(U) Automated SNR Search to Support an Audit

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(U) Abstract: In this paper, we describe how we used MATLAB® to measure the signal to noise ratio in a stack of radiographs of M1 shells. We created a MATLAB® program that converted each image into a matrix of gray values corresponding to each pixel. Using the techniques of a previous technical report, we identified three regions of interest dictated by military specifications. We then recorded statistics associated with each region. The program successfully recorded the average and maximum SNR of each of the three regions of interest. Our methodology allows for more audits to be performed of our production facilities. It also allows for more objectivity when assessing image quality. Finally, the techniques described here allow for potential critical escapes to be quickly identified and brought to the attention of Level 3 radiographers and program managers.

(U) Research Innovation and Objective(s): Our research allowed us to partially automate a production facility audit. By running the submitted images through our SNR search tool, we are able to expedite the preliminary portion of the image audit considerably. The signal to noise ratio is one of the metrics in determining image quality. Radiographs are to possess a certain image quality before any subsequent analysis can be performed.

(U) Impacts on Warfighter Mission: Increasing the speed, accuracy and repeatability of measurements is critical to delivering the best product to the warfighter. Running diagnostics like the one described in this paper allows for more audits to be performed and more importantly, to remove aspects of subjectivity from radiographic interpretation.

(U) Keywords: Automatic Defect Recognition (ADR), SNR, SNR Search, Image Quality, MATLAB®, IQI, Non-Destructive Testing, Radiography

1. (U) Introduction

(U) Radiographic testing is a non destructive testing technique which allows for the detection of subsurface flaws. [1] An important metric in qualifying image quality is the signal to noise ratio, (SNR). An SNR search algorithm has been previously constructed and tested in MATLAB®. We reference and use this algorithm in gathering the SNR statistics on a large dataset. We present the methodology and results below.

2. (U) Method

2.1 (U) Theory

(U) The signal to noise ratio is simply defined as the ratio of the mean to the standard deviation of a signal.

$$SNR = \frac{\mu}{\sigma}$$

For digital radiography, μ is the mean grey value for a given region of interest and σ is the standard deviation of the distribution of grey values for a given region of interest. Qualitatively, the higher the SNR, the higher the image quality. However, an SNR that is too large may indicate little to no attenuation. For 2% sensitivity applications, the SNR should be 130 or higher. [2]

The minimum size of the rectangular region of interest for evaluation of the SNR is 1100 pixels , 20 x 55 per ASTM 2737. [2] Per requirements, SNR should be measured in a homogenous area, near the IQI, or image quality indictator.

(U) “Pixel hunting” is a colloquial term whereby radiographers form a 20x55 box per ASTM and “hunt” around the region of interest till the requirement of 130 has been achieved. While this is the method currently employed by radiographers across the industrial base, it is our belief that while this method can work, it is imprecise and less quantitative than one can achieve with today's technology.

(U) It is the central theme of this paper to remove bias and subjectivity from the SNR reporting process. We introduce two methods of SNR statistical reporting. Building upon an algorithm previously constructed [3], we set out to apply this algorithm to a dataset consisting M1 shells.

2.2 (U) Algorithm

The algorithm of our program is based upon a previously constructed MATLAB® code. We refer the interested reader to the discussion of the algorithm in this technical paper. [3]

For the M1 shells, three image quality indicators, or IQI's are placed on the shell body. Figure 1 shows the setup for radiographic inspection.

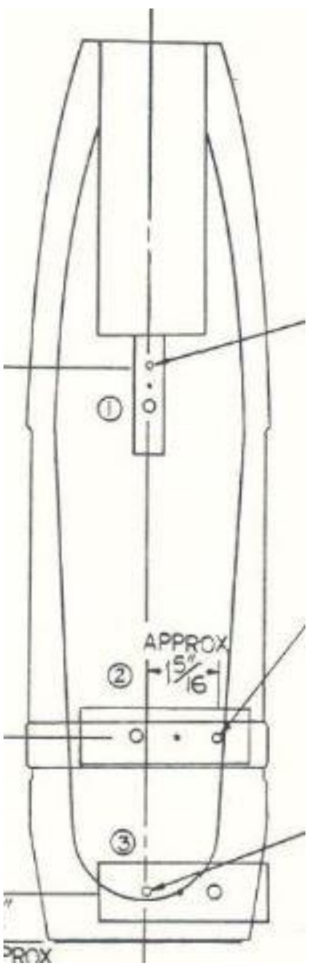

Figure (1) Drawing of IQI placement for an M1 shell [4]

(U) Due to ambiguity of requirements per ASTM 2737, we needed to define the three regions of interest submatrices around the IQI's for measurement of SNR statistics. It is important to note that while the choice of the exact size of these regions was chosen arbitrarily, once chosen, the computer can then standardize the SNR search across the entire image stack. This allows for repeatability in measurement, and allows for a better chacterization of image quality. This is a considerable advantage of our algorithm over SNR "pixel hunting" that was described earlier.

In figure [2] below, we show the regions of interest that were used on an M1 radiograph.

