Mask Motion Adaptive medical image coding

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Abstract— **We combine a mask motion detection algorithm with both the WAAVES adaptive compression algorithm (resulting into MMWaaves) and a JPEG2000 coder (resulting into MMJPEG2000) for the compression of medical images sequences. Several images were compressed using Waaves, MMWaaves, and MMJPEG2000 to observe which tool provided the best visual quality while maintaining a high compression ratio. Compared to Waaves, the MMWaaves achieved compression gains up to 40% for CT scans and 50 % for MRI. In addition, the SSIM values attributed to the compressed images were between 0.96 and 0.988 while the PSNR values were higher than 42. In addition MMWaaves attained a superior performance than MMJPEG2000.**

I. Introduction

Nowadays, medical images from different modalities — X-ray (CR), magnetic resonance imaging (MRI), computed tomography (CT), Ultrasound (US)…— provide the physician with critical information to establish a diagnostic. Therefore, the volume of medical images stored in the hospitals picture archiving and communication systems (PACS) [1] is constantly increasing. Therefore, there is an increasing need to compress these medical images. However, there are two requirements on the compression scheme that are specific to the field of medical images. Firstly, the reconstructed images must enable the physicist to make a medical diagnosis in the same conditions that the original image. Secondly, the compression scheme must be certified as a medical device, according to public health regulations. In the previous works, the compression scheme was based on JPEG2000 [8] [12] [15]. However, JPEG2000 is not certified for medical image compression and it does not guarantee that the reconstructed image is suitable for diagnosis purposes. Therefore, the CIRA society developed an original compression scheme called WAAVES [2]. It offers a high compression ratio while preserving a quality suitable for medical diagnosis. It is compatible with DICOM and it was certified as a Medical Device by INSERM [3] and by the HEGP [14]. These coders are based on intra mode compression, where the original data are transform-coded directly without recourse to prediction that affects the compression performance. However, we observe that for each patient, when an exam is performed, it is composed of several images such as different realization of scanner or MRI; these images in successive sections have a strong similarity. Therefore we introduce in this paper the inter prediction's aspect into these coders in order to improve the compression performance for medical images sequences. Our approach is to combine motion a detection algorithm with the Waaves and JPEG2000 picture coder to create respectively the MMWaaves encoder (Motion Mask Waaves) and MMJPEG2000 (Motion Mask JPEG2000), in order to take advantage of the similarities between the successive images of a medical exam. This paper is organized as follows: the Waaves algorithm is described in section II. The motion detection algorithm and the proposed medical coder MMWaaves are described in section III. A comparative study is detailed in section IV. Finally, we conclude the paper in Section V.

II. Waaves

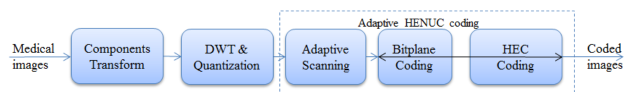

Fig 1. Waaves coder

The Waaves medical coder is a still image codec compatible with the DICOM medical image format and other standard formats (RAW, RGB, etc.); it supports lossy and lossless compression of single component and multi-component (e.g., color) imagery. It consists of 6 distinct processing steps (Fig.1): component transform, DWT, quantization, adaptive scanning, bitplane coding and HENUC coding [4]. After the components transform, the image is decomposed through a multiresolution wavelet transform into sub-bands. All the employed wavelet transforms are fundamentally one dimensional (1-D) in nature. Two dimensional (2-D) transforms are formed by applying 1-D transforms in the horizontal and vertical directions. Thus the multi-resolution nature of DWT makes it ideal for scalable image coding. After transformation, all the coefficients are quantized. Dividing the magnitude of each coefficient by a quantization step size and rounding down accomplishes this. These step sizes can be chosen in such a way to achieve a given level of quality. Next, each sub-band is fed into the adaptive scanning block and the quantized coefficients are adaptively reorganized into 1-D arrays for the purpose of maximizing the local stationarity as follows:

- Define a measure of "expected activity" for each coefficient in the subband.
- Scan the coefficients in the subband into a 1-D array; each time picking the coefficient whose Expected Activity Meausure (EAM) is highest among the not-yet-picked coefficients.

