false detect data were available for systems A, D and F as these systems only produced defect reports at component level and did not output information at joint level. Similar information is provided in Table 5 for the assembly manufactured with an OSP PCB surface finish.

Table 3 : Joint False Detects Summary (NiAu PCB surface finish)

Test Assembly No.	SYS B	SYS C	SYS E
5	12	3	28
10	4	2	2
11	9	1	31
13	8	2	18
31	2	3	12

Table 4 : Component False Detects Summary (NiAu PCB surface finish)

Test Assembly No.	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
5	16	10	3	1	4	5
10	12	2	2	1	1	4
11	16	9	1	1	8	8
13	12	8	2	0	5	9
31	18	2	3	2	3	7

Table 5 : False Detect Summary for Test Assembly 39 with OSP PCB Surface Finish

	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
Joint false detects	?	15	2	?	14	?
Component false detects	19	12	2	3	5	7

The defect location results for each of the five defect-containing assemblies are presented in Tables 6 to 10. These Tables list the component ID (as given in Table 1), the defect type, pin numbers where appropriate, and if the system located the defect.

Table 6 : Defect Results for Assembly 32

Comp.	Defect Type	Pin No.	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
B1	Missing		Y	Y	Y	Y	Y	Y
C10	Wrong component		Y	N	N	N	Y	N
C4	On edge		N	N	Y	N	Y	N
C5	Insufficient		Y	Y	Y	Y	N	Y
C6	Missing		Y	Y	Y	Y	Y	Y
C7	Insufficient		N	N	Y	Y	Y	N
C9	<i>Different Manufacturer</i>		N	N	N	N	Y	N
FC1	Missing		Y	Y	Y	Y	Y	Y
Q1	Insufficient	122	N	Y	Y	Y(1)	Y	N
Q1	Insufficient	129	N	N	N	Y(1)	Y	N
Q1	Excess	128	N	N	N	Y(1)	Y	N
Q1	Bridge	65/66	Y(1)	Y(1)	Y	Y(1)	Y	Y(2)
Q1	Bridge	82/83/84	Y(1)	Y(1)	Y	Y(1)	Y	Y(2)
Q1	Bridge	100/101	Y(1)	Y(1)	Y	Y(1)	Y	Y(2)
Q1	Misalignment	120-125	Y(1)	Y	Y	N	Y	Y(2)
Q1	Misalignment	193-223	N	Y	Y	Y(1)	Y	Y(2)
Q1	Misalignment	1-20	N	Y	N	Y(1)	N	Y(2)
Q1	Bridge	55/56	Y(2)	Y(1)	Y	Y(1)	Y	Y(2)
Q2	Misalignment	1-64	Y(1)	Y	Y	Y(1)	N	Y(2)
Q2	Misalignment	65-128	Y(1)	Y	Y	Y(1)	Y	Y(2)
Q2	Misalignment	150-192	Y(1)	Y	N	Y(1)	N	Y(2)
Q2	Misalignment	193-256	Y(1)	Y	Y	Y(1)	Y	Y(2)
Q2	Bridge	43/44	Y(1)	Y(1)	Y	Y(1)	N	Y(1)
Q2	Bridge	5/6	Y(1)	Y(1)	Y	Y(1)	Y	Y(1)
Q2	Bridge	12/13	Y(1)	Y(1)	Y	Y(1)	Y	Y(1)
Q2	Bridge	25/26	Y(1)	Y(1)	Y	Y(1)	Y	Y(1)
Q2	Bridge	193/223	Y(1)	Y(1)	Y	Y(1)	Y	Y(1)
R1	Missing		Y	Y	Y	Y	Y	Y
R10	<i>Different Manufacturer</i>		N	N	N	N	N	Y
R11	Inverted component		Y	N	N	Y	Y	Y
R12	Component on edge		Y	N	Y	Y	Y	Y
R14	Insufficient		N	Y	Y	Y	N	Y
R18	Misalignment		Y	Y	Y	Y	Y	Y
R2	Missing		Y	Y	Y	Y	Y	Y
R3	Missing		Y	Y	Y	Y	Y	Y
R4	Insufficient		Y	N	Y	Y	Y	Y
R5	Excess		Y	N	Y	N	N	Y
R6	Insufficient		N	Y	Y	Y	Y	Y
R9	Missing		Y	Y	Y	Y	Y	Y
RA1	Misalignment		Y	Y	N	Y	N	Y
RA10	Inverted component		Y	N	N	Y	Y	Y
RA2	Misalignment		Y	Y	Y	Y	Y	Y
RA3	Missing		Y	Y	Y	Y	Y	Y
RA4	Insufficient		Y	Y	Y	N	Y	Y
RA6	Excess		N	N	N	Y	N	N
RA7	Insufficient		Y	Y	Y	N	N	Y
RA9	<i>Different Manufacturer</i>		Y	N	N	N	N	N
S1	Insufficient	7	N	Y	Y	Y(1)	N	Y(2)
S1	Insufficient	10	N	N	Y	Y(1)	N	Y(2)
S2	Wrong Component		Y	N	N	N	N	N
S3	Wrong Component (TI)		Y	N	N	Y	N	N
S4	<i>Different Manufacturer</i>		Y	Y	Y	Y	N	N

Comp.	Defect Type	Pin No.	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
S5	Wrong Orientation		Y	Y	Y	Y	Y	N
S6	Excess	8	Y(2)	N	N	Y(1)	Y	Y(1)
S6	Excess	13	Y(2)	N	N	Y(1)	Y	Y(1)
S6	Bridge	1/2	Y(2)	N	Y	Y(1)	Y	Y
S8	Missing		Y	Y	Y	Y	Y	Y
S9	Misalignment		Y	Y	Y	Y	Y	Y
SJ1	Excess	1	N	N	Y	N	N	Y
SJ1	Excess	5	N	N	Y	N	Y	Y
SJ3	Missing		Y	Y	Y	Y	Y	Y
SOT2	Excess		Y	N	N	N	N	Y
SOT3	Missing		Y	Y	Y	Y	Y	Y
SOT7	Misalignment		Y	Y	Y	N	Y	Y
SOT9	Insufficient		Y	N	Y	Y	Y	N
SS1	Misalignment		N	Y	Y	Y	Y	Y
SS2	Missing		Y	Y	Y	Y	Y	Y
SS3	Excess	1	N	N	N	N	N	Y(2)
SS3	Excess	20	N	N	Y	N	N	Y(2)
SS4	Misalignment		N	Y	Y	Y	Y	Y
SS4	Bridge	1-10	N	Y	Y	N	Y	Y
SS5	Bridge	1-2	Y(1)	Y	Y	Y(1)	Y	Y(2)
SS5	Bridge	17-18	Y(1)	Y	Y	Y(1)	Y	Y(2)
SS6	Insufficient	7	N	Y	Y	N	N	Y(1)
SS6	Insufficient	16	N	N	Y	N	Y	Y(1)
ST1	Wrong Component		Y	N	N	Y	N	N
ST10	Excess		Y	N	Y	N	Y	Y
ST3	Insufficient		N	N	Y	N	N	N
ST4	Missing		Y	Y	Y	Y	Y	Y
ST6	Misalignment		Y	Y	Y	Y	Y	N
ST7	Misalignment		Y	N	Y	Y	N	Y
ST7	Insufficient		Y	N	Y	N	N	Y
ST8	Insufficient		Y	N	N	N	N	Y
ST9	Excess		Y	N	N	N	Y	N
T1	Excess	16	Y(1)	N	N	N	Y	Y(2)
T1	Excess	32	Y(1)	N	N	N	N	Y(2)
T1	Bridge	17/18	Y(1)	N	Y	Y(1)	Y	Y(2)
T2	Misalignment		N	Y	Y	Y	Y	Y
T3	Missing		Y	Y	Y	Y	Y	Y

Notes :**(1) Component fails but individual defect identification not possible****(2) Fault rechecked manually**

Italics indicate a change to the assembly, which although not a defect, may cause a system to false flag (i.e. correct component from an alternative manufacturer).

Table 7 : Defect Results for Assembly 33

Comp.	Defect Type	Pin No.	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
B1	Missing		Y	Y	Y	Y	Y	Y
C1	Insufficient		N	N	N	Y	N	Y
C1	Insufficient		N	N	N	Y	N	Y
C10	Component on edge		Y	N	N	N	Y	Y
C2	Misalignment		N	N	Y	N	Y	Y
C3	Misalignment		N	N	Y	N	N	Y
C5	Wrong Component		N	N	N	N	Y	Y
C6	<i>Different Manufacturer</i>		N	N	N	N	Y	N
C8	Insufficient		Y	N	Y	Y	N	Y
C8	Misalignment		Y	Y	N	Y	Y	Y
C9	Missing		Y	Y	Y	Y	Y	Y
FC1	Missing		Y	Y	Y	Y	Y	Y
Q1	Misalignment	62-64	N	Y	Y	Y(1)	Y	Y(2)
Q1	Bridge	60/61	Y(2)	Y	Y	Y(1)	Y	Y(2)
Q1	Misalignment	225-256	N	Y	Y	N	Y	Y(2)
Q1	Excess	65	N	N	N	N	Y	N
Q1	Excess	128	N	N	N	N	Y	Y(2)
Q2	Insufficient	71	N	N	Y	N	Y	N
Q2	Insufficient	100	N	N	Y	N	Y	Y(2)
Q2	Insufficient	111	N	N	Y	N	Y	N
Q2	Insufficient	47	N	N	Y	N	Y	N
Q2	Bridge	2-3	Y(2)	N	Y	Y(2)	Y	Y(2)
Q2	Bridge	45-46	N	Y	Y	Y(2)	Y	Y(2)
Q2	Misalignment	193-213	Y(2)	Y	N	Y(2)	Y	Y
Q2	Bridge	200/202	N	N	Y	Y(1)	Y	Y(2)
Q2	Bridge	216/218	N	N	Y	Y(1)	Y	Y(2)
Q2	Bridge	129/131	Y(2)	Y	Y	Y(2)	Y	Y(2)
Q2	Bridge	183/184	Y(2)	N	Y	Y(2)	Y	Y(2)
Q2	Bridge	172/174	Y(2)	N	Y	Y(2)	Y	Y(2)
R1	Missing		Y	Y	Y	Y	Y	Y
R14	Insufficient		N	N	Y	Y	N	N
R15	Insufficient		Y	Y	Y	N	N	Y
R16	Component on edge		Y	Y	Y	Y	Y	Y
R18	<i>Different Manufacturer</i>		N	N	N	N	N	N
R2	Missing		Y	Y	Y	Y	Y	Y
R20	Inverted component		Y	N	N	Y	Y	Y
R3	Missing		Y	Y	Y	Y	Y	Y
R4	Missing		Y	Y	Y	Y	Y	Y
R8	Insufficient		N	Y	Y	Y	Y	Y
RA10	Insufficient		Y	N	N	N	N	Y
RA4	Component inverted		Y	N	N	Y	Y	Y
RA5	Component on edge		Y	Y	Y	Y	Y	N
RA6	Insufficient		N	N	Y	Y	N	Y
RA8	Missing		Y	Y	Y	Y	Y	Y
S1	Insufficient	11	N	Y	Y	Y(2)	N	Y(2)
S1	Insufficient	13	N	Y	Y	Y(2)	N	Y(2)
S2	Misalignment		Y	Y	Y	Y	Y	Y
S4	Excess	4	Y(2)	Y	N	Y(2)	Y	Y(2)
S4	Excess	14	Y(2)	N	N	Y(2)	Y	N
S5	Wrong component		Y(2)	N	N	N	N	N

