JPEG 2000, an adapted compression method for ultrasound images?
A comparative study

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ABSTRACT
This paper presents an evaluation of various compression techniques, for ultrasound images transmission, within a telemedicine project. For this work, we selected six lossless compression methods and three lossy ones among which the new image standard JPEG2000. We compared these techniques, thanks to mean square error and coding time measurements, to determine which one would provide the best compromise between coding performance and image quality measured.

Keywords - Ultrasound images, telemedicine, image compression, JPEG, JPEG2000, JPEG-LS

1. INTRODUCTION
This paper presents a comparison among grayscale ultrasound image compression methods dedicated to a tele-scanning robotic system. This work is part of the Otelo project (mObile Tele-Echography using an ultra-Light rObot).

The Otelo project has as its objective to allow an ultrasonographer expert to perform an echography examination from afar. The Otelo system (Fig 1), currently being developed by the Otelo consortium, includes a master station, where the ultrasound specialist handles a fictive probe with a localisation sensor, and a slave station that includes a probe holder robot which moves the real probe according to the fictive probe motions [1]. The echographic images are captured by an ultrasound scan device and sent to the master station via a standard communication link (e.g. terrestrial : ISDN…) to ensure a good quality of service (QoS).

The feasibility of this remotely tele-operated ultrasound probe was demonstrated during the “SHISHA 98” experimentation whose main objective was to perform a tele-echography examination between Bourges (France) and Katmandu (Nepal), thanks to satellite communication [2] [3].

For tele-operated systems such as the one in the Otelo project, where emergency telemedicine is one of the foreseen applications, image compression is an essential step, especially for the improvement of the real-time transmission and control of the probe-holder robot.

Therefore, when using standard communication systems with various bandwidths and rates for the tele-operated robot, it becomes a necessity to optimize the image transmission time while preserving the best quality to best assist the clinical expert in his diagnosis.

There exist two approaches of image compression. The first one concerns lossless image coding. Numerous methods have been proposed, such as Huffman coding, Shannon-Fano, and Lempel-Ziv algorithms [4] [5]. The ability of this methodology might be interesting for our medical application; distortions due to lossy techniques may introduce errors in the reconstructed image and therefore, may present difficulty in giving a correct medical diagnosis. The second approach consists of coding images with little distortion. One can cite among these lossy methods the JPEG standard and the two new image standards JPEG-LS and JPEG 2000 [6] [7] [8].

In this paper, we propose a comparative study on compression techniques dedicated to ultrasound images. Our goal is to determine the method that gives an optimal transmission time and the best image quality for the ultrasound specialist, for a chosen communication channel of 64 Kbps (e.g. terrestrial ISDN) that offers a good QoS.

The paper is composed of four parts. The first one describes the lossless compression we used for this comparison. The second section presents lossy methods. Experimental results are developed in the third section. Conclusion and perspectives of our work are given in the last part.
2. LOSSLESS COMPRESSION METHODS

We selected six compression methods among the most used:
- Huffman coding [4]
- Arithmetic coding [9]
- LZSS coding (Storer and Szymanski’s modified version of Lempel and Ziv’s algorithm) [10]
- RLE coding [12]
- Fano algorithm [12]

Concerning lossless compression methods, we computed three criteria: times of compression ($t_{enc}$), decompression ($t_{dec}$) and compression rate ($CR_t$).

The compression rate $CR_t$ considered in this study defines size in bytes of final image over size in bytes of original image.

3. LOSSY COMPRESSION METHODS

We have tested three lossy compression techniques:
- JPEG: we used the standard (ISO/IEC 10918-1) [6]
- JPEG-LS: the implementation LOCO [13] was chosen for our study (ISO/IEC 14495-1) [7]
- JPEG2000: we used the JasPer implementation for this standard (ISO/IEC JTC1/SC29/WG1) [8]

In order to compare lossy image compression methods, we add several criteria to quantify the quality of the compressed images for a given compression rate $CR_t$: the mean square error (MSE), and the peak signal to noise ratio (PSNR) between the original image and the rebuilt image, and the time of compression ($t_{cc}$).