EAM is a function of the coefficients in the parent band and of the previously picked coefficients in the same band. It is used to reorder the remaining bit sequence. Reordering is efficiency as long as both encoder and decoder do the ordering in the same way. After obtaining the significance map (EAM) of each band, the image is decomposed into multi-resolution bands. At each level of decomposition, an approximation band is decomposed into four sub-bands, with the resolution downscaled by 4. The first four bands, composed of the lowest frequency DWT coefficients, do not have a parent band. For the significance maps of these bands, the encoding scheme uses a DPCM scanning to encode the coefficients without any previous information of the band. The DC bands are scanned according to the steps in algorithm 1. The bitplanes of this sequence are compressed in two steps. Firstly, encode the bitplane of magnitudes by HENUC, an entropy coding method which is efficient in compressing locally stationary binary sequences. Then encode the signs of the nonzero elements of the sequence without compression.

Algorithm 1 : Adaptive Scanning encoding

1) Start scanning the coefficients in the raster scanning order.
2) Compute EAM ($q_{i,j}$) for all $q_{i,j}$ in the band
3) For each significant coefficient $q_{i,j}$encountered and has not been visited.
   - Store the location (i ,j) of $q_{i,j}$ to be signaled as side information,
   - boost (i, j) {
     - For all (k, l) in the neighborhood of (i, j) and has not been visited,
       - ✓ If $q_{k,l}$ is not significant, output a 0
       - ✓ If $q_{k,l}$ is significant, output a 0
         -boost (k, l) }

III. MASK MOTION DETECTION CODERS: MMJPEG2000 AND MMWAAVES

In several medical imaging exams, the images in a sequence present strong similarities. Therefore we can apply the mask motion detection to refine and increase the level of compression predefined by hospitals. This is strongly dependent on the modality (more or less recent). A perfect example are the MRI and CT modalities, where each sequence consists of multiple images that share common information from one image to another; for instance in a sequence of 1cm of thickness, we can record images with a gap of 1mm, therefore each image will keep a certain amount of information from the image that preceded it. This phenomenon is interesting as we have a sort of constant information that we can compress aside, and then add it to the compressed image during the reconstruction. We propose to use a mask motion detection algorithm based on Markov fields to localize moving and static areas in a dynamic scene.

The Markov algorithm was used by Alice Caplier [7] for robust pixel segmentation of successive frames for video surveillance and target follow-up applications. This technique was also used by Frantz Lohier and David Faura, who combined it with a JPEG2000 coder [8]. The idea is to benefit from the temporal redundancy of information between the after-images by carrying out a robust detection of movement based on the fields of Markov before calling the JPEG2000 coder. The analysis of movement is approached mathematically through the extraction of movement information from a sequence of images by means of specific data processing algorithms. We have reworked and developed the Markov model using the potential functions foreseen by motion detection combining the spatial and temporal information. We attribute to each site s(x; y) one of the two labels: 1 if s belongs to a moving area and 0 if s belongs to the static background. The most probable configuration is determined by using the Maximum A Posteriori criterion (MAP).

A. Notations

- E: the set of the frame sites.
- s: a site with (x,y) coordinates.
- $O_{t+1} = \{O_{t+1}(s), s \in E\}$: the absolute value of the frame of difference.
- $I_{t+1} = \{I_{t+1}(s), s \in E\}$: the current frame.
- $O_{t+1}(s)$: indicates one site in the O_{t+1} frame.

B. Algorithm Principle

It is composed of two distinct steps (Fig. 2): The first is a preprocessing phase through which:

- We compute the absolute value of the difference matrix between the current frame I_{t+1} and the reference frame R.

$$O_{t+1} = |I_{t+1} - R|$$

- We binarize the O_{t+1} matrix by setting a threshold θ.
- We determine the variance of the O_{t+1} matrix.

The second is the implementation of the Iterated Conditional Mode algorithm (ICM) [9][10], which updates the binary state of the pixels of difference (moving or not) and is made site by site so that every change in state is taken immediately into account in the relaxation of the neighboring site. For each image site, we calculate the local energy relative to both the immobile and the mobile state. After, we allocate the state which minimizes the energy to the site being treated. The energy minimization has a filtering effect on the noise and allows a partial reconstruction of the moving zones. Leaving the Iterated Conditional Mode algorithm, we achieve an image of minimal energy which represents the binary motion map.

