INSPECTION OF LARGE SOLDERED JOINTS (LASOL)

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Abstract: The LASOL project comprises the development, evaluation and appraisal of a novel automated inspection system specifically designed for large area solder joints[1] (LSJ). The LASOL project started in September 1998 and is co-funded by the Commission of the European Communities, DG XII, under its Brite/EuRam Program with the Project No. BE-4689. Current inspection systems based on grayscale imaging are usually optimized for very small joints (e.g. surface mount). These systems can check for the existence of a joint but provide inadequate information on its condition or quality. The LASOL system utilizes a non-destructive method based on the Coded Light Approach to optically inspect the joint surface in three dimensions. With this method the LASOL team intends to achieve: establishment of generic relations between geometric structures and quality functions (e.g. fluid and gas tightness or mechanical strength); definition of generic rules for process control using geometric measurement data; set-up and validation of an industrial pre-competitive prototype for automated inspection of LSJ's.

Actual results of topography registration, classification and rules of quality assurance of LSJ's are presented.

Keywords: 3D Optical Measurement, Coded Light Approach, Quality Assurance, Closed Quality Control, Solder Joints, Classification, Rules

1 INITIAL SITUATION

Numerous industrial applications (e.g. heat exchangers/radiators, vehicle frames, electrical/ electronic components, food cans, chemical plants, etc.) employ large soldered joints (LSJ).[1] Other considerations (e.g. the gap is larger than is optimal to facilitate pre-assembly) often compromise the design of an LSJ. The soldering process is subject to variations of parts geometry, surface condition, environmental conditions as well as other factors. Automation is difficult and process variations result in large quantities of rejects. Quality of LSJ's is however often essential for product functionality and safety.

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A further important aspect is that LSJ's are generally produced by means of an automatic soldering process. Therefore a further important objective of the proposed project is to develop not only methods to register quality but also methods to reliably control the automatic soldering process.

2 METHOD TO REGISTER THE MANUFACTURING QUALITY OF LSJ'S

Current quality controls take place by so-called manual visual inspections. To this end an inspector assesses the manufacturing quality of the soldered joint. A technology being developed at this time is intended to replace manual visual inspection with an automatic inspection.

2.1 Objective Quality Analysis of the Soldered Joints

In a first working step, the LSJ's of two end users were subjected to an objective quality analysis in order to be able to decide when a soldered joint was qualitatively good and when qualitatively bad. To

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[1] In this paper, a large soldered joint (LSJ) is considered to be a joint with a solder covered surface >2 mm^2.

this end reference samples were made available in sufficient piece number. Table 1 shows the properties of the LSJ's tested as well as the test methods applied in the process.

Table 1. Tools to test solder joint properties.

Joint Property	**Test Tool**
Geometric Features (Surface Topography)	Optical Microscopy, SEM/EDX
Non-Geometric Features (Voids, Lack of Adhesion, Dewetting)	X-Ray, Microsectioning, SEM/EDX
Microstructure (Crack Initiation and Propagation)	X-Ray, Microsectioning, SEM/EDX
Mechanical (Strength, Creep)	Instron Mechanical Tester
Electrical (Resistance)	4 Point Probe
Fatigue Resistance	Temperature Cycling
Volume and Dimension	Optical Microscopy, SEM, X-Ray

The solder joint properties tested are geometric and non-geometric in nature. After detailed analysis of the results, it could however be proven that all known defects in solder joints manifest themselves as significant, geometric features. Consequently, the application of a measuring method to register the geometric properties of solder joints proved to be very suitable.

2.2 Measuring Method to Register the Geometry of Solder Joints

After carrying out an objective quality analysis (see chapter 2.1), a measuring method was selected and designed.

2.2.1 Measuring Method Selection

The measuring method was selected to serve the following purposes:

1. Step: Non-contact three-dimensional geometric measurement of solder joints.
2. Step: Classification of the solder joint quality.

The requirements of a measuring method are a short measuring time and a reliable registration of the solder joint surface. For this reason the possible measuring methods are curtailed. In principle, the following measuring methods are applicable: point triangulation, cross-section method, multiple line projection (fringe technique) [1]. All other methods must be ruled out.

Point triangulation is a one-dimensional measuring method. Therefore the measuring object must move in two directions if the entire surface is to be measured. This is very costly and contributes to additional inaccuracy (use of translation units). For this reason point triangulation is unsuitable for measuring solder joints.

The cross-section method is the one-dimensional extension of point triangulation. Instead of a light point, a light line is projected onto the surface of the object. To measure a two or three-dimensional surface, at least one relative motion between the object and the cross-section sensor (rotation or translation) is necessary. Each cross-section results in an ordered point cloud along each section line. This constitutes a very important advantage of this measuring method. Furthermore, owing to the relative motion, the cross-section method provides the possibility to measure the back side of the measuring object.