- The mean square error (MSE) given by
  \[
  MSE = \sum_{i} \sum_{j} (New_{ij} - Original_{ij})^2 / I \times J
  \]
  measures the distortion brought by the compression technique. It is defined by the mean of the squared distances between every pixel $(i,j)$ of the original image $Original_{ij}$ and each pixel of the rebuilt image $New_{ij}$.

- The peak signal to noise ratio PSNR,
  \[
  PSNR = 10 \log_{10} \frac{Imax^2}{\sqrt{MSE}}
  \]
  represents an unbiased measure of the fidelity of the rebuilt image. More precisely, it represents the MSE, referenced with respect to the dynamics of the image in decibels ($Imax^2$ is the maximal intensity).

The larger the PSNR is, the smaller the MSE gets, the better the rebuilt image quality (that is to say “faithful” to the original image).

4. RESULTS & DISCUSSION

The survey was performed on 10 ultrasound images of size 768*576 similar to the one shown in Fig 2. These images have been acquired by an AU3 ultrasound scanner (ESAOTE) at a rate of 15 images per second, then digitised thanks to a Matrox Meteor board.

The computing was achieved by a Pentium III with 450 MHz, under Windows NT.

![Fig. 2. 768*576 Image database example: ultrasound Image of an adult liver](image)

The following results represent an average measure of the MSE, PSNR, coding computed time $t_{cc}$, $t_{enc}$, $t_{dec}$ and compression rate $CR_t$ calculated on ten rebuilt and original images of our database. The results concerning $t_{cc}$, $t_{enc}$ and $t_{dec}$ have to be looked at in comparison with each others to appreciate the performance of each of the studied techniques.

Table I shows the results for the lossless methods.

<table>
<thead>
<tr>
<th>Methods</th>
<th>$t_{enc}$ (s)</th>
<th>$t_{dec}$ (s)</th>
<th>$CR_t$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arithmetic</td>
<td>05.5</td>
<td>08.5</td>
<td>29.11</td>
</tr>
<tr>
<td>Fano</td>
<td>01.1</td>
<td>00.4</td>
<td>74.61</td>
</tr>
<tr>
<td>Huffman</td>
<td>01.2</td>
<td>00.5</td>
<td>74.41</td>
</tr>
<tr>
<td>RLE</td>
<td>00.6</td>
<td>00.5</td>
<td>100.69</td>
</tr>
<tr>
<td>LZSS</td>
<td>03.4</td>
<td>01.0</td>
<td>36.40</td>
</tr>
<tr>
<td>Adaptive Huffman</td>
<td>00.9</td>
<td>00.7</td>
<td>54.57</td>
</tr>
</tbody>
</table>

**Table I**

Comparison results for lossless methods

It can be concluded that the RLE coding is not suited to ultrasound image, as its $CR_t$ is the largest. Fano et Huffman algorithms give comparable results in terms of $t_{enc}$, $t_{dec}$ and $CR_t$ with poor performances. Adaptive Huffman method presents a compression rate of 54.57% (the final image size is about half of the original one).
The last method, based on arithmetic coding, gives the best compression rate, but is associated with larger compression and decompression times.

In conclusion, the Adaptive Huffman method gives the best compromise between compression rate and computing times.

Figure 3 shows the comparison between the different lossy techniques according to the MSE with respect to \( CR_t \).

![Fig. 3. Comparison between MSE and CR_t](image)

We can see in Figure 4 the PSNR measured for the three lossy compression methods. A criteria of 30db was considered to be the lower value for a good PSNR.

![Fig. 4. Comparison between PSNR and CR_t](image)

For a compression rate greater than 5%, JPEG-LS gives the best image quality, with regard to the PSNR. And for a rate lower than 5%, JPEG 2000 becomes the optimal method. Overall JPEG gives the worst results.

Table II shows the evolution of the different criteria with respect to two compression factor values: a low compression value (near lossless) and a very high compression value.