Comp.	Defect Type	Pin No.	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
S6	Wrong component		Y	N	N	N	N	N
S6	Insufficient	7	Y(2)	N	N	Y	N	Y(2)
S7	<i>Different Manufacturer</i>		Y	Y	N	N	N	N
S8	Missing		Y	Y	Y	Y	Y	Y
S9	Wrong polarity		N	N	Y	Y	Y	Y
SJ1	Bridge	9/10	N	N	Y	N	Y	Y(1)
SJ1	Excess	6	N	N	N	N	Y	Y(1)
SJ2	Misalignment		N	Y	Y	Y	Y	Y
SJ4	Missing		Y	Y	Y	Y	Y	Y
SOT10	Insufficient		Y	N	Y	N	Y	N
SOT3	Misalignment		N	Y	Y	Y	Y	Y
SOT5	Missing		Y	Y	Y	Y	Y	Y
SOT6	Insufficient		Y	N	Y	N	N	N
SOT6	Insufficient		Y	N	Y	N	N	N
SOT7	Missing		Y	Y	Y	Y	Y	Y
SS1	Bridge	1/2	N	Y	Y	Y(2)	Y	Y(2)
SS1	Bridge	19/20	N	Y	Y	Y(2)	Y	Y(2)
SS1	Insufficient	9	N	Y	Y	N	Y	Y(2)
SS1	Insufficient	13	N	N	N	N	N	Y(2)
SS2	Insufficient		N	N*	N	N	N	N
SS4	Misalignment		Y(1)	Y	Y	Y	Y	Y
SS5	Missing		Y(1)	Y	Y	Y	Y	Y
SS6	Excess	10	Y(1)	N	N	Y(1)	Y	Y
ST1	Missing		Y	Y	Y	Y	Y	Y
ST10	Insufficient		N	N	Y	N	N	N
ST2	Insufficient		Y	N	Y	N	N	N
ST3	Excess		N	N	Y	N	N	N
ST4	<i>Different Manufacturer</i>		Y	N	N	N	N	Y
ST5	Misalignment		Y	N	Y	N	Y	Y
ST6	Insufficient		Y	N	Y	Y	N	N
ST8	Insufficient		N	N	Y	N	N	N
ST9	Misalignment		Y	N	Y	Y	N	Y
T1	Missing		Y(1)	Y	Y	Y	Y	Y
T2	Misalignment		N	Y	Y	Y	Y	Y
T3	Excess	17	N	N	N	N	Y	Y

Notes :**(1) Component fails but individual defect identification not possible****(2) Fault rechecked manually**

Italics indicate a change to the assembly, which although not a defect, may cause a system to false flag (i.e. correct component from an alternative manufacturer).

Table 8 : Defect Results for Assembly 34

Comp.	Defect Type	Pin No.	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
B1	Misalignment		Y	Y	Y	Y	Y	Y
C1	Insufficient		N	N	Y	Y	Y	Y
C10	<i>Different Manufacturer</i>		Y	N	N	N	Y	Y
C3	Excess		Y	N	Y	Y	N	Y
C4	Wrong Component		N	N	N	N	Y	Y
C6	Component on edge		Y	N	Y	N	Y	Y
C7	Insufficient		Y	Y	Y	Y	N	Y
C8	Missing		Y	Y	Y	Y	Y	Y
Q1	Misalignment	129-192	Y(2)	N	Y	Y(2)	Y	Y(2)
Q1	Bridge	65/66	Y(2)	Y	Y	Y(1)	Y	Y(2)
Q1	Bridge	98/99	Y(2)	N	Y	Y(1)	Y	Y(2)
Q1	Bridge	112/113	Y(2)	N	Y	Y(1)	Y	Y(2)
Q1	Bridge	126/127	Y(2)	N	Y	Y(1)	Y	N
Q1	Misalignment	200-256	Y(2)	Y	Y	N	Y	Y(2)
Q1	Misalignment	1-32	Y(2)	Y	Y	Y(2)	N	Y
Q1	Bridge	5/6/7/8	Y(2)	N	Y	Y(1)	Y	Y(2)
Q1	Bridge	14/15	Y(2)	N	Y	Y(1)	Y	Y(2)
Q1	Bridge	63/64	Y(2)	N	Y	Y(1)	Y	Y(2)
Q2	Misalignment	1-50	Y(2)	Y	Y	N	Y	Y(2)
Q2	Misalignment	129-192	Y(2)	Y	Y	Y(2)	Y	Y(2)
Q2	Misalignment	220-256	Y(2)	Y	Y	Y(2)	Y	Y(2)
R1	Missing		Y	Y	Y	Y	Y	Y
R11	Wrong Component		N	N	N	N	N	N
R12	Excess		Y	Y	Y	N	N	Y
R13	Excess		Y	Y	Y	Y	Y	Y
R14	Insufficient		N	Y	Y	Y	Y	Y
R15	Insufficient		N	Y	Y	Y	Y	Y
R16	Inverted component		Y	N	N	Y	Y	Y
R17	Component on edge		Y	Y	Y	Y	Y	Y
R2	Missing		Y	Y	Y	Y	Y	Y
R20	Insufficient		N	N	N	Y	N	N
R3	Missing		Y	Y	Y	Y	Y	Y
R4	Missing		Y	Y	Y	Y	Y	Y
R9	Insufficient		Y	Y	Y	Y	N	Y
RA10	Misalignment		Y	Y	Y	Y	Y	Y
RA2	Insufficient		Y	N	Y	N	N	Y
RA3	Inverted		Y	N	N	Y	Y	Y
RA4	Insufficient		Y	Y	Y	Y	N	Y
RA5	Excess		N	Y	N	Y	N	Y
RA6	Excess		N	N	N	Y	N	Y
RA8	Missing		Y	Y	Y	Y	Y	Y
S1	Excess solder	5	Y(1)	N	N	N	Y	Y(2)
S1	Excess solder	12	Y(1)	N	N	N	Y	Y(2)
S1	Excess solder	13	Y(1)	N	N	N	Y	Y(2)
S2	<i>Different Manufacturer</i>		N	N	N	N	N	N
S5	Missing		Y	Y	Y	Y	Y	Y
S7	Wrong Component		Y	Y	N	Y	N	N
S8	Excess solder	5	Y	N	N	N	Y	N
S9	Insufficient	11	Y	N	Y	N	N	Y

Comp.	Defect Type	Pin No.	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
SJ1	Wrong orientation		Y	Y	Y	Y	Y	N
SJ1	Insufficient	24 (18)	N	N	Y	N	Y	N
SJ2	Wrong orientation		Y	Y	Y	Y	Y	N
SJ3	Wrong orientation		Y	Y	Y	Y	Y	N
SOT1	Wrong component		N	N	Y	N	N	Y
SOT10	Missing		Y	Y	Y	Y	Y	Y
SOT2	Excess		Y	N	N	N	N	Y
SOT3	Excess		N	N	Y	N	N	Y
SOT6	Misalignment		N	Y	Y	Y	Y	Y
SOT9	Excess		Y	N	N	N	N	Y
SS1	Insufficient	20	N	N	N	N	N	Y(2)
SS1	Bridge	3/4/5	N	Y	Y	Y(2)	Y	Y(2)
SS1	Bridge	12/13/14	N	Y	Y	Y(2)	Y	Y(2)
SS2	Insufficient	6	N	N	Y	Y(1)	N	Y(2)
SS2	Insufficient	10	N	N	N	Y(1)	N	N
SS2	Insufficient	17	N	N	Y	Y(1)	N	Y(2)
SS2	Insufficient	20	N	N	Y	Y(1)	N	N
SS3	Misalignment		N	Y	Y	Y	Y	Y
SS4	Misalignment		Y	Y	Y	Y	Y	Y
SS6	Missing		Y	Y	Y	Y	Y	Y
ST1	Insufficient		Y	N	Y	Y	N	Y
<i>ST10</i>	<i>Different Manufacturer</i>		Y	N	N	Y	N	N
ST2	Missing		Y	Y	Y	Y	Y	Y
ST3	Misalignment		Y	Y	Y	N	Y	Y(2)
ST3	Insufficient		Y	N	Y	N	N	Y(2)
ST4	Insufficient		N	N	Y	N	N	N
ST5	Excess		N	N	Y	N	N	Y
ST6	Insufficient		Y	N	Y	N	N	Y
ST7	Misalignment		Y	N	Y	N	Y	Y(2)
ST7	Insufficient		Y	N	Y	N	N	Y(2)
ST9	Wrong Component		Y	N	N	N	N	N
T2	Bridge	1/2	N	N	Y	N	Y	Y(2)
T2	Bridge	15/16	N	N	Y	N	Y	Y(2)
T2	Insufficient	12	N	N	Y	N	N	Y(2)
T2	Insufficient	20	N	N	Y	N	N	Y(2)
T2	Insufficient	25	N	N	Y	N	N	Y(2)
T3	Wrong orientation		Y	Y	Y	Y	Y	Y

Notes :**(1) Component fails but individual defect identification not possible****(2) Fault rechecked manually**

Italics indicate a change to the assembly, which although not a defect, may cause a system to false flag (i.e. correct component from an alternative manufacturer).

Table 9 : Defect Results for Assembly 35

Comp.	Defect Type	Pin No.	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
B1	Wrong Orientation		Y	Y	Y	Y	Y	Y
C1	Insufficient		Y	N	Y	Y	Y	Y
C10	Misalignment		Y	Y	Y	Y	Y	Y
C2	Missing		Y	Y	Y	Y	Y	Y
C3	Insufficient		Y	N	Y	Y	N	Y
FC1	Misalignment		N	Y	Y	Y	Y	Y
Q1	Wrong Orientation		Y	Y	N	N	Y	Y
Q1	Insufficient	129-132?	N	Y	N	Y(2)	N	N
Q1	Insufficient	81,83	N	Y	Y	Y(2)	Y	Y(2)
Q1	Insufficient	81,83	N	Y	Y	Y(2)	Y	Y(2)
Q1	Insufficient	61-64	N	N	Y	Y(2)	Y	Y(2)
Q1	Misalignment	193-220	Y(2)	Y	N	Y(2)	Y	Y(2)
Q2	Missing		Y	Y	Y	Y	Y	Y
R10	Insufficient		N	N	Y	Y	Y	Y
R11	Insufficient		Y	Y	Y	Y	N	Y
R12	Insufficient		N	Y	Y	Y	N	Y
R16	<i>Different Manufacturer</i>		N	N	N	N	N	N
R17	<i>Different Manufacturer</i>		N	N	N	N	N	N
R3	Missing		Y	Y	Y	Y	Y	Y
R4	Insufficient		Y	N	Y	Y	Y	Y
R4	Insufficient		Y	N	Y	Y	Y	Y
R5	Insufficient		Y	Y	Y	Y	Y	Y
R6	Missing		Y	Y	Y	Y	Y	Y
RA1	Misalignment		Y	Y	Y	N	Y	Y
RA2	Misalignment		Y	Y	Y	N	Y	N
RA4	Insufficient		Y	Y	Y	Y	Y	Y
RA5	Component on Edge		Y	Y	Y	Y	Y	Y
RA7	Wrong Component		Y	N	N	N	N	N
RA8	Insufficient		Y	Y	Y	N	N	Y
RA9	Insufficient		Y	Y	Y	Y	N	Y
S1	Wrong Orientation		Y	Y	Y	Y	Y	Y
S2	Wrong Component		Y	N	Y	N	N	N
S3	Excess	13	Y(2)	N	N	Y(2)	Y	Y(2)
S3	Misplaced Component	11	Y(2)	N	Y	Y(2)	N	Y(2)
S3	Excess	2	Y(2)	N	N	N	N	Y(2)
S3	Insufficient	1	Y(2)	N	Y	Y(2)	N	Y(2)
S4	Wrong Orientation		Y	Y	Y	Y	Y	Y
S5	Wrong Component		Y	N	Y	Y	N	N
S7	Misalignment		Y	Y	N	Y	Y	Y
S9	Wrong Component		Y	N	Y	Y	N	N
SJ1	Insufficient	13	N	N	N	N	Y	N
SJ1	Insufficient	24	N	N	Y	N	Y	N
SJ1	Insufficient	26	N	N	N	N	N	N
SJ2	Wrong Orientation		Y	Y	Y	Y	Y	N
SOT1	Excess		Y	N	N	N	N	Y(2)
SOT1	Excess		Y	N	N	N	N	Y(2)
SOT3	Excess		Y	N	N	N	N	Y
SOT6	Insufficient	1	Y	N	Y	Y	N	Y
SOT6	Insufficient	2	Y	N	N	Y	N	Y

