

Toolbox for 3D Acoustic Imaging of Manufactured Electronic Circuits

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Abstract

A signal processing toolbox has been realized to enhance the acoustic signal processing of manufactured electronic systems. The toolbox contains a range of signal processing algorithms to help better differentiate the 3D scanned acoustic signals acquired from manufactured parts. The processing has been used to assess the through-life reliability of systems by non-destructively sampling systems during extended reliability tests.

The algorithms are based on a variety of novel signal processing methods such as wavelet, time frequency domain imaging, dictionaries and Fast Fourier Transform (FFT) for comparison. The paper will explore how the various algorithms can be tuned to test samples using the designed toolbox. The toolbox has a graphical user interface (GUI) designed in MATLAB. It can control the processing and display of 3D image data “cubes” acquired from an array of A-Scans of a sample obtained by an acoustic microscope. In this case a Sonoscan Gen6 C-SAM acoustic microscope has been used, but if the data format is known the toolbox can be applied to any 3D cube of data. The data sizes can be large, so processing times can be of the order of minutes for 1k x 1k x 1k array. Recently the execution times have been speeded up considerably by employing parallel algorithms and multicore processing. Some routines now only take seconds which is a very significant speed-up.

Introduction

The rapidly decreasing size of electronic devices and constant increase in components within a device has made non-destructive evaluation of electronics even more challenging. Acoustic Micro Imaging (AMI) [1][2] is a non-destructive evaluation technique used to detect faults in objects. The objects under test are acoustically scanned using Scanning Acoustic Microscopy (SAM) [3] to obtain 1D or 2D acoustic images of the test object. Sonoscan Gen6 C-SAM acoustic microscope is one such microscope and has been used to obtain the acoustic images in this paper. However, it cannot produce 3D images directly. The toolbox has been developed for nondestructive evaluation of electronics in 3D using the data obtained from the 1D and 2D acoustic scans.

Ultrasound and Acoustic Micro Imaging basics

Ultrasound is an elastic sound wave that propagates mainly through solids and liquids at frequencies above 20 kHz. It cannot propagate through a vacuum.

Acoustic Micro Imaging or AMI uses high frequency ultrasound (typically >10MHz) to look inside objects, detect defects, characterise material properties and changes. The ultrasound pulse for AMI is created using

piezoelectric transducers. The pulse is reflected, scattered, absorbed or blocked by the flaws present in the material differently as compared to the surrounding material. The reflected pulses are captured by the same transducer thereby resulting in a set of echoes. In AMI, A-Scan is an oscilloscope display of the signal (echoes) received by the transducer. Ultrasonic echoes detected earlier in time occur at the beginning of the trace and those occurring later are shown to the further right. Depending on the polarity and amplitude of the signals in an A-Scan the characteristics of the materials can be determined. Figure 1 shows a typical A-Scan.

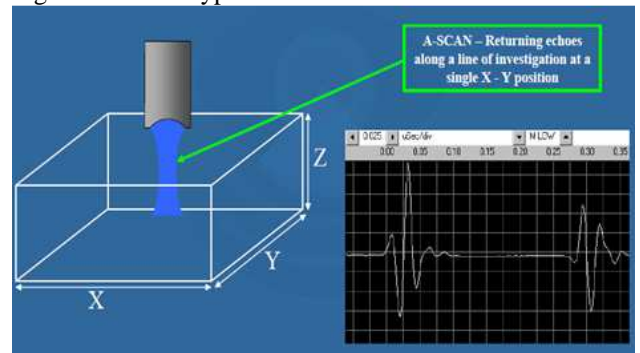


Figure 1: A typical A-Scan showing echoes along a line of investigation at a single X-Y position (left) along with the oscilloscope display (right). (Courtesy of Sonoscan)

Gate is an electronic ‘window’ that helps to select which segment/echo on an A-scan will be imaged. It allows us to create separate top surface, interface and back surface images as shown in figure 2.

