Ultrasound Image Processing

SBI102 - ICT in the Clinical Environment

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Introduction

The University College London Hospitals (UCLH) Scientific Computing department supports the informatics infrastructure of the wider Medical Physics team. This includes quality assurance testing for medical devices, most commonly ultrasound equipment. This service is critical to the safe use of medical devices and is provided to internal and external clients. The function of an ultrasound transducer is expected to decrease over time as a result of continued use. Transducer errors can include delamination, cable breaks, short circuiting and weak or dead elements, all of which can contribute to misdiagnoses in clinical practice where sonographers are unable to identify defective transducers (Martensson et al., 2009). Within UCLH Medical Physics, a strategy was developed to assess transducer efficiency using the reverberation patterns of air molecules subject to the ultrasound projections. This method of transducer quality assessment using these patterns has previously been recommended by IPEM (2010). The need for image processing software was identified within the department, whereby the intensity values of the ultrasound images could be used to identify weak or dead elements in the transducers. This document outlines the development and completion of image processing software for this purpose.

Functional Requirements

To document the functional expectation of the computing software, requirements were gathered from a lead clinical scientist within the department. The completed image processing software should be able to:

- Read an ultrasound image in JPEG or DICOM format as an array of values.
- Extract the ultrasound reverberation pattern from the image, without auxiliary information such as the manufacturer details
- Analyse the image in consistent segments and record the intensity values in each segment across the reverberation pattern
- Produce a plot of the ultrasound intensities summarised by a common metric

Non-functional (technical) requirements

In order to integrate with the current computing infrastructure, the following technical requirements must be met by the software:

- Provide a command line interface for automation and integration with existing scripts
- Use the OpenCV library for image processing for efficiency and to allow future portability
- Provide plots in and original data in a logical output directory structure, the root of which can be optionally specified by the user on the command line

Use Case

This software is designed for routine quality assurance of ultrasound equipment. The typical use case would follow the receipt of an ultrasound image from the sonographer, whereby the image processing software will produce plots for the image to be viewed by a clinical scientist and assessed for significant damage to the elements on the ultrasound transducer.

Software Implementation

The software was written in Python (**Appendix A**) and utilises the OpenCV image processing library as defined in the requirements gathering process. Previous studies have measured transducer sensitivity using grey level profile down the central axial line of the reverberation image or by measuring the depth of the last reverberation band (Quinn and Verma, 2014). A similar technique was used here, where the intensity values in images produced from curved arrays were read in radial increments starting from the edge-line. The values produced by ‘sweeping’ across the image provided source data for the plots produced.

QA test images were provided by the medical physics department, originating from ultrasound machines manufactured by two different vendors (Figure 1). The first step was to isolate the reverberation pattern from the images, identifiable by the curved band in the center of the images.

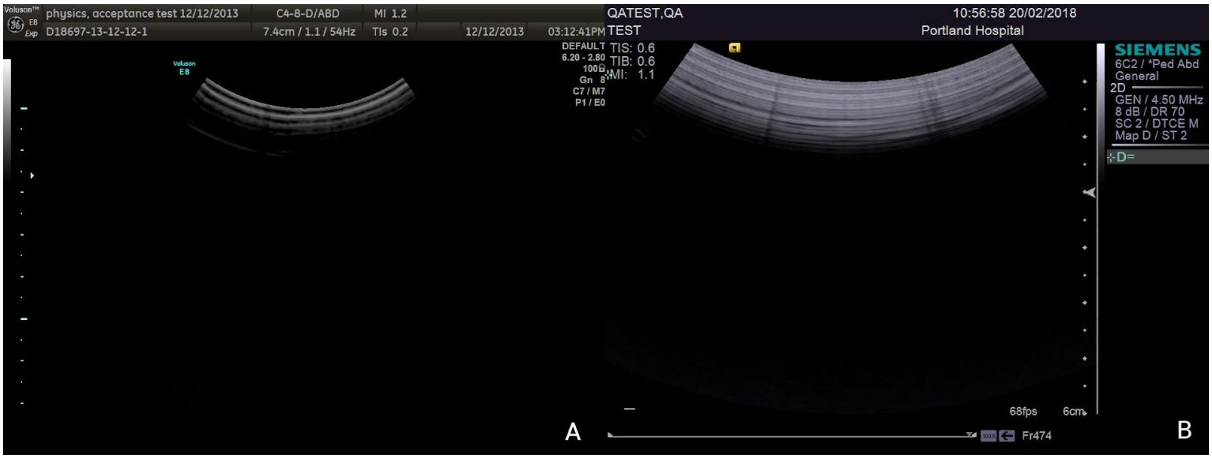

Figure 1: Ultrasound in-air reverberation images produced by Voluson (A) and Siemens (B) vendors.