Comp.	Defect Type	Pin No.	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
SOT6	Insufficient	3	Y	N	Y	Y	N	Y
SOT9	Insufficient		Y	N	Y	N	Y	Y
SS1	Wrong Component		Y	Y	N	N	Y	N
SS3	Wrong Orientation		Y	Y	Y	Y	N	N
SS4	Insufficient	1-20	Y	N	Y	Y	Y	Y
SS6	Wrong Orientation		Y	Y	Y	Y	Y	Y
ST1	Insufficient	1	Y	N	Y	N	N	Y
ST1	Insufficient	2	Y	N	Y	N	N	Y
ST1	Insufficient	3	Y	N	Y	N	N	Y
ST10	Insufficient		N	Y	Y	N	N	Y
ST2	Excess		Y	N	N	N	N	Y
ST4	Excess	1	Y(1)	N	N	N	Y	Y(1)
ST4	Insufficient	2	Y(1)	N	Y	N	Y	Y(1)
ST4	Insufficient	3	Y(1)	N	Y	N	Y	Y(1)
ST5	Insufficient		N	N	Y	N	N	Y
ST6	<i>Different Manufacturer</i>		Y	N	N	N	N	Y
ST7	Insufficient		Y	N	Y	N	Y	Y
ST9	Bridge		Y	N	Y	Y	Y	Y
T1	Wrong Orientation		Y	Y	Y	Y	Y	Y
T3	Insufficient	11	N	N	Y	Y(2)	N	N
T3	Bridge	1/2	Y(2)	N	Y	Y(2)	Y	Y(2)
T3	Insufficient	18	N	N	Y	Y(2)	N	Y(2)
T3	Insufficient	19	N	N	Y	Y(2)	N	Y(2)
T3	Insufficient	17	N	N	N	Y(2)	N	N
T3	Bridge	27/28	Y(2)	N	Y	N	Y	Y(2)

Notes :**(1) Component fails but individual defect identification not possible****(2) Fault rechecked manually**

Italics indicate a change to the assembly, which although not a defect, may cause a system to false flag (i.e. correct component from an alternative manufacturer).

Table 10 : Defect Results for Assembly 36

Comp.	Defect Type	Pin No.	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
B1	Wrong Orientation		Y(2)	N	Y	Y(2)	Y	Y(2)
B1	Misalignment		Y(2)	Y	Y	Y(2)	Y	Y(2)
C10	Misalignment		Y	Y	Y	N	Y	Y
C5	Excess		Y	N	N	Y	Y	N
C6	Excess		Y	N	Y	Y	Y	Y
C9	Misalignment		Y	Y	Y	Y	Y	Y
FC1	Misalignment		N	Y	Y	Y	Y	Y
Q1	Bridge	130/132	Y(2)	Y	Y	Y(2)	Y	Y(2)
Q1	Insufficient	129-192	N	N	Y	Y(2)	N	Y(2)
Q1	Bridge	67/68	Y(1)	N	Y	Y(2)	Y	Y(2)
Q1	Insufficient	65-95	Y(1)	Y	Y	Y(2)	Y	Y(2)
Q1	Misalignment	65-90	Y(1)	Y	Y	Y(2)	Y	Y(2)
Q1	Bridge	1/2	Y(1)	Y	Y	Y(1)	Y	Y(2)
Q1	Bridge	3/4/5	Y(1)	Y	Y	Y(1)	Y	Y(2)
Q1	Bridge	12/13	Y(1)	Y	Y	Y(1)	Y	Y(2)
Q1	Insufficient	58-64	Y(1)	Y	Y	Y(2)	Y	N
Q1	Misalignment	1-30	Y(1)	Y	N	Y(2)	N	Y(2)
Q1	Insufficient	193-256	Y(1)	N	Y	Y(2)	Y	Y(2)
Q1	Misalignment	193-225	Y(1)	Y	Y	Y(2)	Y	Y(2)
Q2	Wrong Orientation		Y(2)	Y	Y	Y(2)	Y	Y
Q2	Insufficient	180-192	N	N	Y	Y(2)	N	Y(2)
Q2	Misalignment	129-160	Y(2)	Y	N	Y(2)	N	Y(2)
Q2	Misalignment	97-128	Y(2)	Y	Y	Y(2)	Y	Y(2)
Q2	Misalignment	50-64	Y(2)	Y	N	Y(2)	N	Y(2)
Q2	Insufficient	193-225	N	N	Y	Y(2)	Y	Y(2)
Q2	Misalignment	193-225	Y(2)	Y	Y	Y(2)	Y	Y(2)
R1	Missing		Y	Y	Y	Y	Y	Y
R12	Misalignment		N	N	Y	N	Y	Y
R13	Misalignment		N	N	Y	Y	Y	Y
R14	Misalignment		N	N	N	Y	Y	N
R15	Misalignment		N	Y	Y	Y	N	Y
R2	Missing		Y	Y	Y	Y	Y	Y
R3	Missing		Y	Y	Y	Y	Y	Y
R4	<i>Different Manufacturer</i>		N	N	N	Y	N	N
R5	<i>Different Manufacturer</i>		N	N	N	N	N	N
R6	Missing		Y	Y	Y	Y	Y	Y
R7	Missing		Y	Y	Y	Y	Y	Y
RA10	Misalignment		N	Y	Y	Y	Y	Y
RA2	Missing		Y	Y	Y	Y	Y	Y
RA3	Insufficient		N	Y	Y	Y	Y	Y
RA5	Component on Edge		Y	Y	Y	Y	Y	Y
RA6	Wrong Component		N	N	N	N	N	N
RA7	Wrong Component		N	N	N	N	N	N
RA8	<i>Different Manufacturer</i>		Y	N	N	N	Y	N
RA9	<i>Different Manufacturer</i>		Y	N	N	N	N	N
S1	Misalignment		Y	Y	Y	Y	Y	Y
S10	Misalignment		Y	Y	Y	N	Y	Y
S3	<i>Different Manufacturer</i>		Y	N	Y	N	N	N
S4	Bridge	13/14	Y(1)	Y	Y	Y	Y	Y(2)

Comp.	Defect Type	Pin No.	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
S5	Bridge	13/14	Y(1)	Y	Y	Y	Y	Y(2)
S7	Wrong Orientation		Y	Y	Y	Y	Y	Y
S8	Missing		Y	Y	Y	Y	Y	Y
S9	Misalignment		Y	Y	Y	Y	Y	Y
SJ1	Missing		Y	Y	Y	Y	Y	Y
SJ2	Insufficient	13	Y(1)	N	N	N	Y	Y(1)
SJ3	Bridge	25/26	N	N	Y	N	Y	Y(1)
SJ3	Insufficient	22	N	N	N	N	Y	Y(1)
SJ4	Bridge	25/26	N	N	Y	N	Y	Y(1)
SOT1	Wrong Component		N	N	Y	N	N	Y
SOT4	Misalignment		Y	Y	Y	Y	Y	Y
SOT5	Wrong Component		Y	N	Y	N	N	N
SOT6	Bridge		Y	N	Y	Y	Y	Y
SOT7	Excess		Y(2)	N	Y	N	N	Y(2)
SOT7	Excess		Y(2)	N	N	N	N	Y(2)
SOT8	Misalignment		Y	Y	Y	Y	Y	Y
SS1	Misalignment		Y	Y	Y	Y	Y	Y
SS4	Wrong Component		Y	Y	N	N	Y	N
SS5	Insufficient	9	N	N	N	N	N	N
SS5	Insufficient	10	N	N	N	N	N	N
SS5	Insufficient	16	N	N	Y	N	N	N
SS5	Insufficient	17	N	N	Y	N	N	N
SS5	Bridge	19/20	Y(2)	Y	Y	N	Y	Y(2)
SS6	Wrong Orientation		Y	Y	Y	Y	Y	N
ST1	Misalignment		Y	Y	Y	Y	Y	Y
ST10	Wrong Component		Y	N	Y	Y	N	N
ST2	Bridge		N	N	Y	N	Y	Y
ST5	Wrong Component		Y	N	N	Y	N	N
ST7	Misalignment		Y	N	Y	Y	Y	Y
ST8	Missing		Y	Y	Y	Y	Y	Y
ST9	Excess		Y	N	Y	Y	N	Y
T1	Insufficient	16	N	Y	Y	Y(1)	Y	Y(1)
T1	Insufficient	14	N	N	Y	Y(1)	N	Y(1)
T1	Bridge	1/2	Y(2)	Y	Y	Y(2)	Y	Y(2)
T1	Insufficient	32	N	Y	Y	Y(2)	Y	Y(2)

Notes :**(1) Component fails but individual defect identification not possible****(2) Fault rechecked manually**

Italics indicate a change to the assembly, which although not a defect, may cause a system to false flag (i.e. correct component from an alternative manufacturer).

5.0 DISCUSSION OF RESULTS

The defect detection results for similar components across all the benchmarking assemblies have been collected together and summarised to form a series of “confidence” charts. Where a system found all occurrences of the component defect type, it was given a high plus (H+) confidence rating. Where a system found more than 67% of occurrences of a defect type, it was given a high (H) confidence rating. If defect location was between 67% and 33% of defect occurrences, then the system was rated with a medium (M) confidence rating. Similarly if the system located less than 33% of defect occurrences, the rating assigned was low (L). Where a system did not find any occurrences of defect type, it was given a low minus (L-) confidence rating. The defects column indicates the number of defect occurrences that the rating is based on.

5.1 Ball Grid Arrays

Table 11 lists the defect detection confidence ratings for component B1 (PBGA256 (1.27mm pitch)).

Table 11 : Ball Grid Array Defect Detection Confidence Ratings

BGA	Defects	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
Missing	2	H+	H+	H+	H+	H+	H+
Misalignment	2	H+	H+	H+	H+	H+	H+
Wrong orientation	2	H+	M	H+	H+	H+	H+

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

Table 11 indicates that all systems dealt well with the limited set of defects occurring on the BGAs. The only exception was the orientation detection on system B, but this could almost certainly be improved with more test programme refinement. Obviously no joint inspection is possible on BGA components as it is not possible to have visual access to the solder joints. No trends can be detected between line scanner, vertical camera or angled camera capabilities. It should be noted that this analysis is based on just two occurrences of each defect. No comparison with the results from the previous NPL AOI benchmarking project (Reference 1) using SnPb solder joints was possible as the assembly used for that evaluation did not include any BGAs. Figure 4 shows images of some of the BGA defects from the benchmarking assemblies.