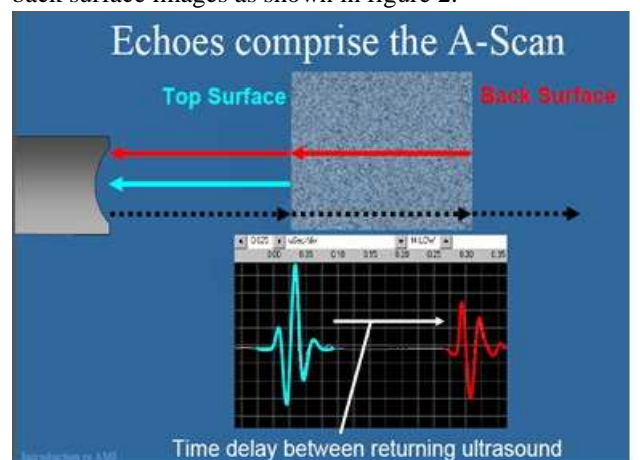


Figure 2: Echoes reflected from the top, interface and back surface of an object as seen in an A-Scan. (Courtesy of Sonoscan)

A C-scan is a 2D data representation applied to the pulse-echo technique of ultrasonic detection that produces a plane view of the specimen. Each C-scan image provides information at a pre-selected depth. C-scan of a flip chip is shown in figure 3.

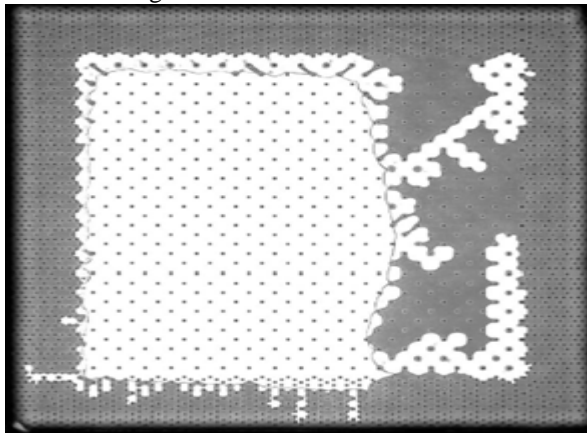


Figure 4: C-Scan of a flip chip obtained using the toolbox.

The Toolbox

The toolbox also known as ‘Acoustic Time Frequency Domain Imaging’ has an easy to use GUI designed in MATLAB to test image processing algorithms like FFT and Matching Pursuit (MP) on the data collected from the acoustic images of manufactured electronic parts. In order to use the GUI, one should have a good understanding of the ultrasonic/acoustic imaging basics as well as the image processing techniques. In this paper, the working of toolbox will be explained using acoustic scans of a faulty flip chip and an embedded QFN package. A Sonoscan Gen6 C-SAM acoustic microscope was used to obtain the scans as shown in figure 4. These images have a file extension .SWD that can be directly opened using the toolbox.



Figure 4: Sonoscan Gen6 C-SAM acoustic microscope setup. (Courtesy of Sonoscan)

Figure 5 shows the toolbox. As can be seen it is a GUI designed in MATLAB and hence familiarity with MATLAB is desirable to efficiently operate it. To run the toolbox, MATLAB version 2010 or higher with the parallel computing toolbox is needed. It can operate in Windows(32 or 64bit), Mac OS(64 bit) or Linux(64 bit)

systems with a multicore processor for parallel computing. It uses an NVIDIA Graphical Processing Unit (GPU) with a computation ability of 2.0 or higher. MATLAB does not support AMD or INTEL GPUs at this time. As can be seen on figure 5, the toolbox consists of 4 windows that show the show A-scan, C-Scan, algorithm tuning using time-frequency selection and final output after image processing corresponding to the file accessed. The toolbox has many buttons designed around the windows for user interface and processing parameter selection.

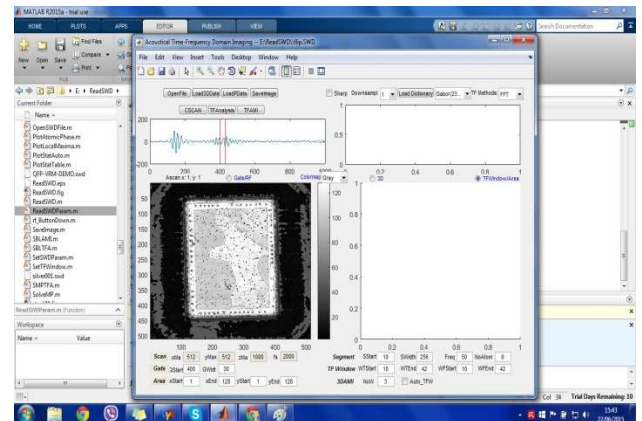


Figure 5: The toolbox in MATLAB showing the A-scan (top left), C-scan (bottom left) of a flip chip, window for algorithm selection (top right) and final output (bottom right).