In general, segmentation is the name given to the image processing technique of isolating objects from an image and is essential when the group of pixels that make up the object are not known beforehand. The classical technique for performing this is thresholding, where values below a selected intensity threshold are reduced to 0 and those above are given the maximum value, producing a binary representation in image histograms (Russ, 2016). For this process, the image must be loaded in grayscale, reducing the pixel array from three dimensions (Red, Blue and Green) to one. Selection of the threshold is crucial, as several segmentation methods rely on a high-contrast edge between objects. In this program, **Otsu’s binarization algorithm** was used to automate the selection of the maximal threshold from the data (Russ, 2016), the after-effects of which can be seen in Figure 2. Gaussian blurring and histogram equalisation was used to spread and amplify the pixel values to produce a more bimodal histogram for improved thresholding (Figure 3).

Figure 2: Ultrasound image with thresholding applied at an intensity selected using Otsu's binarization

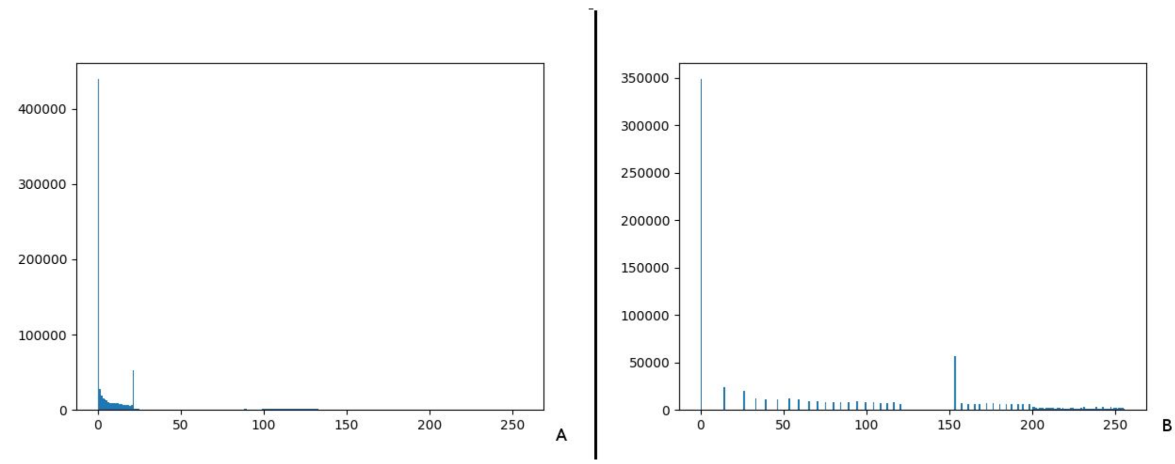

Figure 3: A. Histogram of grayscale tonal values in the raw ultrasound JPEG image. B. Histogram of grayscale tonal values in the ultrasound image with Gaussian Blurring and Histogram Equalisation applied.

From the binary image, the pixels containing ultrasound reverberation pattern are extracted using the OpenCV findContours' module (OpenCV Dev Team, 2018) which identifies contours in binary images using the algorithm presented by Suzuki (1985). After an assessment using the test ultrasound images, the contour containing the reverberation pattern was selected for based on one of the following conditions:

- A contour area of >200,000 units. This indicates a large, clean reverberation pattern that occupies approximately 75% of the image field.
- The first contour with an aspect ratio between 2 and 5. In test images, the appropriate contour displayed an average aspect ratio of 3.33, which formed a consistent quantitative shape descriptor regardless of the reverberation pattern size.