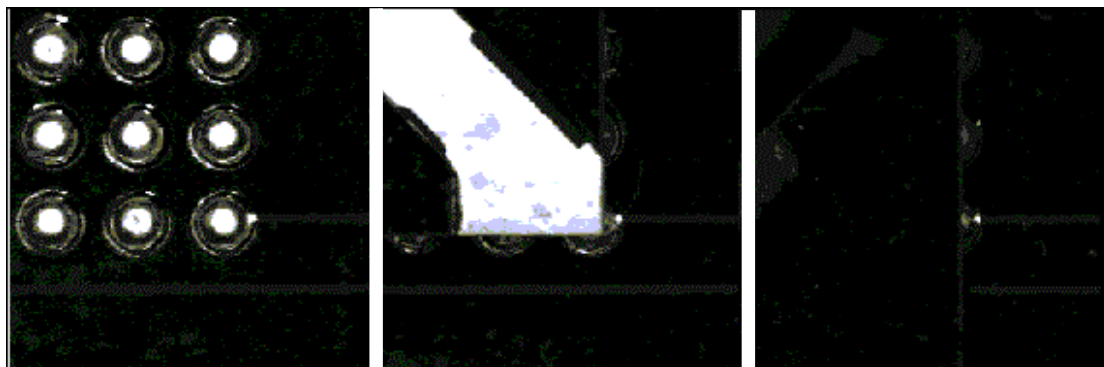


Figure 4 : Images of BGA defects (left - missing, centre - misalignment, right - wrong orientation (source : Agilent))

5.2 Micro Ball Grid Arrays

Table 12 provides the defect detection confidence ratings for component FP1 (μ BGA48 (0.457mm pitch)).

Table 12 : Micro Ball Grid Array Defect Detection Confidence Ratings

μ BGA	Defects	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
Missing	2	H+	H+	H+	H+	H+	H+
Misalignment	3	L-	H+	H+	H+	H+	H+

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

Table 12 indicates that all the camera-based systems dealt well with the limited set of defects occurring on the μ BGAs. The line scanner based system (SYS A) located missing components well but failed to locate any of the three misaligned components. Figure 5 shows images of some of the μ BGA defects from the benchmarking assemblies. It should be noted that this analysis is based on just two or three occurrences of each defect. No comparison with the results from the previous NPL AOI benchmarking project (Reference 1) using SnPb solder joints was possible as the assembly used for that evaluation did not include any μ BGA components.

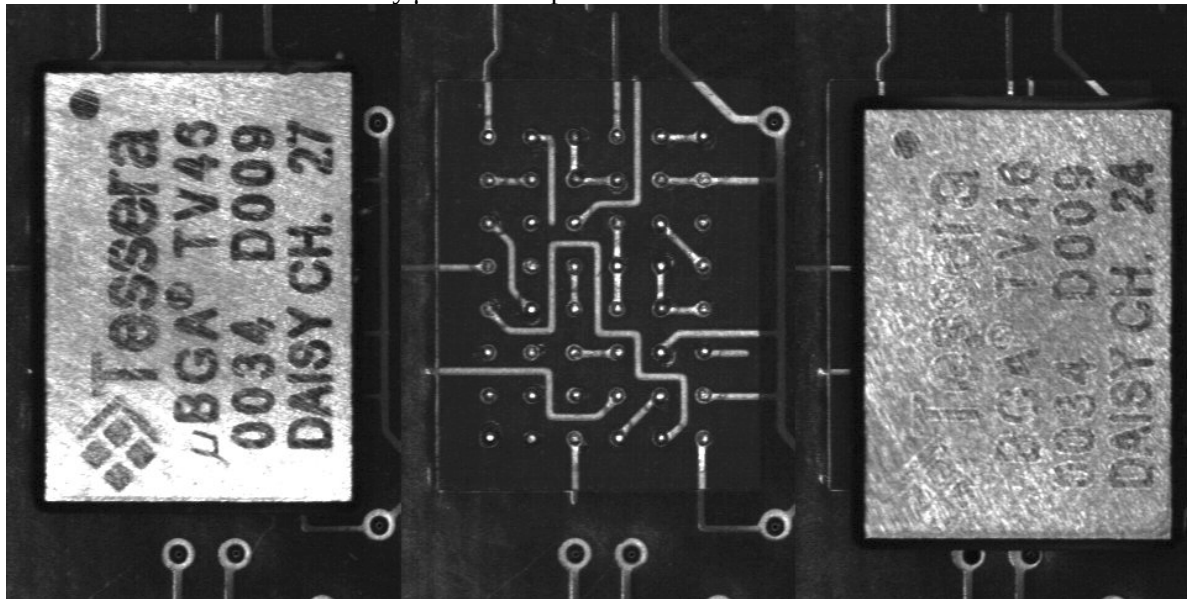


Figure 5 : Images of μ BGA defects (left - good, centre - missing , right - misalignment (source : Agilent))

5.3 Chip Capacitors

Table 13 presents the defect detection confidence ratings for chip capacitors C1 to C10 (C0603).

Table 13 : Chip Capacitor Defect Detection Confidence Ratings

C0603	Defects	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
Missing	4	H+	H+	H+	H+	H+	H+
Misalignment	6	M	M	H	M	H	H+
Component on edge	3	M	L-	M	L-	H+	M
Excess	3	H+	L-	M	H+	M	M
Insufficient	9	M	L	H	H+	L	H
Wrong component	3	M	L-	L-	L-	H+	M

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

Table 13 indicates a spread of performance with only systems A & F not incurring a low rating in their responses. None of the systems achieved high confidence for all defect categories. Missing and misalignment categories were generally well covered with all systems achieving high or medium confidence. No trends could be detected in the relative performances of the line scanner, vertical camera or angled camera systems. Figure 6 shows images of some of the C0603 defects from the benchmarking assemblies.

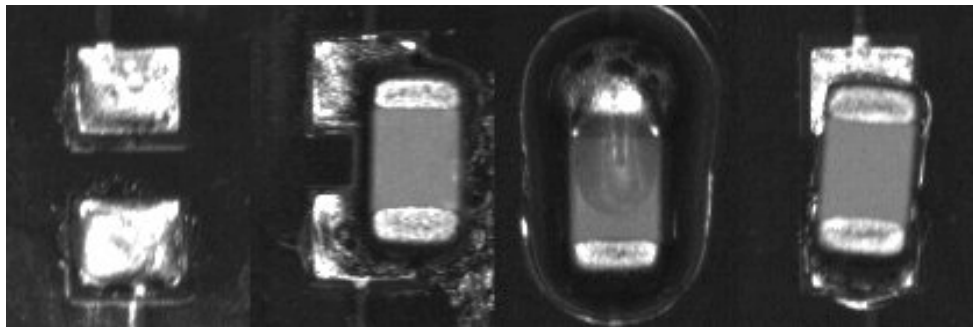


Figure 6 : Images of C0603 defects (left - missing, centre left - misalignment , centre right - excess, right - insufficient (source : Agilent))

Table 14 lists the results from the previous NPL AOI benchmarking project (Reference 1), which reviewed a different set of systems. Those results are very similar to the current set of results for lead-free C0603s, with only one system achieving all high or medium ratings. This comparison indicates that location of C0603 defects in lead-free assemblies is little different from their location on SnPb assemblies.

Table 14 : SnPb solder joint chip capacitor confidence chart (Reference 1)

C0603 (SnPb)	SYS U	SYS V	SYS W	SYS X	SYS Y	SYS Z	AXI
Missing	H+	H+	H+	H+	H+	H+	H+
Misalign	H+	H+	H+	H+	M	M	M
Excess	L-	M	M	H+	H+	H+	M
Insufficient	M	M	M	H+	M	M	M
Wrong component	H+	L-	L-	H+	L-	L-	NC

Generally based on occurrence of 3 defects.

NC = not capable

5.4 0402 Chip Resistors

Table 15 records the defect detection confidence ratings for chip resistors R1 to R20 (R0402).

Table 15 : 0402 Chip Resistor Defect Detection Confidence Ratings

R0402	Defects	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
Missing	19	H+	H+	H+	H+	H+	H+
Misalignment	5	L	M	H	H	H	H
Component on edge	3	H+	M	H+	H+	H+	H+
Excess	3	H+	M	H+	L	L	H+
Insufficient	18	M	M	H	H	M	H
Inverted component	3	H+	L-	L-	H+	H+	H+

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

Table 15 again highlights a spread of performances with only system F not incurring a low rating in its responses. This system was also the only system to achieve high confidence for all defect categories. Of the occurrences of low ratings, two of these were for inverted components, which could probably be improved by better programming, and is a defect classification considered by many end users as not important enough to report. Similarly, several systems achieved only low ratings for excess solder joints, a defect category which has a low occurrence in production assemblies. It is encouraging that all the systems achieved medium or high ratings for locating the “insufficient defects” on these components. No trends could be detected in the relative performances of the line scanner, vertical camera or angled camera systems. Figure 7 shows images of some of the R0402 defects from the benchmarking assemblies. No comparison with the results from the previous NPL AOI benchmarking project (Reference 1) using SnPb solder joints was possible as the assembly used for that evaluation did not include any R0402 components.



Figure 7 : Images of R0402 defects (from left to right - missing, misalignment, component on edge, excess, insufficient, inverted (source : Agilent))

5.5 0603 Chip Resistors

Table 16 shows the defect detection confidence ratings for chip resistors RA1 to RA10 (R0603).

Table 16 : 0603 Chip Resistor Defect Detection Confidence Ratings

R0603	Defects	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
Missing	4	H+	H+	H+	H+	H+	H+
Misalignment	6	H	H+	H	M	H	H
Component on edge	3	H+	H+	H+	H+	H+	M
Excess	3	L-	L	L-	H+	L-	M
Insufficient	10	H	H	H	M	L	H+
Inverted component	3	H+	L-	L-	H+	H+	H+
Wrong component	3	L	L-	L-	L-	L-	L-

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

The results for the R0603 were very similar to those obtained on the R0402 components (cf Tables 15 and 16). Excluding wrong component, only systems D & F achieved all high or medium ratings. Of the occurrences of low ratings, two of these were for inverted components, which could probably be improved by better programming, and is a defect classification considered by many end users as not important enough to report. Several systems achieved only low ratings for excess solder joints, a defect category which has a low occurrence in production assemblies. With regard to the wrong component defect results, only system A used optical character recognition (OCR) capabilities. Several of the other systems had OCR capability but did not use them in their test programmes. No trends could be detected in the relative performances of the line scanner, vertical camera or angled camera systems. Figure 8 presents images of some of the R0603 defects from the benchmarking assemblies.