The perpendicular red lines on the A-Scan window represent the gate position. These lines can be adjusted manually or by inserting the X-Y positions of the gate in the boxes provided for the ‘Gate’ button in the toolbox. Once the gate position has been determined the C-Scan of the image can be generated by pressing the ‘CScan’ button of the toolbox at a preselected depth provided by the user. In addition to the grey scale, the toolbox also has other colour maps that can be chosen from the drop down of the ‘Colormap’ button. Figure 6 shows the toolbox using ‘JET’ colourmap

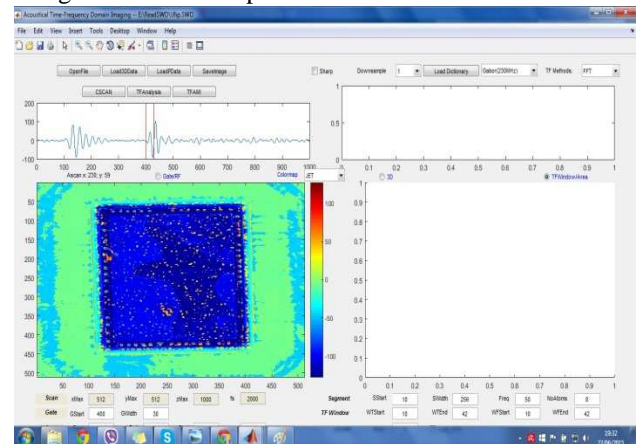


Figure 6: The toolbox in MATLAB showing the A-scan(top left), C-scan(bottom left) of a flip chip, window for algorithm selection(top right) and final output(bottom right) in ‘JET’ colourscheme.

Once the C-scan of the flip chip is obtained, the toolbox can be used to apply FFT [4] and MP [5] image processing algorithms to the C-Scan and generate 2D and 3D images of the object under test. Image processing is the process of analysis and manipulation of an image done in order to improve its quality and extract relevant information from it.

FFT [4] is an important image processing tool used to decompose any image into real and imaginary components thereby converting the image into frequency domain. For the processed image, the number of frequencies in the frequency domain is equal to the number of pixels in the image domain. To implement the FFT algorithm the maximum frequency for sampling and its amplitude is needed. It is used for noise removal, pattern/texture recognition and filtering of the image. To generate the FFT of an image using the toolbox, the FFT option needs to be selected from the 'TFMethod' drop down menu. Then 'TFAnalysis' button needs to be pressed which generates a time-amplitude signal at the top right window. This step also generates a replica of the C-Scan image in the bottom right window. After selecting the required time and amplitude values, the area on which the FFT needs to be computed needs to be selected from the replicated image in the bottom right window. The FFT can then be generated by pressing the 'TFAMI' button. The output image replaces the replicated image in the bottom right window and a pop-up window will appear that will let you save the output image. Figure 7 shows the FFT of the faulty flip chip under test. As can be seen from the figure, the FFT of the flip chip shows the faulty areas (white areas) more prominently.

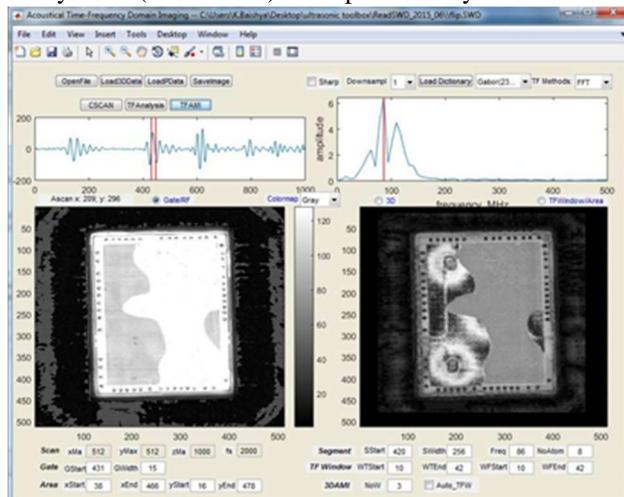


Figure 7: FFT of the faulty flip chip

Matching Pursuit (MP) is a novel wavelet based image processing technique. One of the most crucial problems in image analysis is to construct efficient low-level representations of its features like edges and texture. So the different types of image features were modelled into a very redundant family of 2D wavelets (also known as atoms) collectively known as the Gabor dictionary [3]. This Gabor dictionary describes the local properties of the image like localisation, scale, preferred orientation, amplitude and phase of discontinuity. The dictionary is

