Simplified JPEG Compression of Radar Sub-Surface Images
and the Application of Threshold Filtering

Héctor J. Ortiz Peña
Advisor: Dr. Hamed Parsiani

Electrical and Computer Engineering Department
University of Puerto Rico, Mayagüez Campus
Mayagüez, Puerto Rico 00681-5000

Abstract

The purpose of this research is to apply Simplified JPEG Compression method to radar sub-surface images of the same survey area. The simplified 3-D JPEG compression incorporates a 3D DCT algorithm and a quantization method to reduce the amount of data to be transmitted or stored. A sequence of 15 sub-surface images of size 512x512 each was compressed, resulting in a compression ratio of 13.11, and a reconstruction Root Mean Square Error (RMSE) of $4.4 \times 10^{-3}$. The compression of the frames was using a 3-D DCT, which is a separable transformation. Important details of the image, such as buried objects, were highlighted and shown, using a threshold filter based on the results of the image histogram.

1. Introduction

Ground penetrating radar (GPR) has an enormously wide range of applications. It has the highest resolution of any geophysical method for imaging the subsurface. It can reach scale resolution in centimeter values. GPR system measures and records electric field amplitudes as a function of spatial position, orientation and time. This provides scientists, engineers, and researchers information about subsurface material properties and geometries. Depth of investigation varies from less than one meter to more than 5,000 meters in polar ice; which means that a huge storage capability is needed. Compression methods have been developed to deal with that kind of situation. In the last 10 years JPEG [1] has been used with great success for compression. The JPEG compression is based on a Discrete Cosine Transform (DCT). A 3-D DCT compression is applied to the multiple GPR images. DCT uses only real value coefficient, and is completely loss less and separable. A quantization table developed by JPEG was applied to the 3-D DCT coefficients, to reduce the amount of information necessary for storage or transmission.

2. 3-D DCT Compression

Discrete Cosine Transform (DCT) was first used for image compression by Ahmed, Natarajan and Rao in 1974; an important achievement for the research community working on image compression. The 3D-DCT compression takes advantage of the degree of correlation between pixel values in a sequence of frames or images in the spatial and temporal domains. It is based on the following equations [3]:

$$S(w,v,u) = \alpha_{3D}(w,v,u) \sum_{u=0}^{NI-1} \sum_{v=0}^{NR-1} \sum_{z=0}^{NC-1} s(z,y,x) \frac{\cos((2x+1)\alpha \pi)}{2N} \sum_{y=0}^{NY-1} \sum_{x=0}^{NX-1} s(z,y,x) \frac{\cos((2y+1)\beta \pi)}{2N} \sum_{z=0}^{NZ-1} s(z,y,x) \frac{\cos((2z+1)\gamma \pi)}{2N}$$

Where $s(z,y,x)$ is the 3-D input image with spatial coordinates $x,y,z$; and $S(w,v,u)$ is the 3-D output image with DCT domain coordinates $w,v,u$. NI, NR and NC are the number of images, number of columns and number of rows, respectively.
\[ \alpha_{3D}(w, v, u) = \sqrt{\frac{2}{NF}} \frac{2}{NR} \frac{2}{NC} C(w)C(v)C(u) \]

and

\[ C(k) = \begin{cases} 
\frac{1}{\sqrt{2}} & k = 0 \\
1 & \text{otherwise}
\end{cases} \]

Inverse 3-D DCT equations are [3]:

\[
s(z,y,x) = \sum_{w=0}^{NI-1} \sum_{v=0}^{NR-1} \alpha_{3D}(w, v, u) \ast S(w,v,u) \\
\ast \cos((2u+1)\pi z / 2NC) \ast \cos((2v+1)\pi y / 2NR) \\
\ast \cos((2w+1)\pi x / 2NI)
\]

with the same definitions for constants, variables and coefficients as above.

Since 3D DCT is separable, it is equivalent to a 2D DCT calculation over the rows and columns of the image, followed by a 1D DCT calculation for each frame[2].

### 3. Quantization Process

A quantizer is used [2] to reduce the number of bits needed to store the transformed coefficients. Quantization can be performed on each individual coefficient, which is known as Quantization Scale (QS). Quantization followed by a DCT produces a lossy compression.