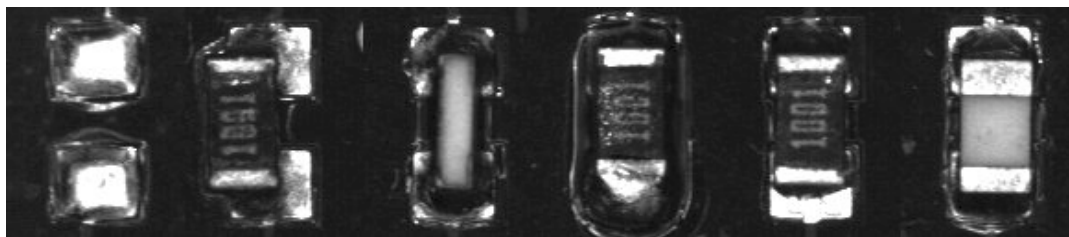


Figure 8 : Images of R0603 defects (from left to right - missing, misalignment, component on edge, excess, insufficient, inverted (source : Agilent))

Table 17 shows the results from the previous NPL AOI benchmarking project (Reference 1), which reviewed a different set of systems. Those results are very similar to the current set of results for lead-free R0603s, with the possible exception of excess and inverted component detection, when better results were obtained for the SnPb assemblies. These differences probably reflect the current priorities in test programming rather than any difficulties there may be in detecting these defects on lead-free components. Taking this into account, the similarities in the defect location results indicates that location of R0603 defects in lead-free assemblies is little different from locating them on SnPb assemblies.

Table 17 : SnPb solder joint chip resistor confidence chart (Reference 1)

R0603 (SnPb)	SYS U	SYS V	SYS W	SYS X	SYS Y	SYS Z	AXI
Missing	H+	H+	H+	H+	H+	H+	H+
Misalign	H+	H+	H+	H+	M	M	M
Excess	L-	M	M	H+	H+	H+	M
Insufficient	M	M	M	H+	M	M	M
Inverted Component	H+	H+	H+	H+	H+	H+	NC
Wrong Component	H+	?	?	H+	L-	?	NC

Generally based on occurrence of 3 defects.

NC = not capable.

? = claimed capability but insufficient data to confirm

5.6 Small Outline ICs (SOICs)

Table 18 presents the defect detection confidence ratings for small outline IC components (S1 to S10 (SOIC14, 1.27mm pitch)).

Table 18 : SOIC Defect Detection Confidence Ratings

SOIC	Defects	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
Missing	4	H+	H+	H+	H+	H+	H+
Misalignment	6	H+	H+	H	H	H+	H+
Bridge	3	H+	M	H+	H+	H+	H+
Excess	10	H+	L	L-	M	H	H
Insufficient	10	M	L	H	M	L-	H+
Wrong component	8	H+	L	M	M	L-	L-
Wrong orientation	5	H	H	H+	H+	H+	H

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

The performances of the systems regarding the SOIC components were variable (see Table 18). The detection of missing components, misalignment, bridges and wrong orientation, was very successful with high ratings for all systems except one, which scored a medium rating. Several systems achieved only low ratings for excess solder joints, a defect category which has a low occurrence in production assemblies. With regard to the wrong component detect results, only system A used OCR capabilities and this was the only system to score a high rating. Several of the other systems had OCR capability but did not use them in their test programmes. No trends could be detected in the relative performances of the line scanner, vertical camera or angled camera systems. Figure 9 shows images of some of the SOIC defects from the benchmarking assemblies.

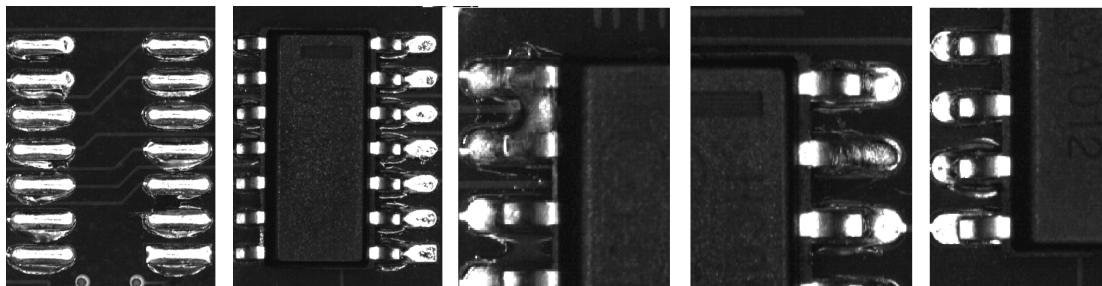


Figure 9 : Images of SOIC defects (from left to right - missing, misalignment, bridge, excess, insufficient (source : Agilent))

Table 19 reproduces the results from the previous NPL AOI benchmarking project (Reference 1), which reviewed a different set of systems. Those results were very similar to the current benchmark data and indicate that location of SOIC defects in lead-free assemblies is little different from locating them on SnPb assemblies.

Table 19 : SnPb solder joint SOIC confidence chart (Reference 1)

SOIC (SnPb)	SYS U	SYS V	SYS W	SYS X	SYS Y	SYS Z	AXI
Missing	H+	H+	H+	H+	H+	H+	H+
Misalign	M	H+	H+	H+	M	M	H+
Bridge	H+	H+	H+	H+	H+	H+	H+
Excess	L-	H+	L-	H+	L-	L-	H+
Insufficient	L-	M	M	H+	L-	M	H+
Wrong component	H+	H+	H+	H+	L-	L-	NC
Wrong orientation	H+	M	H+	H+	M	H+	NC

Generally based on occurrence of 3 defects.
NC = not capable

5.7 Small Outline J-lead ICs

Table 20 shows the defect detection confidence ratings for small outline J-lead IC components (J1 to J4(SOIC14, 1.27mm pitch)).

Table 20 : SOJ Defect Detection Confidence Ratings

SOJ	Defects	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
Missing	3	H+	H+	H+	H+	H+	L-
Misalignment	1	L-	H+	H+	H+	H+	H+
Bridge	3	L-	L-	H+	L-	H+	H+
Excess	3	L-	L-	M	L-	M	H+
Insufficient	6	L	L-	L	L-	H	L
Wrong orientation	4	H+	H+	H+	H+	H+	L-

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

The results provided in Table 20 suggest that the systems performed differently in the detection of defects related to SOJ components. Generally detection of missing components, misalignment and wrong orientation, was successful with high ratings for most systems. The two systems which achieved low ratings for these defects, should be capable of improvement with more programme refinement. System F was the only vertical camera based system to achieve high or medium ratings for bridges and excess solder joints, whilst both angled camera based systems achieved this feat. System E, an angled camera based system, was the only equipment to achieve a high rating for insufficient solder joints. Indeed, all the other systems achieved only low ratings.

The reduced ability of vertical camera systems to locate joint defects on SOJ components is certainly due to the lack of visual access afforded by these types of equipment to a solder joint which is largely under the body of the component. Figure 10 presents images of a solder bridge on an SOJ component from an angled system and vertical system for comparison. Figure 11 shows images of some of the SOJ defects from the benchmarking assemblies.

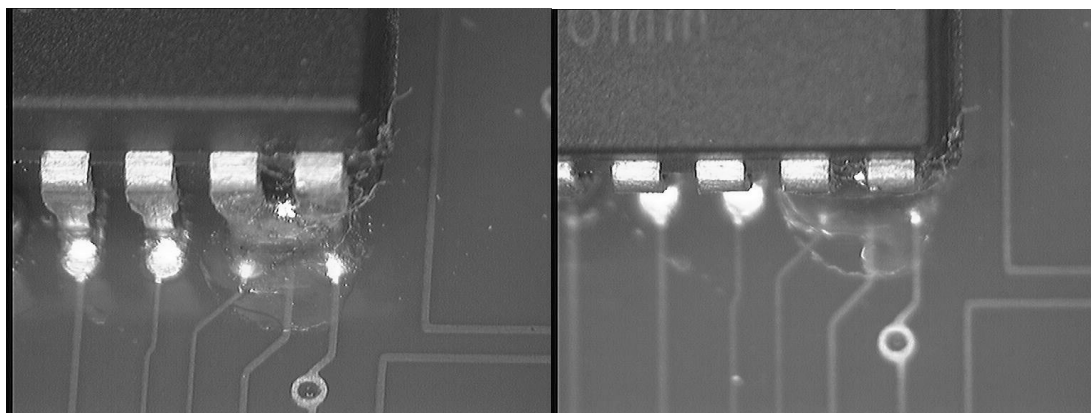


Figure 10 : Comparative images from angled camera system (left) and vertical camera system (right) of SOJ solder bridge

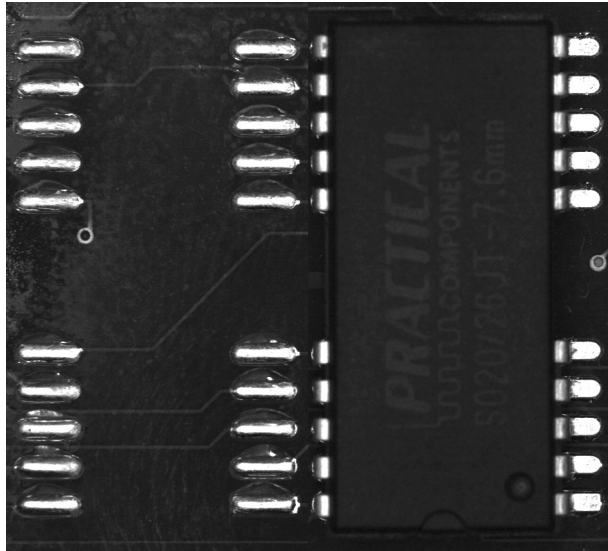


Figure 11 : Images of SOJ defects (left - missing, right - misalignment (source : Agilent))

Table 21 reproduces the results from the previous NPL AOI benchmarking project (Reference 1, which reviewed a different set of systems), for PLCC components, which have the same J-lead joint format as the SOJ components used in the current study. Those results are very similar to the current benchmark data and indicate that location of SOJ defects in lead-free assemblies is little different from locating them on SnPb assemblies.

Table 21 : SnPb solder joint PLCC confidence chart (Reference 1)

PLCC (SnPb)	SYS U	SYS V	SYS W	SYS X	SYS Y	SYS Z	AXI
Missing	H+	H+	H+	H+	H+	H+	H+
Misalignment	L-	H+	L-	H+	H+	H+	H+
Bridge	M	M	L-	H+	H+	L-	H+
Excess	L-	M	?	L-	H+	H+	H+
Insufficient	L-	H+	H+	H+	H+	M	H+
Wrong Orientation	H+	M	H+	H+	M	M	NC

Generally based on occurrence of 3 defects.

? = claimed capability but insufficient data to confirm

NC = not capable

5.8 Finer Pitch Small Outline ICs (SSOPs)

Table 22 lists the defect detection confidence ratings for SSOP components, SS1 to SS6 (SSOP20, 0.65mm pitch).

Table 22 : SSOP Defect Detection Confidence Ratings

SSOP	Defects	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
Missing	3	H+	H+	H+	H+	H+	H+
Misalignment	6	M	H+	H+	H+	H+	H+
Bridge	8	M	H+	H+	H	H+	H+
Excess	3	L	L-	L	L	L	H+
Insufficient	16	L	L	M	M	L	M
Wrong component	2	H+	H+	L-	L-	H+	L-
Wrong orientation	3	H+	H+	H+	H+	M	L

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

It is evident that whilst the performances of the systems is variable, they are similar to those achieved for the coarser pitch SOIC components. Detection of missing components, misalignment, bridges and wrong orientation, was very successful with high or medium ratings for all systems. The only exception to this was system F which scored low for wrong orientation. This system result should be capable of improvement with more test programme refinement. Most systems achieved only low ratings for excess solder joints, a defect category which has a low occurrence in production assemblies. No system achieved a high rating for detection of insufficient solder joints.