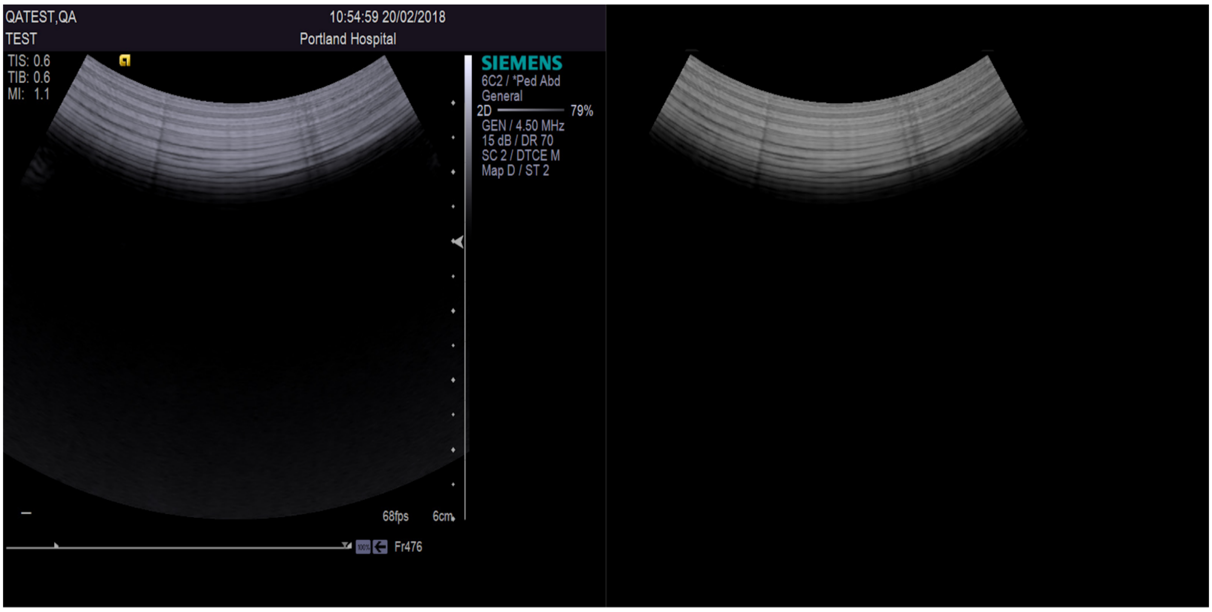

Figure 4. LEFT: Raw ultrasound image captured from vendor for quality control assessment. RIGHT: Ultrasound in-air reverberation pattern masked from vendor image using thresholding and contour detection.

The resulting contour is provided as a vector of coordinates and is used to mask the reverberation pattern from the original image (Figure 4), completing the segmentation process. The pixel intensities in the reverberation pattern are then read from the masked image. Figure 5 outlines this procedure which results in an array of tonal values, read from the left edge of the pattern to the right in increments of 0.04 rads. A final chart of the average intensities across each line is produced by the software for assessment by a clinical scientist (Figure 6).