very large in size, normally in the gigabytes range. Instead of decomposing a given image over the whole set of Gabor functions, MP is used. MP selects the Gabor elements corresponding to the main features of the image to give the best approximation of the given image. The resultant image is a compact representation, with fewer features that still reveal the local properties. Similar to FFT, to generate the 2D or 3D MP [6] of an image using the toolbox, the MP option needs to be selected from the 'TFMethod' drop down menu. Next the relevant Gabor dictionary needed for MP computation needs to be loaded by selecting the appropriate dictionary from the drop down menu of the 'Load Dictionary' button at the top right hand corner of the toolbox. Then 'TFAnalysis' button needs to be pressed that loads the relevant frequency-time window in the top right window along with a replica of the C-Scan image in the bottom right window. For 2D MP the frequency-time at which to compute the MP needs to be selected from the frequency-time window. The values 'WTStart', 'WTEnd', 'WFStart', and 'WFEnd' under the button 'TFWindow' of the toolbox will indicate the frequency time values of the selected window. These values can also be updated manually. For 3D MP, a minimum of 3 time-frequency values need to be selected. The MP can then be generated by pressing the 'TFAMI' button. The output image replaces the replicated image in the bottom right window and a pop-up window will appear that will let you save the output image. Figure 8 shows the 2D MP of a faulty embedded QFN package under test. Figure 9 shows the 3D image of the same package.

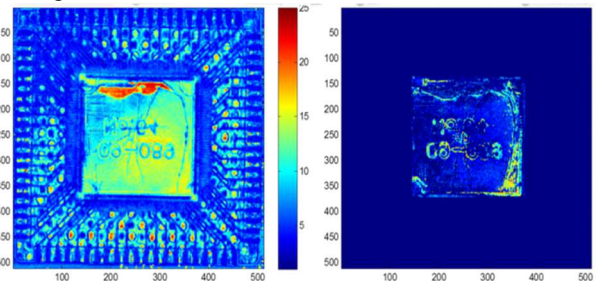


Figure 8: 2D MP of an embedded QFN package

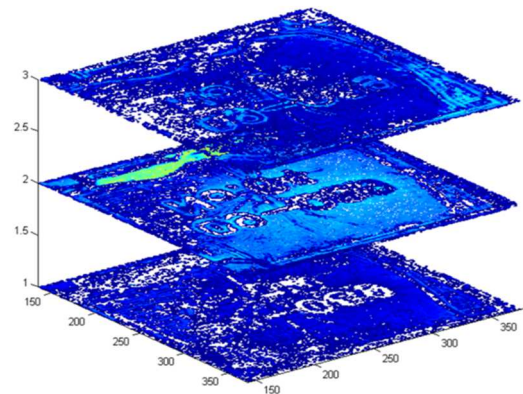


Figure 9: 3D MP of an embedded QFN package

As can be seen from figure 8, the 2D MP of the QFN package shows the faulty areas represented by the white,

yellow and green areas. In Figure 9, the exact layer viz. layer 2 where delamination has occurred has been detected. Each layer in the 3D image represents an interface within the test object. This is despite overlapping acoustic signals that have effectively been unravelled by the MP algorithm.

Conclusions

A toolbox for applying different image processing algorithms to obtain 3D images of 1D and 2D acoustic scans has been presented in this paper. This is a completely new approach towards 3D acoustic imaging of electronic devices using image processing algorithms. The toolbox, which is controlled by a GUI developed in MATLAB, has been successfully used able to implement novel algorithms on acquired acoustic images to obtain product information in 3D.

The results show that given an acoustic image, the toolbox can be used to process it to generate 3D scans which in turn, help to identify any defects or abnormalities in the object under test. It was found that defects that were otherwise unclear in acoustic scans became more easily detectable when processed by the toolbox.

Although in this paper only electronic devices have been used to demonstrate the efficiency of the toolbox, its usage can be extended to any object or device that can be acoustically scanned. Also the toolbox can be further edited to incorporate a number of additional signal processing algorithms without altering its other functions. This serves as a huge advantage since it can be modified to the user's convenience and interest. Depending on the data size, processing times vary. Since the toolbox uses parallel processing for execution the processing time is faster compared to serial execution thus making the system more productive.

Acknowledgments

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