With regard to the wrong component detect results, only system A used OCR capabilities and this system scored a high rating. Two other systems also achieved a high rating for wrong component, although this was probably achieved by virtue of dimensional changes. No trends could be detected in the relative performances of the line scanner, vertical camera or angled camera systems. Figure 12 shows images of some of the SSOP defects from the benchmarking assemblies. No comparison with the results from the previous NPL AOI benchmarking project (Reference 1) using SnPb solder joints was possible as the assembly used for that evaluation did not include any SSOPs

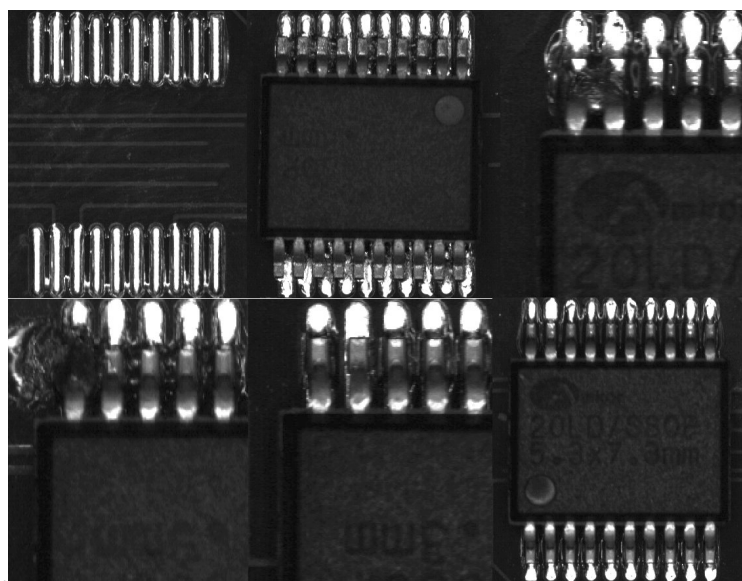


Figure 12 : Images of SSOP defects (clockwise from top left - missing, misalignment, bridge, excess, insufficient, wrong orientation (source : Agilent))

5.9 Finer Pitch Thin Small Outline ICs (TSOPs)

Table 23 summarises the defect detection confidence ratings for TSOP components, T1 to T3 (TSOP32, 0.5mm pitch).

Table 23 : TSOP Defect Detection Confidence Ratings

TSOP	Defects	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
Missing	2	H+	H+	H+	H+	H+	H+
Misalignment	2	L-	H+	H+	H+	H+	H+
Bridge	6	M	L	H+	M	H+	H+
Excess	3	M	L-	L-	L-	M	H+
Insufficient	10	L-	L	H	H	L	H
Wrong orientation	2	H+	H+	H+	H+	H+	H+

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

The ratings, whilst varying from system to system, are very similar to those achieved for the coarser pitch SOIC components. Detection of missing components, misalignment, bridges and wrong orientation, was very successful with high or medium ratings for most systems. Exceptions to this were system A (line scanner) which scored low for misalignment, and system B which scored low for bridges. Again the majority of systems achieved only low or medium ratings for excess solder joints, a defect category which has a low occurrence in production assemblies. However, three systems achieved a high rating for detection of insufficient solder joints. It should be remembered that no system achieved this for the SSOP components, despite the finer pitch of the TSOPs. No trends could be detected in the relative performances of the line scanner, vertical camera or angled camera systems. Figure 13 presents images of some of the SOIC defects from the benchmarking assemblies. No comparison with the results from the previous NPL AOI benchmarking project (Reference 1) using SnPb solder joints was possible as the assembly used for that evaluation did not include any TSOPs.

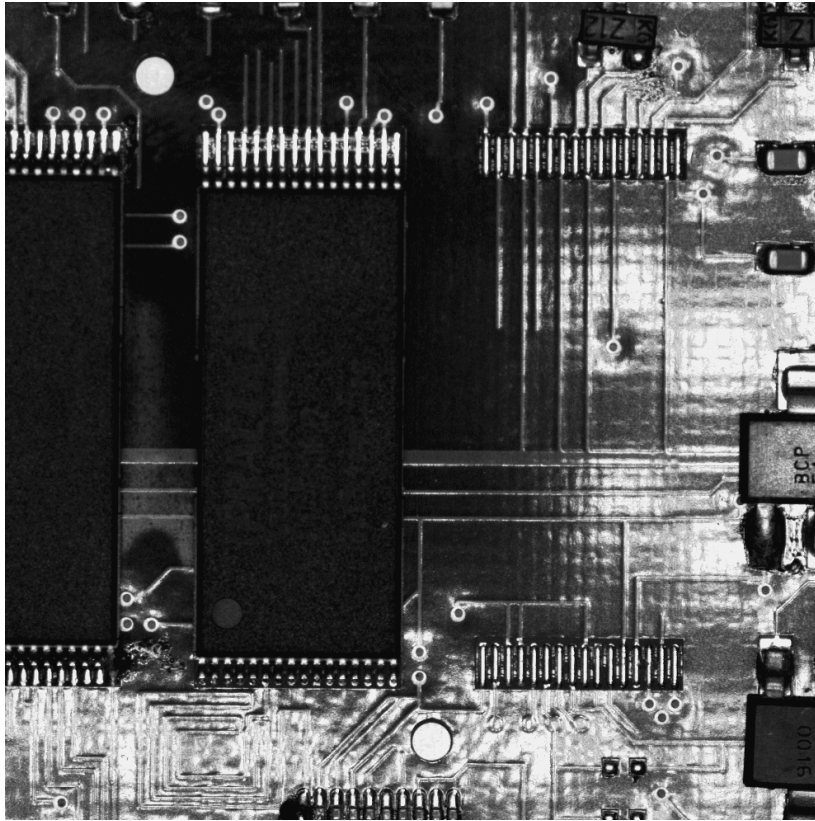


Figure 13 : Images of TSOP defects (left - misalignment, right - missing (source : Astro))

5.10 SOT223 Transistors

Table 24 lists the defect detection confidence ratings for SOT223 transistors, SOT1 to SOT10.

Table 24 : SOT223 Defect Detection Confidence Ratings

SOT223	Defects	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
Missing	4	H+	H+	H+	H+	H+	H+
Misalignment	5	M	H+	H+	H	H+	H+
Bridge	1	H+	L-	H+	H+	H+	H+
Excess	9	H	L-	L	L-	L-	H+
Insufficient	8	H+	L-	H	M	M	M
Wrong component	3	L	L-	H+	L-	L-	M

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

A variation in performance is again indicated in Table 24, with only system F not including a low rating in its responses. The only low rating for system C was for excess solder joints, a defect category which has a low occurrence in production assemblies. Only two systems achieved a high rating for excess solder joints. Most systems again achieved high ratings for missing, misalignment and bridges. Only one system did not achieve a medium or high rating for locating insufficient defects on these components. No trends could be detected in the relative performances of the line scanner, vertical camera or angled camera systems. Figure 14 shows images of some of the SOT223 defects from the benchmarking assemblies. No comparison with the results from the previous NPL AOI benchmarking project (Reference 1) using SnPb solder joints was possible as the assembly used for that evaluation did not include any SOT223s.

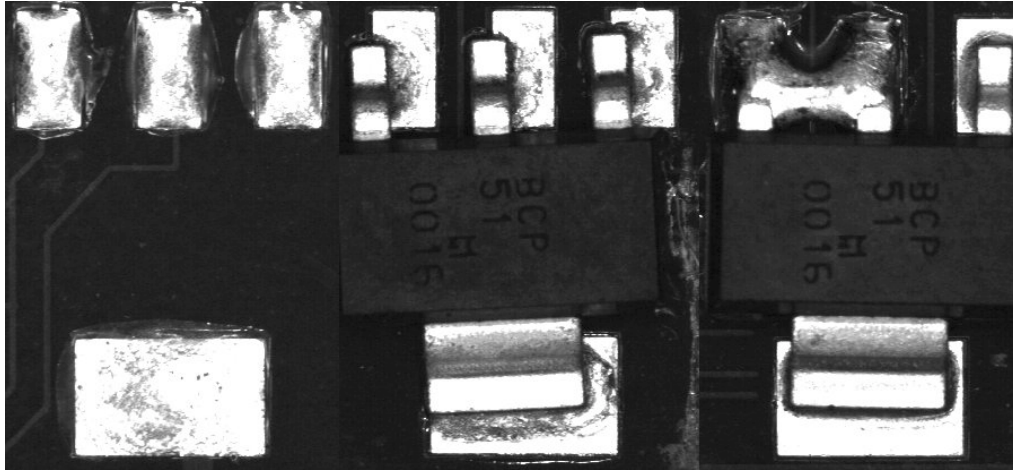


Figure 14 : Images of SOT223 defects (from left to right - missing, misalignment, bridge (source : Agilent))

5.11 SOT23 Transistors

Table 25 summarises the defect detection confidence ratings for SOT223 transistors ST1 to ST10.

Table 25 : SOT23 Defect Detection Confidence Ratings

SOT23	Defects	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
Missing	4	H+	H+	H+	H+	H+	H+
Misalignment	8	H+	M	H+	M	H	H
Bridge	2	M	L-	H+	M	H+	H+
Excess	7	H	L-	M	L	M	H
Insufficient	19	H	L	H	L	L	H
Wrong component	4	H+	L-	L	H	L-	L-

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

The results shown in Table 25 are very similar to the results obtained for the larger and coarser leaded SOT223 components (see Table 24). Most systems again achieved high or medium ratings for missing, misalignment and bridges. Insufficient and excess detection was perhaps slightly more successful for SOT223s than for the SOT23s, as might be expected as the latter's leads are smaller. No trends could be detected in the relative performances of the line scanner, vertical camera or angled camera systems. Figure 15 presents images of some of the SOT23 defects from the benchmarking assemblies. No comparison with the results from the previous NPL AOI benchmarking project (Reference 1) using SnPb solder joints was possible as the assembly used for that evaluation did not include any SOT23s.

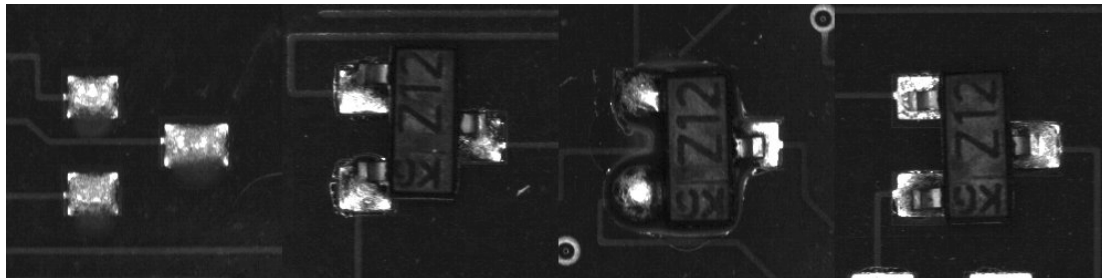


Figure 15 : Images of SOT23 defects (from left to right - missing, misalignment, excess & insufficient (source : Agilent))

5.12 Quad Flat Pack ICs (QFPs)

Table 26 presents the defect detection confidence ratings for QFP components, Q1 to Q2 (QFP256, 0.4mm pitch).