Figure (2) Depicted is a radiograph of an M1 shell. The rectangular regions are the regions of interest submatrices near the IQI placement

Once the regions of interest are defined, a 20x55 sized SNR search box per ASTM 2737, scans each region and records the maximum SNR and average SNR over the entire region of interest. See figure [3] below.

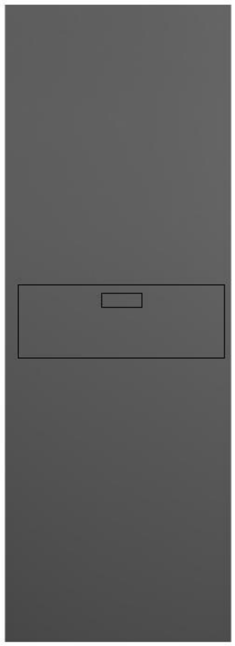

Figure 3. Two rectangles. The larger rectangle defines the region of interest submatrix, and the smaller rectangle shows the SNR box for which the SNR is a maximum.

(U) Before we run our program over the entire image stack, we thought it would be instructive to demonstrate the program on one radiograph.

(U) Let us define regions according to the military specifications. Figure 4 contains a drawing with the segmentation of an M1 shell. Figures 1 and 4 reveal where the IQI's are to be placed. One IQI is to be placed in Segment C, one in Segment B and the last in Segment A.

(U) We start with segment C. Using the region of interest submatrices shown in figure (2) our program calculated the average SNR of this region to be 329. The maximum SNR was found to be 824. Both of these values exceed the requirement of 130 per ASTM 2737.

(U) Next we calculate the SNR statistics in the region of interest submatrix in segment B. Our program calculated the average SNR of this region to be 291. The maximum SNR was found to be 412. Both of these values exceed the requirement of 130 per ASTM 2737. Figure 5, shows the region of interest submatrix as well as the location of the greatest SNR measured.

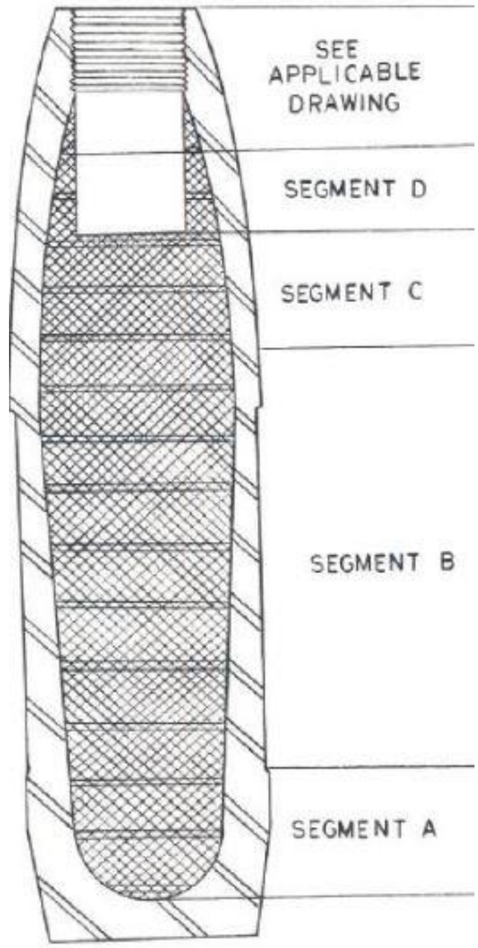

Figure (4). Segments of an M1 Shell. [4]

(U) Using the algorithm described in a previous paper, [3], we can further characterize the SNR metrics in this region. The minimum SNR in this region was found to be 151. A histogram of the SNR Search over the entire region of interest is shown in figure (6).

(U) Lastly, we calculate SNR statistics in the region of interest submatrix in segment A. The average SNR of this region was calculated to be 417. The maximum SNR in this region was calculated to be 682.

Figure (5). Segments B of an M1 Shell containing the Region of Interest Submatrix and the location of the greatest SNR.

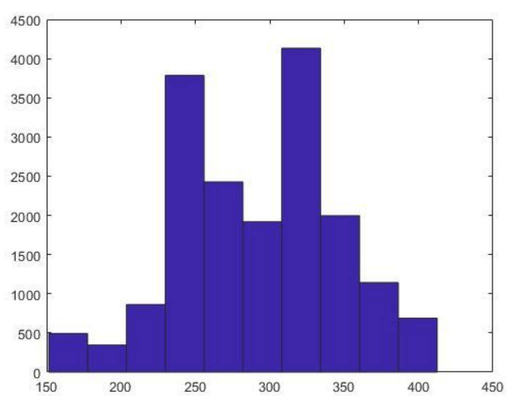

Figure (5). Histogram of SNR Search Values over the region of interest in segments B of an M1 Shell. The X Axis represents the SNR bin, while the y axis represents the frequency.

(U) In order to validate our program we did several experiments. First, we went through the M1 dataset by hand and separated the radiographs that contained IQI's. After this, we measured the SNR by the traditional method of pixel hunting. We compiled a spreadsheet of our results. After compiling a matrix of SNR values by hand, we ran the algorithm twice. In the first test, the algorithm measured the average SNR over the entire region of interest submatrix. We recorded the average for each of the three region of interest submatrices for every radiograph. In the second test, we recorded the maximum SNR over each of the three region of interest submatrices. In the discussion that follows we summarize our findings.