To reduce the necessary relative motion between the sensor and the measuring object, the multiple line projection method (fringe technique) can be applied. Owing to discontinuous differences in altitude along the surface of the object, it is possible that he fringe lines intersect (merge). Consequently, the results obtained may be ambiguous. The coded light approach resolves this problematic effect. This method makes a reliable measurement of surfaces possible. Owing to encoding of the fringes, unambiguous identification of each section line is feasible.

Both methods, the cross-section method and the coded light approach, are applied in dependence on the geometry of solder joints.

2.2.2 Application of the Method to the LASOL Project Partners' Products

The end user 1 in the LASOL project manufactures capacitors with two connectors on the top side. Figure 1 shows two LSJ's of an electrolytic capacitor. These solder joints have more or less a flatness topography, so the coded light approach was selected.

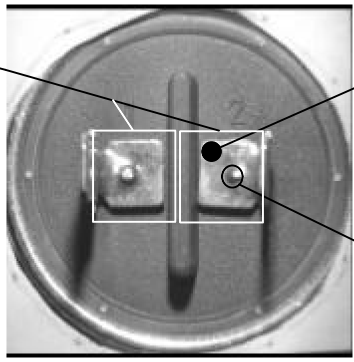

Figure 1. Picture of an elecrolytic capacitor with two soldered joints.

Measuring Principle Applied

In the conception of the measuring system for contour recognition the following process parameters must be observed:

- measuring volume:	10 x 10 x 5 mm
- measuring cycle:	approx. 10 s
- material properties:	strongly reflecting surfaces (direct reflections, reflective areas on the surface of the LSJ's)
- space for assembly:	greatly limited when integrating the measuring system in the manufacturing line

In view of the limited conditions of space and the short measuring time, it is necessary to introduce an extensive measuring procedure which dispenses with a relative motion between the measuring system and measuring object. The coded light cross-section operates according to the principle of triangulation and meets these requirements.

A projector projects sequential interference fringes into the locus of the object which are recorded by a camera. The light-dark contact surfaces in the fringes are analyzed and, together with the mathematical models of the optical properties of the projector and camera, produce the 3-D coordinates of the measuring object.

The optical model of the camera describes the image of the three-dimensional locus of the object in the image plane. For this, the TSAI procedure applied here uses the model of the central projection with six „outer" camera parameters, which describe the location of the imaging center and the orientation of the coordinate system of the camera, and 5 „inner" camera parameters (the focal length of the objective, the position of the principle point of the image, a scaling factor and a coefficient for the description of the radial distortion of the objective).

The projector projects a fixed number of linear marks into the locus of the object, which in ideal cases produce straight lines. If central projection is used as the basis, the straight lines become planar surfaces (light planes). This relatively simple implementation does not however allow modeling of imaging errors such as most particularly serious symmetrically radiating distortions. In order to minimize such error causing influences, a quadratic approach was selected to describe the projected light areas.

The intersection of a imaging beam of the camera with the light area which belongs to it leads to the sought-after 3-D coordinates of the object.

The coding of the illumination resolves the correspondence problem between the light area and the imaging beam. This technique, often designated space-time coding of the measuring locus, projects n light-dark interference fringes one after another, which, in accordance with the Gray code, are based on a one-step binary code.

These light fringes (see projection planes in Figure 2) are projected one after another into the measuring locus and each recorded in a camera picture. Each of these fringes corresponds with a digit plane in the n-digit Gray code.

The high measuring speed is a great advantage. If in normal light sections for n lines n pictures are still necessary, then it is only log2(n) here. As a result the video speed is, in the case of 128 lines for example, larger by the factor 18.3 when the light section is coded [2].

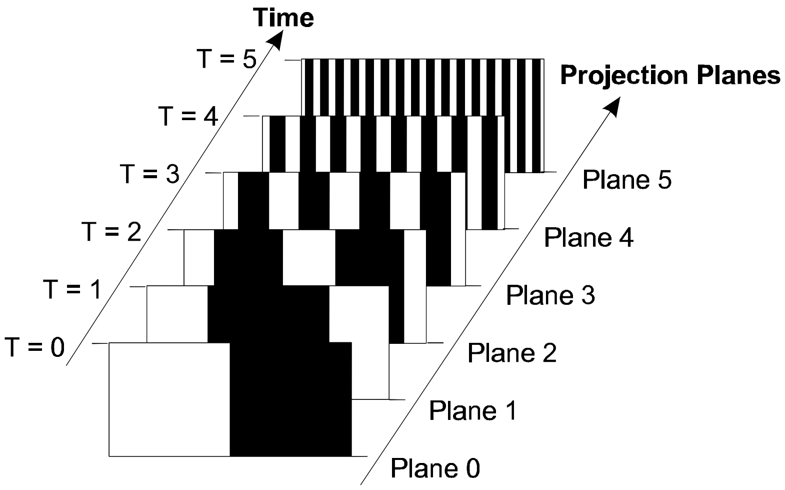

Figure 2. Sequence of 6 projection planes coded with the Gray code.