Table 26 : QFP Defect Detection Confidence Ratings

QFP	Defects	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
Missing	1	H+	H+	H+	H+	H+	H+
Misalignment	30	H	H	H	H	M	H+
Bridge	29	H	M	H+	H	H	H
Excess	3	L-	L-	L-	L	H+	L
Insufficient	17	L	L	H	H	H	M
Wrong Orientation	2	H+	H+	M	M	H+	H+

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

Once again, the results highlight a variation in performance of the systems, this time for the QFP components. Detection of missing components, misalignment, bridges and wrong orientation, was very successful with high or medium (mostly high) ratings for all systems. As with a number of other joint types, most systems achieved only low ratings for excess solder joints, a defect category which has a low occurrence in production assemblies. Three systems achieved a high rating for detection of insufficient solder joints. No trends could be detected in the relative performances of the line scanner, vertical camera or angled camera systems. Figure 16 provides images of some of the QFP defects from the benchmarking assemblies.

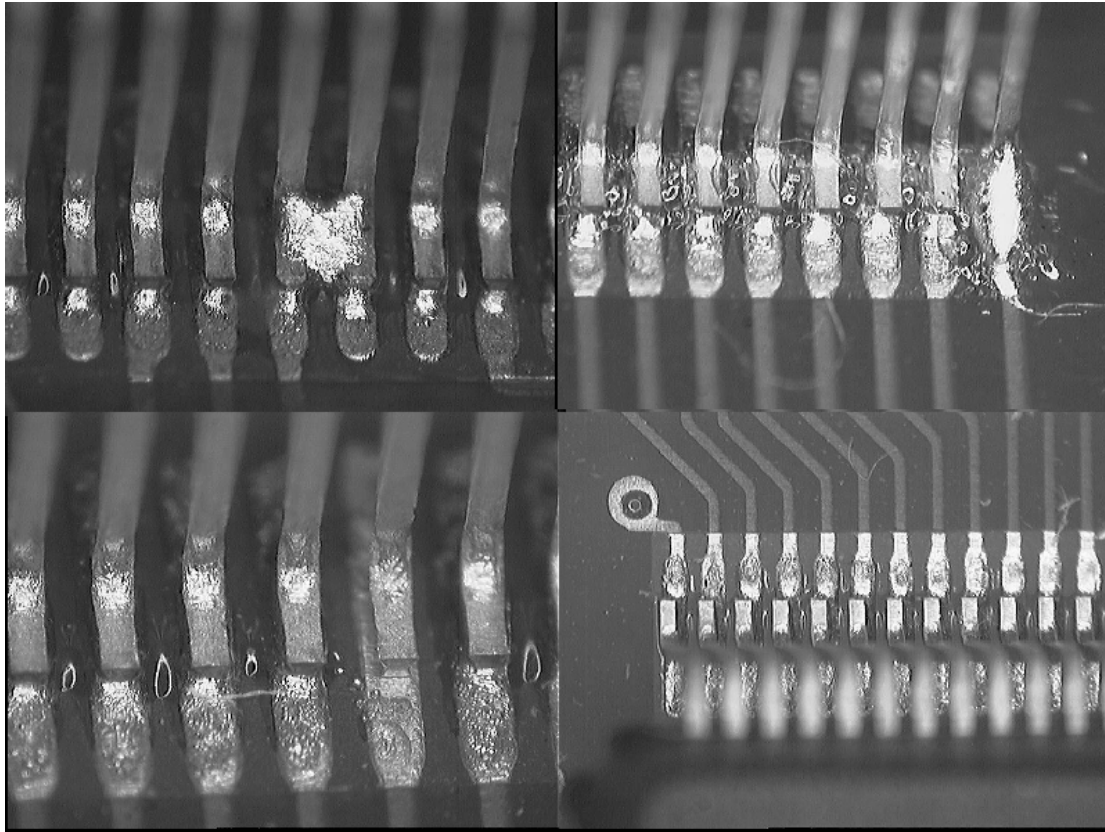


Figure 16 : Images of QFP defects (clockwise from top left - bridge, excess, misalignment, , insufficient)

Table 27 reproduced the results from the previous NPL AOI benchmarking project (Reference 1), which reviewed a different set of systems. The results for the lead-free evaluation are slightly improved on the previous results for the SnPb solder joints, despite the fact that the pitch for the current lead-free project is significantly finer (0.4mm) compared to the earlier study (0.65 & 0.5mm). The success of the lead-free results indicate that location of QFP defects in lead-free assemblies presents no more problems than for SnPb assemblies.

Table 27 : SnPb solder joint QFP confidence chart (Reference 1)

QFP (SnPb)	SYS U	SYS V	SYS W	SYS X	SYS Y	SYS Z	AXI
Missing	H+	H+	H+	H+	H+	H+	H+
Misalignment	M	M	H+	H+	M	M	M
Bridge	H+	M	M	M	M	H+	H+
Excess	L	M	L	L	H+	H+	H+
Insufficient	M	M	L	M	M	M	M
Wrong Orientation	H+	?	H+	H+	M	H+	NC

? = claimed capability but insufficient data to confirm

NC = not capable

5.13 Missing Components

Table 28 provides an analysis of the ability of each of the systems to locate the missing components incorporated into this study. Clearly this type of defect holds few problems for any of the systems. As previous discussed, the performance of system F in locating missing SOJ components should be capable of improvement with more test programme refinement. No trends could be detected in the relative performances of the line scanner, vertical camera or angled camera systems.

Table 28 : Analysis of systems ability to detect missing components

<i>Missing</i>	<i>Defects</i>	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
BGA	2	H+	H+	H+	H+	H+	H+
C0603	4	H+	H+	H+	H+	H+	H+
μBGA	2	H+	H+	H+	H+	H+	H+
QFP	1	H+	H+	H+	H+	H+	H+
R0402	19	H+	H+	H+	H+	H+	H+
R0603	4	H+	H+	H+	H+	H+	H+
SOIC	4	H+	H+	H+	H+	H+	H+
SOJ	3	H+	H+	H+	H+	H+	L-
SOT223	4	H+	H+	H+	H+	H+	H+
SOT23	4	H+	H+	H+	H+	H+	H+
SSOP	3	H+	H+	H+	H+	H+	H+
TSOP	2	H+	H+	H+	H+	H+	H+

line scanner

vertical cameras

angled cameras

5.14 Component Misalignment

Table 29 provides the analysis of the systems' ability to locate misaligned components. The camera-based systems (B-F) all returned mainly high ratings with some medium ratings for systems B, D and E (one only). System A achieved high ratings for only 40% of components, and generally scored low ratings for the finer pitch or smaller components (μBGA, R0402, TSOP), QFPs being the exception.

Table 29 : Analysis of systems' ability to detect component misalignment

<i>Misalignment</i>	<i>Defects</i>	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
BGA	2	H+	H+	H+	H+	H+	H+
C0603	6	M	M	H	M	H	H+
μBGA	3	L-	H+	H+	H+	H+	H+
QFP	30	H	H	H	H	M	H+
R0402	5	L	M	H	H	H	H
R0603	6	H	H+	H	M	H	H
SOIC	6	H+	H+	H	H	H+	H+
SOJ	1	L-	H+	H+	H+	H+	H+
SOT223	5	M	H+	H+	H	H+	H+
SOT23	8	H+	M	H+	M	H	H
SSOP	6	M	H+	H+	H+	H+	H+
TSOP	2	L-	H+	H+	H+	H+	H+

line scanner

vertical cameras

angled cameras

5.15 Bridges

Table 30 shows the analysis of the ability of each system to locate bridges between leads. Three systems (C, E & F) achieved high ratings for bridges on all component types. Of the remaining systems, two scored mainly high or medium, with system B recording four low ratings. Half the systems managed only a low rating for SOJ bridges. As previously stated many end-users will be unconcerned by this as it is a defect classification has low incidence in practice. No trends could be detected in the relative performances of the line scanner, vertical camera or angled camera systems.

Table 30 : Analysis of systems' ability to detect bridges

Bridges	Defects	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
QFP	29	H	M	H+	H	H	H
SOIC	3	H+	M	H+	H+	H+	H+
SOJ	3	L-	L-	H+	L-	H+	H+
SOT223	1	H+	L-	H+	H+	H+	H+
SOT23	2	M	L-	H+	M	H+	H+
SSOP	8	M	H+	H+	H	H+	H+
TSOP	6	M	L	H+	M	H+	H+

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

5.16 Components on Edge

Table 31 presents the analysis of the ability of each system to locate chip components on edge. Generally, location ability is good with the exception of 0603 chip capacitors where only one system (E) achieved a high rating. This may be due to the small differences between the height and width of these components. In addition, many users do not worry about this defect as it does not unduly affect reliability, and therefore effort is not wasted in trying to locate them. No trends could be detected in the relative performances of the line scanner, vertical camera or angled camera systems.

Table 31 : Analysis of systems ability to detect component on edge

On Edge	Defects	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
C0603	3	M	L-	M	L-	H+	M
R0402	3	H+	M	H+	H+	H+	H+
R0603	3	H+	H+	H+	H+	H+	M

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

5.17 Excess Solder Joints

The analysis of the ability of each system to locate excess solder joints is presented in Table 32. Success in locating of this defect type is probably the poorest for all types across the systems. No system achieves a high rating for all component types although system F comes closest with high ratings for 70% of components, the only low rating being for QFPs. This system manages to achieve a high rating for R0402 but only a medium rating for the larger R0603 & C0603 components so perhaps improvement would be possible with improved programming. All the other systems score at least four low ratings. This again may not be of concern for many end users, particularly those who are

concerned with reflow soldering, as this type of defect is uncommon and even when present, may not adversely affect component or joint reliability. Indeed, discussions with some of the equipment suppliers indicates that decreasing emphasis has been placed on locating this type of defect in recent years. No trends could be detected in the relative performances of the line scanner, vertical camera or angled camera systems.

Table 32 : Analysis of systems' ability to detect excess solder joints

<i>Excess</i>	<i>Defects</i>	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
C0603	3	H+	L-	M	H+	M	M
QFP	3	L-	L-	L-	L	H+	L
R0402	3	H+	M	H+	L	L	H+
R0603	3	L-	L	L-	H+	L-	M
SOIC	10	H+	L	L-	M	H	H
SOJ	3	L-	L-	M	L-	M	H+
SOT223	9	H	L-	L	L-	L-	H+
SOT23	7	H	L-	M	L	M	H
SSOP	3	L	L-	L	L	L	H+
TSOP	3	M	L-	L-	L-	M	H+

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

5.18 Insufficient Solder Joints

The analysis of the ability of each system to locate insufficient solder joints is presented in Table 33. Generally, success with SOJ components was poor, with only one angled camera system achieving a high rating. Systems C & F performed well with only the SOJ joints receiving a low rating. Perhaps surprisingly, the only component for which all systems achieved high or medium ratings was the R0402 component. This perhaps reflects the degree of effort put into programming these smaller components in the limited time available rather than this type of defect being inherently easier to locate on these components. No trends could be detected in the relative performances of the line scanner, vertical camera or angled camera systems.

Table 33 : Analysis of systems' ability to detect insufficient solder joints

<i>Insufficient</i>	<i>Defects</i>	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
C0603	9	M	L	H	H+	L	H
QFP	17	L	L	H	H	H	M
R0402	18	M	M	H	H	M	H
R0603	10	H	H	H	M	L	H+
SOIC	10	M	L	H	M	L-	H+
SOJ	6	L	L-	L	L-	H	L
SOT223	8	H+	L-	H	M	M	M
SOT23	19	H	L	H	L	L	H
SSOP	16	L	L	M	M	L	M
TSOP	10	L-	L	H	H	L	H

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

5.19 Inverted Components

Table 34 presents the analysis of the systems' ability to locate inverted components. Essentially, the systems either found all examples of the defects, or none at all, reflecting programming rather than ability to locate. No doubt, the performance of the latter systems could be improved with more test programme refinement. No trends could be detected in the relative performances of the line scanner, vertical camera or angled camera systems.