3. (U) Results and Discussion

(U) Overwhelmingly the radiographs in our dataset met or exceeded the SNR requirements. Let us analyze the results in a systematic fashion.

(U) First, we present the results of recording the SNR via "pixel hunting". We went through each radiograph, formed a box per ASTM 2737 and recorded an SNR value. The overwhelming majority of radiographs passed SNR requirements in all three regions. 53 failures were found in a total of 904 radiographs. It is important to note that in the cases where the SNR requirements failed to be met, this occurred either in segment B, or in segment A.

(U) Second, we report the findings of our algorithm using the Maximum SNR of each region of interest submatrix. Using this methodolgy, all radiographs passed requirements in all three segments.

(U) Lastly, we report the findings of our algorithm using the Average SNR of each region of interest submatrix. Using this methodology, we get 206 failures out of a total of 944 radiographs with most failures occuring due to a low average SNR in region B.

(U) SNR is one measure of image quality. The second measure of image quality is the presence and appearance of the Image Quality indicator or IQI. Together, the SNR and the appearance of the IQI establish that sufficient image quality has been achieved. Using the paradigm of average SNR, we examined shells that didn't reach an average SNR of 130 in greater detail. Out of the 206 serial numbers that failed this requirement in region B, 112 of those rounds failed image quality due to a lack of IQI visibility. That is, approximately 54% of the failures that were detected by humans can be explained via our algorithm that measured the average SNR over the submatrices defined earlier. This is a remarkable finding.

4. (U) Conclusion

(U) The authors are skeptical that current SNR requirements are indicative of acceptable image quality. The lack of standardization and repeatability of these measurements should be reason enough to reject the notion of "pixel hunting".

(U) Further work needs to be done on defining the region of interest which the authors admit was arbitrary. However, it is our firm belief that this allows for standardization and a better characterization of image quality.

(U) We remark on several key advantages of our implementation of SNR Search. First, the run time is far faster in our implementation compared to human radiographers. Second, our program gathers statistics beyond the maximum SNR. In fact, our program generates: the maximum, minimum, mean and standard deviation of each region of interest submatrix. If desired, a histogram of SNR values and a surface plot can be produced. Last and most importantly, our implementation removes the need for "pixel" hunting. Repeatability and accuracy are the hallmarks of quality assurance and allow for the best product to be delivered to the warfighter.

5. (U) Future Work

(U) Continuing to use computers and technology to support acqusition and review of X-Radiographic inspection is a central theme of our laboratory. As machine learning and computer vision become more prelevant in the private sector, the technology becomes more accessible and reliable. Currently we are building a convolutional neural network for detection of IQI's within a radiograph. Again, it is our hope that this will aid radiographers in delivering the best quality of product to the warfighter expediently.

6. (U) Appendix

Shown below is the MATLAB® code for the region of interest submatrix for region C.

```
cd 'C:\Images\'
I = dir('C \Images\*.dcm');
nfiles = length(I);

S = strings(nfiles,1);
%Initialization of SNR Matrix
for i = 1:nfiles
filename =
strcat('C:\Users\walter.s.rose5\Documents\Images\M1 IQI', I(i).name);
X = dicomread(I(i).name);
S(i,1) = filename;
S(i,2) = string(I(i).name);
L = 20; %length of snr box
w = 55; %width of snr box
%Submatrix Window
ymin = 480;
ymax = 900;
xmin = 230;
xmax = 450;
W = X(ymin:ymax,xmin:xmax);
m = ymax-ymin+1;
n = xmax-xmin+1;
snrh = zeros(m-L+1,n-w+1);
snrv = zeros(m-w+1,n-L+1);
%SNR Horizontal Orientation 20x55
for i_1 = 1:m-L+1
for j_1 = 1:n-w+1
Y =  W(i_1:L-1+i_1, j_1:w-1+j_1);
mean = mean2(Y);
std = std2(Y);
snrh(i_1,j_1) = mean/std;
end
end
[snrmaxh,Idxh] = max(snrh(:));

%SNR Vertical Orientation 55x20
for i_1 = 1:m-w+1
for j_1 = 1:n-L+1
Y =  W(i_1:w-1+i_1, j_1:L-1+j_1);
mean = mean2(Y);
std = std2(Y);
snrv(i_1,j_1) = mean/std;
end
end
[snrmaxv,Idxv] = max(snrv(:));
S(i,3) = max(snrmaxv,snrmaxh);
end
```

References

1. Rodriguez et al. X-Radiographic Parallax Reduction with 3D-Printed Fixturing, DTIC Technical Reports,2019
2. ASTM E2597-07 Standard Practice for Manufacturing Characterization of Digital Detector Arrays
3. Rose, Automated Statistical Analysis of Signal to Noise Ratio, DTIC Technical Reports, 2019
4. MIL-DTL-45195F(AR)w/AMENDMENT 3