Sensor Design

As can be seen in Figure 3, the sensor consists of a camera as well as a fringe projector. Both are mounted at an angle of approx. 35° to each other. This angle corresponds with an optimum corresponding with the necessary measuring accuracy as well as the achievable robustness. After the first test measurements, the reflective areas which appear turned out to be problematic. The different reflections appear as a function of the surface gradient. Even with an adjusted lens stop aperture or brightness control of the projector these reflections cannot be reduced. Only the utilization of a CMOS cameras could put things right. The components employed are described in detail below.
Figure 3 illustrates the principle behind the experimental set-up realized.

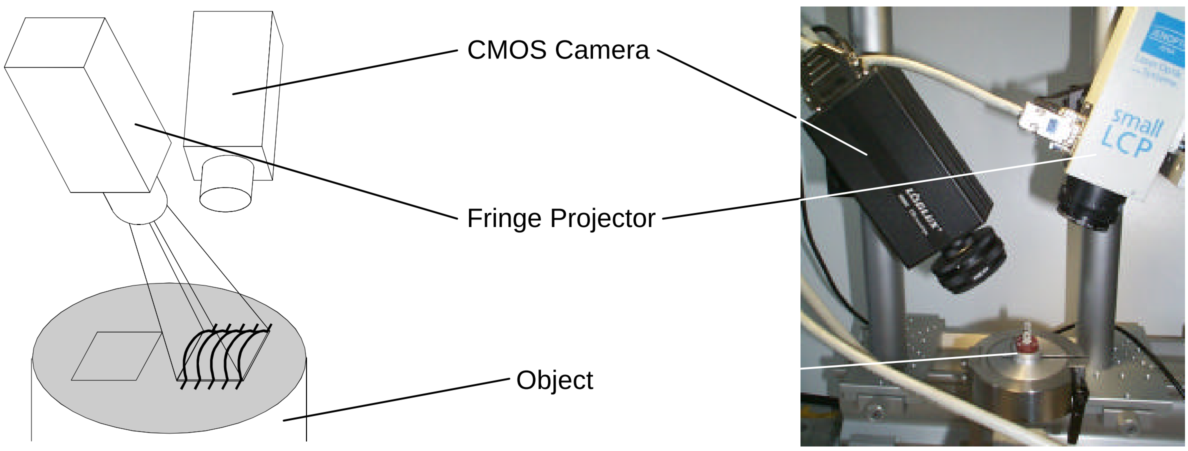

Figure 3. Experimental set-up for applying the coded light approach.

CMOS Camera

Compared with well known CCD technology, CMOS cameras provide considerable advantages, for example:

- high speed readout,
- high dynamic range of $1:10^6$,
- high signal-to-noise-ratio (SNR),
- array size scalability,
- process can be prototyped.

Pixel allaising and saturation behavior could be minimized on the basis of the very high dynamic range of $1:10^6$ and the ensuing logarithmic characteristic of the CMOS sensor. Figure 4 shows the images of the Gray code using a CMOS camera. Up to 30% more measuring points could be analyzed. As a result the overall measuring process could be stabilized [3].

Fringe Projector

In view of the necessary very small measuring field, a projector had to be found or, to be precise, developed which projects a field of approx. 15 x 15 mm. Distorting reflections, that is the adjustment of the triangulation angle, presuppose that which the camera permits a brightness control. For this, the firm Jenoptik provides a projector LCP-Small which was used in this project [4].

This fringe projector can project 160 lines on a surface of 10.9 x 10.9 mm^2 which can be controlled individually and can be electronically rotated 90°.

The core component of the projector is a TN-LCD, a twist nematic liquid crystal display, the advantages of which are the high contrast readings and the most extensive wave length independence of the electro-optical characteristics. That means that one can remain independent of the type of illumination and as a result various light sources can be utilized. A cold light source which permits a brightness control proved ideal.