Table 34 : Analysis of systems' ability to detect inverted components

Inverted	Defects	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
R0402	3	H+	L-	L-	H+	H+	H+
R0603	3	H+	L-	L-	H+	H+	H+

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

5.20 Wrong Component

Table 35 summarises the analysis of the ability of each system to locate wrong components. Results are mixed with only system A using OCR and this system perhaps achieves the best results. Where other systems have successfully detected component changes, this has been achieved using small changes in component dimensions. As a programming strategy, this may be unsuccessful if the wrong component is a different value component from the same manufacturer, in which case component dimensions would not be dissimilar. Discussion with equipment suppliers indicates that OCR capability is offered by other systems but the reliability is patchy due to the poor quality of marking on many components. In production this facility is switched off to prevent an excess of false calls and is generally only used when checking initial assemblies after placement equipment set up. It is perhaps, unfair to include C0603 wrong components in this study, as with no markings they are practically impossible to detect by visual inspection systems, whether manual or automatic. No trends could be detected in the relative performances of the line scanner, vertical camera or angled camera systems.

Table 35 : Analysis of systems' ability to detect wrong components

Wrong Component	Defects	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
C0603	3	M	L-	L-	L-	H+	M
R0603	3	L	L-	L-	L-	L-	L-
SOIC	8	H+	L	M	M	L-	L-
SOT223	3	L	L-	H+	L-	L-	M
SOT23	4	H+	L-	L	H	L-	L-
SSOP	2	H+	H+	L-	L-	H+	L-

line scanner	vertical cameras	angled cameras
--------------	------------------	----------------

5.21 Wrong Orientation

Table 36 presents the analysis of the ability of each system to locate wrongly orientated components. Generally, there were few problems here that could not be improved with further test programme refinement. Five out of six systems achieved high or medium ratings with the majority of ratings

being high. No trends could be detected in the relative performances of the line scanner, vertical camera or angled camera systems.

Table 36 : Analysis of systems' ability to detect wrong orientation

Orientation	Defects	SYS A	SYS B	SYS C	SYS D	SYS E	SYS F
BGA	2	H+	M	H+	H+	H+	H+
QFP	2	H+	H+	M	M	H+	H+
SOIC	5	H	H	H+	H+	H+	H
SOJ	4	H+	H+	H+	H+	H+	L-
SSOP	3	H+	H+	H+	H+	M	L
TSOP	2	H+	H+	H+	H+	H+	H+



The left side of Figure 17 shows a comparison between the average component level false detect rates per assembly for the systems covered in the current lead-free evaluation. Generally these were similar with values of around five components per assembly or less. System C achieved an average false detect rate at joint level of slightly more than two joints per assembly. This equates to a rate of less than 0.2% of solder joints per assembly. The line scanner system (A) average false detect rate was significantly higher than the camera-based systems at 15 components per assembly. It should also be noted that of the camera-based systems, the system that generally did best at defect location (system F), was also the system which had the highest false detect rate. False detect rates may be reduced by further refinement of test programmes without unduly impacting on sensitivity, although the effect on detection rates after such refinements was not monitored in this study.

The right hand side of Figure 17 shows the similar results from the NPL's previous SnPb AOI benchmarking project. Although the assemblies were different, joint counts were similar and a comparison indicates similar levels of average false detects. ***This leads to the conclusion that there are no particular false detect issues associated with lead-free assemblies.***

Figure 18 illustrates a comparison between the average component false detect rate per assembly for the NiAu finished assemblies and the single OSP finished PCB assembly. It can be seen that the rate for the OSP assembly is generally higher than for the NiAu assembly. ***This suggests that some adjustment of the test programmes would be required if a production line were changed from utilising NiAu PCBs to OSP PCBs, but that the amount of reprogramming would not be significant.***

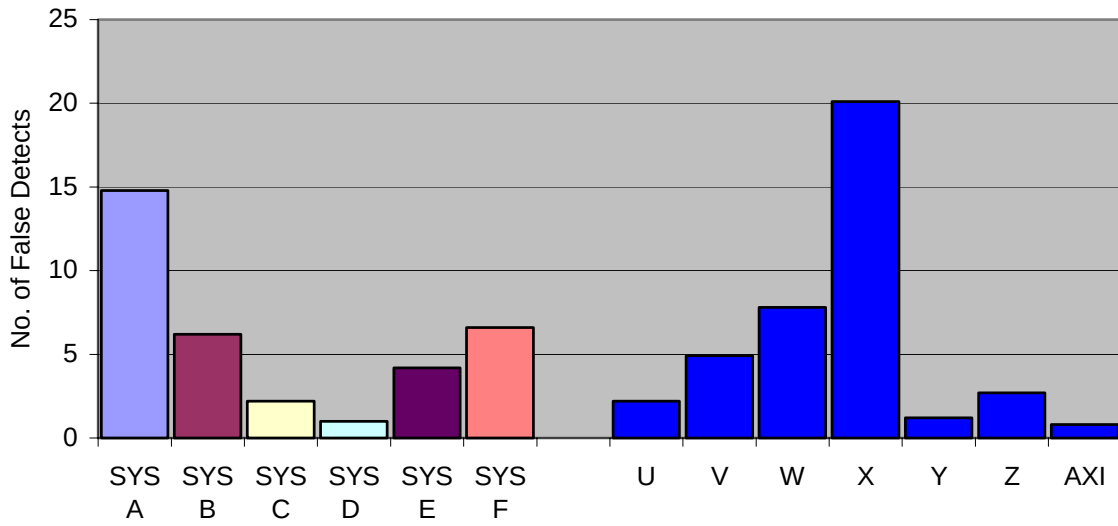


Figure 17 : Comparison of the average lead-free component false detect rates per assembly with the false detect rates from the previous SnPb project

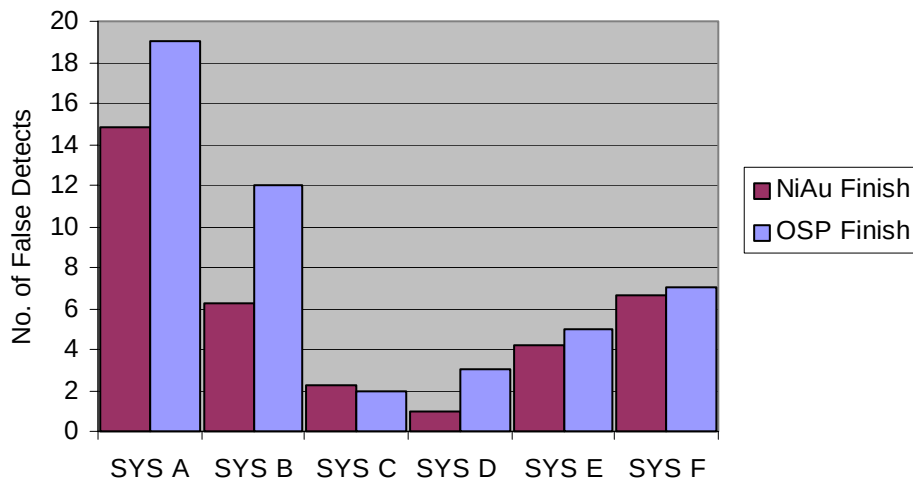


Figure 18 : Comparison of average component false detect rates per assembly for all systems for NiAu and OSP finished PCBs

6.0 CONCLUSIONS

The purpose of this project was to determine if lead-free assemblies presented any unforeseen problems when using automatic optical inspection equipment. The results detailed above clearly indicate that all the systems in this study proved capable of inspecting lead-free assemblies. In this study the same algorithms were used in programming the systems that are normally used for programming the inspection of SnPb assemblies. Algorithm thresholds may be set differently so that different programmes would be required if the same assembly were manufactured with both types of solder, but the results achieved were similar or better than for SnPb assemblies in the previous AOI benchmarking project. False detect rates were also similar for both sets of results.

Thus the overall conclusion from this work must be that automatic optical inspection of lead-free surface mount assemblies presents no more challenges than would SnPb assemblies. Indeed, current programmes developed for SnPb assemblies could be adapted to work for lead-free assemblies with some changes in the accept/reject values.

In comparing different system types (line scanner, vertical or angled camera systems), few differences could be found between the abilities of the different systems. Camera systems did generally outperform the scanner system for location of misalignments of finer pitch components (exception being QFPs). Angled camera systems did normally perform better at detecting some J-lead defects such as bridges and insufficient joints. Overall, the majority of systems did struggle in the location of excess solder joints, J-lead bridges & J-lead insufficient joints. In all defect categories at least one system achieved a high rating. The only exceptions to this were the R0603 wrong components, and SSOP insufficient solder joints.

All the systems were generally successful at locating the following types of defects :

Missing (BGA, μ BGA, C0603, R0402, R0603, SOIC, SOJ (not system F), SSOP, TSOP, SOT223, SOT23, QFP)

Misalignment (BGA, μ BGA (not line scanner), R0603, SOIC, SOJ (not system A), SSOP, SOT223, QFP)

Bridges (SOIC, SSOP, SOT223 (not system B))

Component on edge (R0402, R0603)

Wrong orientation (BGA, μ BGA, SOIC, SOJ (not system F), TSOP)

Based on the data in this report, end-users wishing to locate the following types of defect would need to choose an AOI with care :

Misalignment (C0603, R0402, TSOP, SOT23)

Bridges (SOJ, TSOP, SOT23, QFP)

Component on edge (C0603)

Excess (C0603, R0402, R0603, SOIC, SOJ, SSOP, TSOP, SOT223, SOT23, QFP)

Insufficient (C0603, R0402, R0603, SOIC, SOJ, SSOP, TSOP, SOT223, SOT23, QFP)

Inverted component (R0402)

Wrong component (C0603, SOIC, SSOP, SOT223, SOT23)

Wrong orientation (SSOP, QFP)

Compared to the results for the AOI systems benchmarked in the previous SnPb study, the systems in this study achieved a greater success rate at locating misalignments and insufficient solder joints in fine pitch QFPs, and wrong orientation in SOICs and J-leaded devices. No comparison was possible with BGAs, μ BGAs, TSOPs, SOT23s, SOT223s, R0402s and SSOPs as these were not included in the previous project.

7.0 REFERENCES :

- (1) NPL Report CMMT (A) 173 : Benchmarking Assisted and Automatic Inspection of Electronic Assemblies : M Wickham and C Hunt : June 1999
- (2) IPC-A-610 Revision C January 2000 : Acceptability of Electronic Assemblies
- (3) IEC 61191-2 : Printed board assemblies : Part 2 : Sectional specification - Requirements for surface mount soldered assemblies
- (4) IEC 61191-3 : Printed board assemblies : Part 3 : Sectional specification - Requirements for through-hole mount soldered assemblies

8.0 ACKNOWLEDGEMENTS :

The authors wish to acknowledge the following companies for their contributions to this project.

Agilent Technologies, DiagnoSYS Ltd., H K Wentworth, Machine Vision Products, Teradyne, Viscom and ViTechnology.

The work was carried out as part of a project in the MPM Programme of the UK Department of Trade and Industry.