Progressive Image Transmission by Refining Sampling Lattice

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Abstract

This paper applies nonuniform sampling technique to progressive image transmission (PIT) so that it can place more attention on vital parts of the image. The system first segments an image based on quad-tree structure and the resulting variable block size data has it suitable sampling lattice under a tolerable loss. With this information, transmitter can adjust the lattice for each region matched with the desired bit rate and error. Simulation results show that low overhead and information are necessary for each stage of transmission while improved images can be reconstructed at the receiver.

1. Introduction

Digital image data can be usually represented as a two dimensional matrix. This formation corresponds to uniform sampling of an image acquisition system. Each element in the matrix which is called a sample or a pixel (picture element) contains intensity of its associated location in the image. In this sense, digital image is a representation of an analog image by a finite amount of data and the closer the samples are, the less the approximation error based on the original image. Thus, a huge amount of densely positioned samples is required for high quality reproduction of a digital image. In view of this shortcoming, various algorithms have been proposed to reduce the size of storage data [1] or to speed up the transmission and for displaying the digital image [3]. These techniques share the same goal that is to maintain the highest reproduction quality.

Progressive image transmission (PIT) [5] is one such kind of a technique. It is aimed to shorten user time in accessing and browsing remote image database. This advantage comes from the ability of PIT to provide information of an image in hierarchical order of importance and to build a higher quality image upon the user's request. Some PIT algorithms have the ability to produce an exact version of input image at the last stage. The proposed technique can be applied to both results. By rearranging transmission order of sampled data from the traditional raster scan method, transmitter can successively send samples in such a way that it will gradually enhance the reproduction quality and approximation error will be distributed evenly throughout the entire output image. Moreover, the proposed system transmits patterns instead of the original information except during the first stage so it always uses a small amount of data in each stage.

2. Efficient Image Representation

For uniform sampling, digital image samples lie in some arbitrary pattern. Sampling density which is measured from the separation among pixels specifies spatial resolution of an image. To avoid aliasing, high resolution image which has sampling density above Nyquist rate is required. This restriction results in a lot of redundancy when applying to uniformly sampled images. Natural image is a kind of nonstationary signal. It contains both homogeneous regions in background areas and nonhomogeneous regions in detail areas. With regular lattice like the one in uniformly sampled images, uniform sampling places the same number of samples over the entire image thereby causing either loss of information due to aliasing or redundancy of information. This dilemma can be avoided by using efficient image representation. This representation which first analyzes local characteristics of each region allocates samples suitable with the expected amount of information i.e. less number of samples in background and vice versa.

Theoretically, sampling density is specified by cutoff frequency of data. However, accurate frequency spectrum becomes complex for a nonstationary data since

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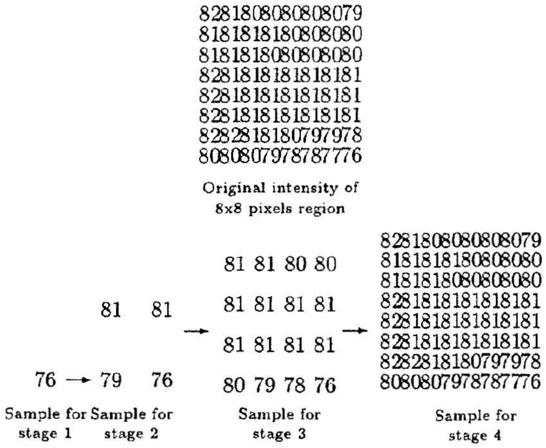

Figure 1. Example of the sampling lattice during transmission.

its characteristics change among data. This kind of fluctuation refrains regular sampling lattice from optimal result. Irregular lattice, on the other hand, seems to be a promising tool for efficient image representation. It will not have any restriction from sampling structure but it will have trouble with lattice formation. Nonuniform lattice basically moves the problem from image representation to lattice representation. This problem is common in any adaptive system. We cannot afford to have infinite lattice formations. Only some of them are worth appearing in a practical system. In this paper, we use lattice which is locally regular. By adjusting the size of the area, the lattice can also be adjusted. Size of area has to be controlled in an effective way for the efficiency of the system.