C. Reference coder MMJPEG2000

We redeveloped an original compression algorithm named MMJPEG2000 [16], which increased the quality of the third part of the JPEG2000 standard [12]. To enhance the compression ratio, we divided the images flow into images of reference and images of difference. Next, we applied a masking technique to the images of difference.

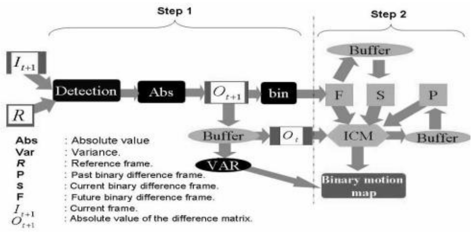

Fig. 2 Generation of the binary map which reduces the variation of the luminance that results

The mask was a motion binary map obtained from the motion detection algorithm detailed in the previous section. After the motion detection steps, JPEG2000 performed the discrete wavelet transform, quantization bloc and embedded block coding with optimized truncation (EBCOT) as its primary algorithm. The algorithm of EBCOT was divided into two sub modules: bit-plane coder and binary arithmetic coder [15].

D. MMWaaves medical coder

We developed a mask motion detection adaptive HENUC coder (MMWaaves) [11]. It consisted of 7 distinct processing steps: Mask Motion detection, component transform, DWT, quantization, adaptive scanning, bitplane coding and HENUC coding [4]. Fig. 3 gives the implementation architecture of the MMWaaves processing steps. The different blocs were developed under Linux C++. For reconstruction of the compressed bitstream into imagery, each of the seven processing steps was performed in reverse order, to obtain the reconstructed medical image.

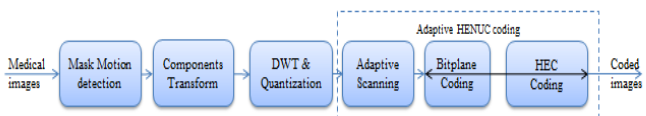

Fig 3. Mask Motion Waaves

IV. COMPRESSION COMPARATIVE STUDY

In order to demonstrate the performance of MMWaaves in medical images coding, the image data sets *shown in Fig. 4* were as follows:

- CT (Computed Tomography): 512x512 pixels, 16 bit gray level, total number of 75 images.
- MR (Magnetic Resonance Imaging): 256x256, 8 bit gray level, total number of 80 images.
- XA (X-Ray Angiography): 512x512 pixels 8 bit gray level, total number of 90 images.

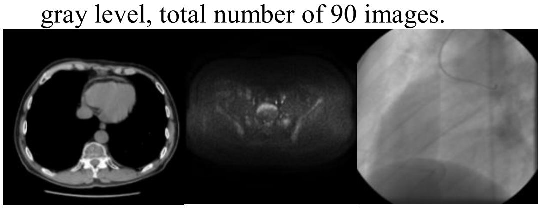

Fig. 4. Set of greyscale DICOM images used in our experiments. Left to right, top to bottom: CT scan 512*512 8-b pixels; MRI 256*256 8-b pixels; X-ray angiography 512*512 8-b pixels

For comparison purposes, we considered the following two other image coders:

1) MMWaaves as described in III.
2) MMJPEG2000: as described in III.

A. Comparative study: MMWaaves vs.Waaves

We focused our interest on the gain of compression to assess the mask motion algorithm and the adaptive scanning algorithm in medical images compression. The results presented below correspond to a CT scan exam. The size's evolution of images compressed by Waaves and MMWaaves (Fig.5) show that MMWaaves reached a mean compression gain of 40 %. The different pics result from the change of the reference images during the simulation.