<table>
<thead>
<tr>
<th></th>
<th>( t_{cc} ) (s)</th>
<th>( CR_t ) (%)</th>
<th>MSE</th>
<th>PSNR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low compression</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JPEG 2000</td>
<td>0.2</td>
<td>80</td>
<td>0</td>
<td>( \infty )</td>
</tr>
<tr>
<td>JPEG</td>
<td>0.1</td>
<td>12</td>
<td>36</td>
<td>32</td>
</tr>
<tr>
<td>JPEG LS</td>
<td>0.2</td>
<td>33</td>
<td>0</td>
<td>( \infty )</td>
</tr>
<tr>
<td><strong>High compression</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JPEG 2000</td>
<td>0.3</td>
<td>2.98</td>
<td>55</td>
<td>30</td>
</tr>
<tr>
<td>JPEG</td>
<td>0.1</td>
<td>1.78</td>
<td>1200</td>
<td>17</td>
</tr>
<tr>
<td>JPEG LS</td>
<td>0.08</td>
<td>2.77</td>
<td>188</td>
<td>25</td>
</tr>
</tbody>
</table>

TABLE II
COMPARISON RESULTS FOR LOW AND HIGH COMPRESSION

As we noticed before, JPEG-LS gives the best compression rate in the lossless case (33% vs 80%). For a high compression rate, JPEG 2000 also shows its efficiency. Generally, JPEG-LS grants a faster compression, with a factor ranging between 2 and 2.5.

The experiments reveal that Adaptive Huffman was the best method among the lossless ones. We can notice here that JPEG-LS, in the lossless case, presents a better \( CR_t \) than Adaptive Huffman (33% vs 54.57%), for a comparable compression time.

5. CONCLUSION & PERSPECTIVES

The goal of this survey was to determine the best compression method dedicated to ultrasound images for an ultrasound scanning tele-operated robotic system. We tested six lossless techniques and three lossy ones. We compared them based on the following criteria: the rebuilt image quality, given by mean square error and signal to noise ratio, the compression and decompression times, and the compression rate.

Experimental results performed on ten ultrasound images establish that the JPEG-LS technique seems to be the best lossless method for our tele-medicine application.

In the lossy case, JPEG-LS is the best method when the compression rate expected is greater than 5%. And for very high compression, JPEG 2000 becomes the optimal technique.

Indeed, in each case, these methods give the best compromise between the image quality, the compression rate and the coding time. They should satisfy our needs for our real-time tele-operated robotic system.

In our tele-echography experiment, we may have only one ISDN line of 64 kbps available. For a given ultrasound image the medical expert may be interested...
in a specific region of interest (ROI) within a received ultrasound image. As an example, we can consider this ROI to be 200*200 pixels that is 40 kbytes.

In a lossless case, JPEG-LS achieves a compressed ROI of about 12 kbytes (CR_t=33%). With a channel capacity of 8kbytes/s (64kbps), the medical specialist would be able to receive 0.75 image per second.

In the lossy case and for the highest possible compression available (PSNR ≥ 30dB), JPEG 2000 achieves a ROI of approximately 1.5 kbytes (CR_t=2.98%). This technique would allow 5 images per second to be transmitted to the expert.

From his master station, the ultrasonographer expert will decide the size of the desired ROI and the compression level, in order to perform the best diagnosis.

Some of the algorithms tested in this study can not be performed on the color pictures. But with a larger number of available ISDN lines, that is also a larger bandwidth, one of the improvements will be to take into account the three RGB images, in order to be able to include color Doppler image compression.

For future experiments, another step will be added to the compression chain. That is the selection of a region of interest (ROI) in the acquired ultrasound image. The capacity of this complementary step will be tested to evaluate the compression performance and eventually the reduction in coding time.

In order to measure the transmitted image quality and to validate the chosen method, we plan to perform an analysis of diagnosis fidelity. For this purpose, R.O.C.S. curves methodology (Receiver Operator Characteristics), and psycho-visual methods will be implemented as well as the use of standard phantom devices to have a quantitative approach of the ultrasound images received at the end of the telemedicine chain.

We wish to widen our survey with ultrasound sequence video (e.g. cardiac investigation), while testing techniques of movement compensation and MPEG compression.

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REFERENCES