Transmitter uses quad-tree partiontioning [4] to analyze and control details in each region of the image. Image is successively split based on tree structure until it conforms to the uniformity criterion and becomes leaf of the tree. Additionally, the splitting process halts when it reaches bottom level of the tree and that region is automatically converted to a leaf. If a degree of detail is a criterion, only limited amount of information is allowed in each leaf unless that leaf is at the bottom level. Using leaves in the tree structure, transmitter can place samples in a more efficient manner that is by giving an equal number of samples to each leaf. In this way, all samples will represent th same amount of information. In other words, loss will propagate uniformly over the image. The system can also control the error by adjusting the sample allocation to match with the detail within a region.

3. Transmission Algorithm

3.1. Lossless approach

The major attribute of PIT is that it will set up a sequence of information for different quality levels of images. The proposed technique achieves this function by using a distinct sampling lattice for each stage of transmission. At the first stage, a crude version of an image is tolerable and hence the diluted lattice, say one sample for each region, is applied to all leaves. To obtain better results in later stages, sampling lattice is changed to the denser one. The lattice for the final stage of transmission has the same sampling density as the original image which means that all samples will be sent and the reproduced image will be a replica of the input image. Unlike other traditional multiresolution techniques, lattice density in the proposed technique is globally nonuniform. As mentioned before, this structure yields less error. Example of sampling lattice for 8×8 pixels region is shown in Fig.1. Task of the receiving end is adding the received data to the estimated value at the right position and then filling the remaining positions by means of linear interpolation.

A major concern in designing a PIT system is to minimize the overhead and eliminate the redundancy involved in multitransmission. Only information of quad-tree structure is required thereby overhead including the transmission is small. To utilize the inherent correlation within a region, the proposed scheme exploits prediction for the nontransmitted samples. This prediction which is required at both transmitter and receiver is based on the information within its region only. Receiver recovers a sample with predicted value and the received data, while transmitter always sends the error between predicted value and the actual value. Error for the previous stage data is always zero because the information is already known and there is no need to retransmit this error. Since the range of intensities i.e., the difference between the maximum and the minimum intensity in the whole area is used as the criterion for quad-tree partitioning, the receiver can get an idea of the expected intensity when it receives the first sample. For example, if the range threshold is 32, all pixels in that region are guaranteed to have intensities between 68 and 132 (assuming that first data is 100). Transmitter can use shorter length code for transmitting the prediction information such as 6 bits for the previous case. This procedure yields an exact replica at the final stage. To obtain a lower bit rate, the lossy version of this technique will be described in the next section.

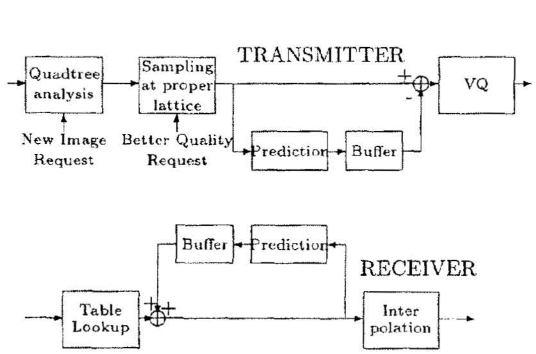

Figure 2. Block diagram of the proposed system.

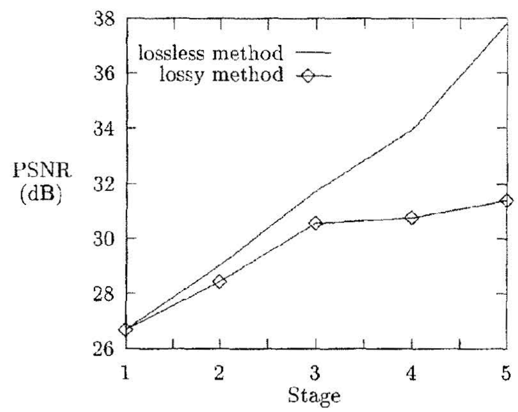

Figure 3. Comparison performance of Lena with the proposed coding system using different approaches.