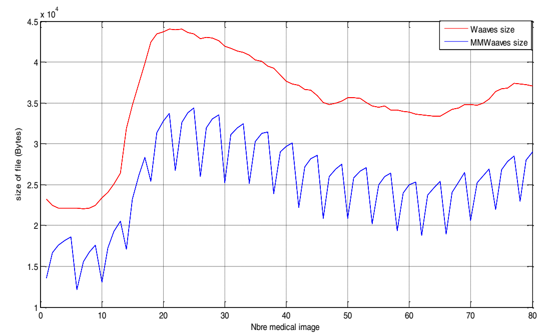

Fig. 5. Compression rate MMWaaves vs Waaves for CT Scan exam

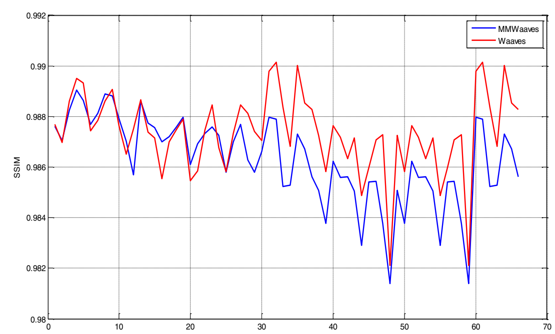

Fig. 6. SSIM MMWaaves vs Waaves for CT scan images

We compared also MMWaaves and the original Waaves coder on the quality decoded image. As shown in Fig.6 we traced the averages SSIM [13] values vs. 67 CT scan images. We demonstrated that adding the mask motion detection to the adaptive Wavelet HENUC coder significantly increased the the compression rate while keeping a very good quality.

B. Comparative study: MMWaaves vs.MMJPEG2000

After having validated the impact of inter-prediction coding in medical image compression, we analyzed the PSNR as well as the SSIM index versus the compression ratio for MMWaaves and MMJPEG2000. A maximum compression level was fixed depending on the resolution of each modality, to ensure a good quality of the resulting compressed images. Hence a max compression ratio of 15X (X means times) was attributed to images with 512by512px resolution and 10X for 256by256px. Table1 lists the PSNR average values achieved for MMWaaves and MMJPEG2000 for three sequences of the images. It should be noted that these PSNR values were calculated directly from the decompressed reconstructed images.

Image	Coder	Compression Ratio=10;15
Ct scan	MMWaaves MMJPEG2000	48.66 46.54
MRI	MMWaaves MMJPEG2000	45.69 42.06
Ax-RAY	MMWaaves MMJPEG2000	42.87 39.54

Table 1. PSNR values [$10.log_{10}(255^2/MSE)$] for MMWaaves, EZW and MMJBEG 2000.

The quality analysis of the reconstructed medical image was assessed in collaboration with the french National Institute of Health and Medical Research INSERM [3]. MMWaaves surpassed MMJEPEG2000 for all images, since the model for the JPEG2000 coder incorporated no inter-prediction information. In the graph of the image 7, an index SSIM was fixed depending on modality. We coded three exams (CT scan, MRI and X-ray as it is shown in fig.4) of 75 images each. We obtained compression gains of 30 %, 40% and 42 % for CT scan, MRI and X-ray exams, with respect to Waaves.

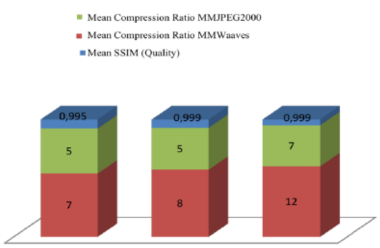

Fig. 7. SSIM vs. Avg compression ratio for MMWaaves and MMJPEG 2000

In fig.8 we compare the size's evolution of the compressed images by MMWaaves and MMJPEG2000 for an XA exam of 65 images. MMWaaves provided important compression gain relative to MMJPEG2000. This gain varies from 30% to 45 % which complies with the previous results. The performances of our encoder were compared with the results of MMJPEG2000 based arithmetic coding. Experiments showed that the mask motion approach was better in terms of compression rate and medical image quality.

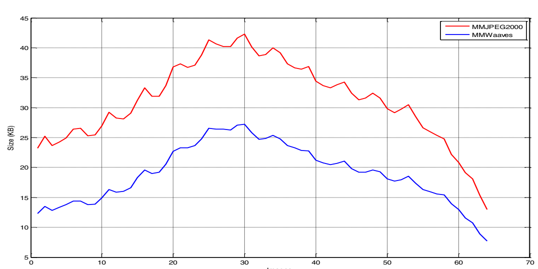

Fig. 8. Compression rate MMWaaves vs MMJEPEG2000 for X_RAY exam

V. Conclusion

In this work we introduced and developed an inter-prediction algorithm based on markov fields combined to both Waaves and JPEG2000 encoder. We obtained very satisfactory compression ratio depending on the medical images modalities. For example, comparing MMWaaves to Waaves, we obtained a 50 % gain for MRI and 40 % for CT. An established study of performance evaluation proved that MMWaaves achieved values of SSIM higher than 0.97, and it maintained a good quality compared to the original medical image and the MMJPEG2000 encoder for all modalities.

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