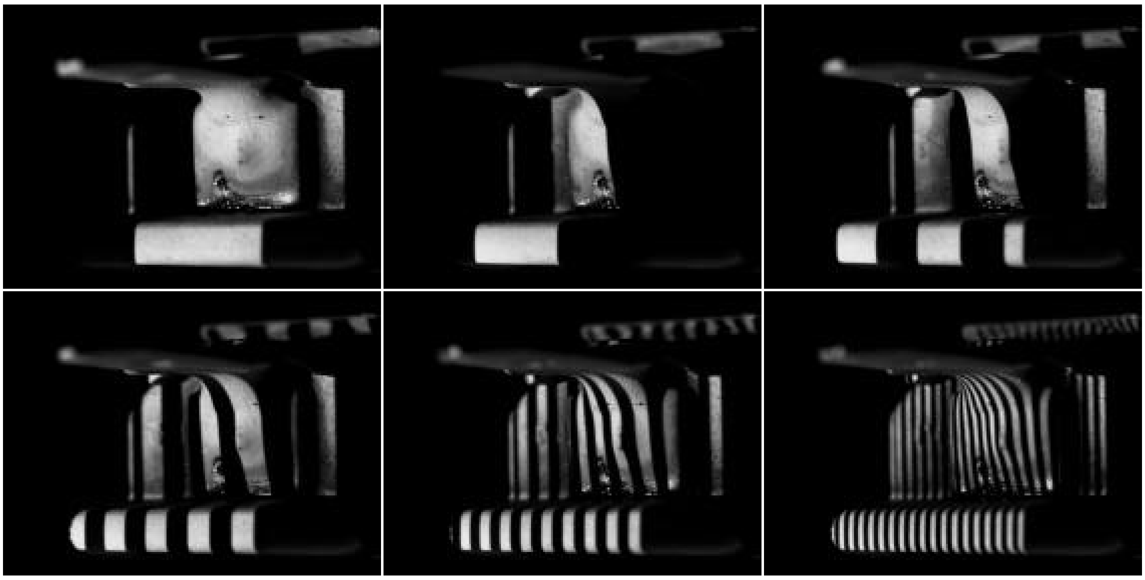

Figure 4. Projected light fringes coded with the Gray code.

The light and dark fringes are easily recognizable in the pictures and interpretable by means of image processing.

2.3 Classification

Around 1500 measuring points are digitalized on the surface of the solder joints. An interpretation of the measuring points by comparison and classification into various surface forms in 3-D space has to be developed. Figure 5 shows the measuring pictures of a soldered joint surface.

A compromise had to be found between a rapid interpretation as well as a very certain interpretation. To this end, in comparison with a „normal surface“, only the maximal and the average height as well as the volume of the solder joints are calculated in 3-D space. As a further criterion for the quality of the soldered joints, individual cross-sections are calculated from the Gray code and their forms evaluated (see Figure 6). Excellent results are achieved using this process. In the first test series an error rate of only 3% could be ascertained.

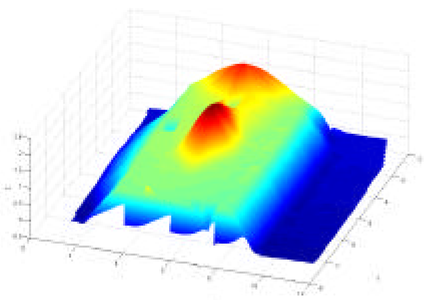

Figure 5. Three-dimensional topography of an LSJ with the connecting wire in the middle.

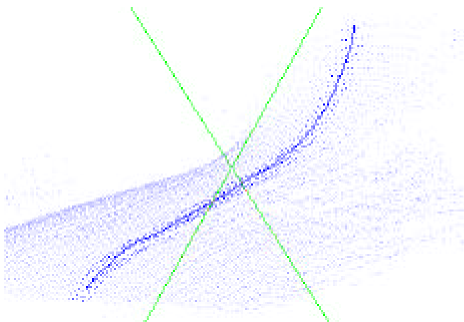

Figure 6. 3D point cloud of the LSJ as well as the contour line produced by a planar cross-section.

For the calculation and comparison of the solder joint describing parameters, the following procedure was choosen:

1. Transformation of the measured 3D point cloud: For the transformation the level of the capacitor cup was used as a base level. The first and last point from one section and one more point from another section sets the three points B1,B2,B3 of the base level B. The vectors from the point B1 to the points B2 and B3 are used to calculate the normal vector of the level B. The angel between the normal vector nb and the axe Z is calculated and used for the calculation in the transformation matrix RO. All points of the point cloud are then transformed under the equation: Point' = RO * Point.
2. Curve fitting: Cause our data in the point cloud are determined experimentally, it is possible that the data contains errors, "noise". It is appropriate to use the curve fitting, which smooths the data.
3. Polynomial Approximation: Calculation of the coefficients of an polynomial function.
   Best Fit: For the recognition of the correct solder joint is used the method of the best fit. There are two steps in the method: preparation and realization.

A) Preparation: Data of the ideal joint-ideal PCloud

BEST FIT on the ideal fuction

Finding the ideal PARAMETERS of the ideal fit function (correct joint)

B) Realization: Real data

Evaluating of data by comparing of real parameters with the ideal parameters

3 RESULTS ACHIEVED

Actually an integration of the measuring set-up in the manufacturing line will be prepared. Series of measurements will take, to train the classifying parameters. The following working step is the definition of generic rules for process control of the automatic soldering process using geometric measurement data. Further applications within the project consortium will be implemented within this year.

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