QM is the JPEG Standard quantization matrix, given by:

\[
QM = \begin{bmatrix}
16 & 11 & 10 & 16 & 24 & 40 & 51 & 61 \\
12 & 12 & 14 & 19 & 26 & 58 & 60 & 55 \\
14 & 13 & 16 & 24 & 40 & 57 & 69 & 56 \\
14 & 17 & 22 & 29 & 51 & 87 & 80 & 62 \\
18 & 22 & 37 & 58 & 68 & 109 & 103 & 77 \\
24 & 35 & 55 & 64 & 84 & 104 & 113 & 92 \\
49 & 64 & 78 & 87 & 103 & 121 & 120 & 101 \\
72 & 92 & 95 & 98 & 112 & 100 & 103 & 99
\end{bmatrix}
\]

Quantized indexes are obtained by linearly quantizing each DCT coefficient with the determined quantization step QS, which are the coefficients in the QM matrix.

#### 3.1 Calculation of index (i) for any QS value:

\[
i = \frac{DCT \text{ coefficient}}{QS} + A
\]

where

\[
A = \begin{cases} 
\frac{1}{2} & \text{if } \text{DCT Coefficient} > QS/2 \\
-\frac{1}{2} & \text{if } \text{DCT Coefficient} < -QS/2 \\
0 & \text{if } \text{- QS/2 < DCT Coefficient < QS/2}
\end{cases}
\]

### 4. Simplified JPEG method & Histogram

A complete diagram for the simplified JPEG compression process could be represented as in Figure 1.

**Figure 1. Simplified JPEG Compression diagram**

Fifteen Radar sub-surface images (512x512 each) pass through a low pass filter, and decimation process where the size of each image is reduced by 4. The 3-D DCT is applied to the images as shown in Figure 2.

**Figure 2. 3D DCT application**

Quantization indexes are obtained using JPEG-QM standard and the equations in Section 3.1. In our case, the quantization indexes transmitted and received are assumed to be exactly the same. The inverse of each of these processes are applied at the decoder level,
following the order of Figure 1. Interpolation is used to restore the ‘received’ images to their original size. A Simple Compression Ratio SMR defined as

\[
\text{SMR} = \frac{\text{total number of pixels}}{\text{total number of non-zero pixels}}
\]

is calculated. The RMSE between original and the decompressed received images is calculated as a measure of compression image quality.

A histogram, Fig. 6, provides us information about the frequency of occurrence of the different pixel values. With this information, we are able to select a threshold value that establishes a good range of possible values that emphasizes regions of interest on the image. We know that high intensity reflections from buried material received by the GPR are represented in the image by the peak of the parabolas, Fig. 5. We establish threshold values that highlight most of those regions and almost eliminate every other part.

5. Results

The simplified JPEG compression process results in a RMSE of 4.4 \(10^{-3}\). This negligible error is due to the recovery of the 15 original images after their compression. The compression ratio for the process was 13.11. Figure 4 shows a visual comparison between 4 sub-surface images that were compressed and recovered using the complete process.

Figure 4. Application of Simplified JPEG Compression, e.g. of 4 out of 15 images

and the possible buried artifacts were revealed as shown in Fig. 7. Radar reflections from each artifact appear in a form of a parabola. The size of the parabola depends on the size of the buried object. The same was repeated with a threshold value of 80, and the result is as shown in Fig. 8.

Figure 5. Original Sub-surface image

Figure 6. Histogram of the sub-surface image
6. Conclusions

The threshold filter highlights specific areas of the radar sub-surface images. The objects observed are dependent on the chosen threshold. Analysis of image histogram provides an idea of where the threshold could be established to obtain the wanted information. Application of additional image processing techniques should be applied to enhance and clean the images. In a large survey area, the GPR produced image size can be reduced using compression techniques. In this work, simplified JPEG compression was successfully applied to sub-surface images, reducing the amount of data needed for storage or for transmission. The data was compressed greatly at a very low RMS error. As a future work, the simplified compression will include Huffman coder/decoder and pack/unpack algorithms for a more complete compression of GPR images.

7. References