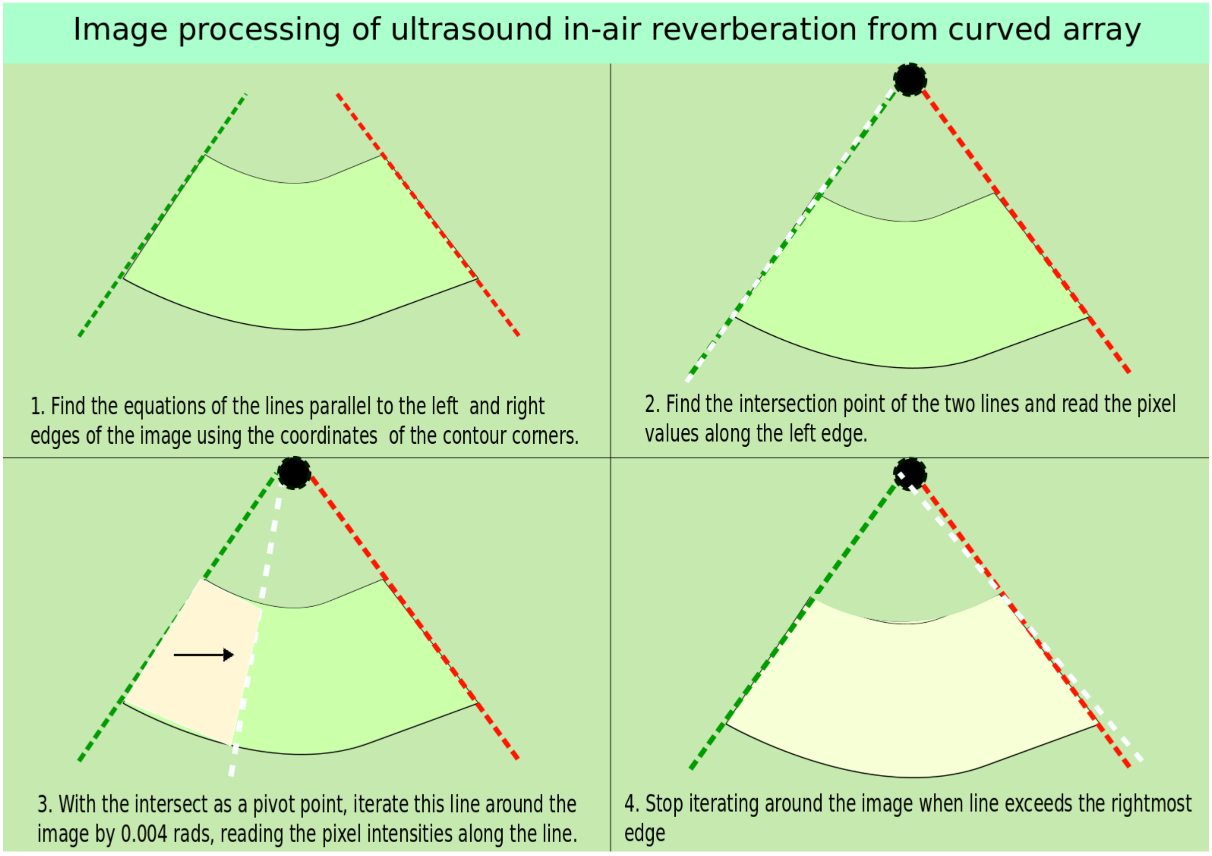

Figure 5. Protocol for reading pixel values from the curved ultrasound array.

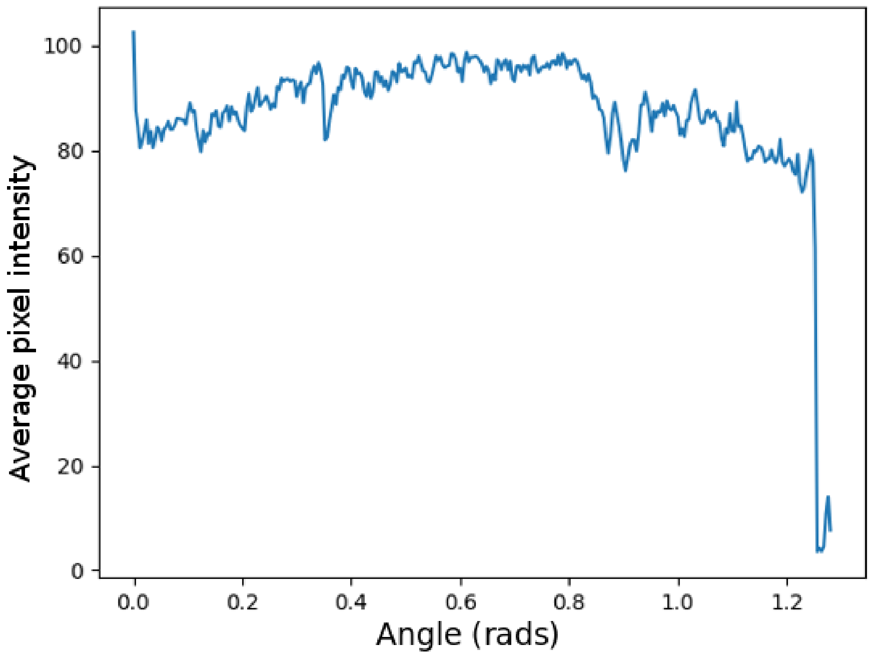

Figure 6. Average grayscale pixel intensity values across the ultrasound reverb image. Intensity values are recorded along a line parallel to the left edge of the image in increasing increments of 0.04 rads.

Limitations

The software meets the functional and technical criteria outlined in at the project's conception, however there are limitations that may be improved in future versions. Firstly, the software is limited by the orientation of the reverberation pattern, which is expected to 'fan-out' downwards as presented in the test images. When reading the output image to assess quality, the clinical scientist would benefit from a guideline or threshold as a visual indicator of regions with low average intensity. Finally, the option to silence specific output files from the command line would allow users to limit outputs to only those required.

Conclusion

This use of this software improves patient care by affording earlier detection of ultrasound equipment that is not fit for purpose. This aids compliance with governance such as the EU medical devices directive (EMDD), which harmonises the use of medical devices in healthcare across the EU to ensure patients safety and standards of care (European Union, 2017). In the UK these directives are assessed through audits by independent regulators such as the Care and Quality Commission (Care Quality Commision, 2018). Quality assurance testing of medical devices is required to demonstrate compliance with the EMDD. The ability to record and document the maintenance, quality control and management of faults is an essential for ultrasound equipment to reliably be used for clinical diagnostics (Russell, 2014). This program supports the maintenance process by providing quantitative evidence of the equipment function from the in-air reverberation patterns.

Appendix A:

UltrasoundReverbQC.py - Python module for reading ultrasound reverb quality control (URQC)

URQC_repository - Public github repository containing all code and tests for URQC

Urqc.zip - A zip file containing the code and tests for URQC

The program produces a series of output data files for each input image, where 'prefix' is the input file prefix for each image if no output prefix is given on the command line:

- prefix_urqc_img.png (The image used for contour and analysis)
- prefix_urqc_avgs.png (The chart of the average intensity)
- prefix_urqc_avgs.csv (The data used to produce the average intensity)
- prefix_urqc_data.csv (The raw intensities read across the masked image)

References

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