3.2. Lossy approach

Fewer bits are possible to simplify the procedures described in the previous section by lossy approaches. Lossy encoder attempts to represent a prioritized sequence of data with the smallest size and error. Coder performs well in this system since it will face a more specific data. Quad-tree structure separates detail area from background. Slightly correlated nodes that are leaves simply because they are in the bottom level are considered to be detail areas. The remaining background which is highly dependent can be approximated without significant distortion and coder can be designed efficiently by concentrating on detail parts. The proposed system incorporates this feature in its lossy mode. Vector quantization (VQ) is selected to code samples on lattices because it can exploit nonlinear relationship of the main detail well.

Input vector is constructed based on characteristics of samples in lattice. Several input vectors are set up for each area corresponding to lattice density. Prediction process is employed in background area to utilize its dependent nature as previously described. Except the first stage, components of a background input vectors comprise the difference between samples in the current lattice and samples in the lower resolution lattice. These input vectors try to find the additional detail of the area based on the previous lattice. System quantizes these vectors with appropriate codebooks and gives an estimated additional detail to form the higher density lattice. Prediction technique, however, is not effective in detail regions where additional detail is less correlated with the information of the previous lattice. Input vectors in this case are basically a group of samples of the higher density lattice.

4. Simulation Results

Structure in Fig.2 has been used to evaluate the performance of the proposed system. Transmitter sends information on irregular lattice upon request from receiver. In this experiment, 3 densities of lattice relevant to the initial configuration are used to produce a 5 transmission stages. Configuration of lattice is determined from size of partitioned region after quad-tree decomposition. This size depends on its local information in terms of range but it must cover at least 4×4 pixels. All background leaves have range under the predefined threshold and occur in variable sizes while the remaining 4×4 pixel leaves are detail nodes. Prediction technique as previously explained is adopted in the input vector formation to allow a higher compression ratio. To establish the transmission, tree structure overhead (1 bit per node in the tree) is first transmitted followed by data of the first stage. Empirical lattice of each stage is tabulated in Table 1.

Four different codebooks are used to quantize input vectors in subsequent stages. Each codebook is trained by 6 typical images to code a particular lattice. Table 2 shows parameters of codebooks used in this paper. Linear interpolation specifies the missing samples in the original resolution based on information on the current lattice [2]. Test image 'Lena' which has resolution 512×512 pixels with 8 bits per pixel is transmitted with the proposed method. Results of the transmission with a threshold of 50 are listed in terms of PSNR (Table 3). Overhead embedded in transmission in this case is 8765 bits (0.033 bpp). Figure 3 plots the performance of the VQ based lossy system together with that of lossless system. Subjective results of 'Lena' are demonstrated in Fig. 4. It may be observed that the proposed system provides a pleasant quality at the low bit rate. It is also worth mentioning that improvement in detail area is important and an advance compression technique can be used at this process.

Table 1. Lattice densities

Stage	*Background leaf*	*Detail leaf*
1	1×1	1×1
2	1×1	2×2
3	2×2	2×2
4	2×2	4×4
5	4×4	4×4

Table 2. Codebook Parameters

Stage	*dimension*	*codebook size*
2	3	256
3	3	256
4	12	1024
5	12	256

Table 3. Simulation results for Lena image

Stage	*Bit Rate* (bpp)	*PSNR* (dB)
1	0.234	26.687
2	0.304	28.437
3	0.435	30.585
4	0.522	30.776
5	0.653	31.404

5. Conclusions

New transmission system has been developed in this paper. It serves the requirements of PIT well because it tries to retrieve the vital information in the area first. Loss in the reconstruction process is also limited with the benefit of quad-tree decomposition. Moreover, this scheme can provide a graceful improvement over the crude data of the previous stage by using the appropriate lattice density. This method is applicable for lossless transmission. Prediction based VQ is also employed in the lossy system for low bit rate compression. Results of the proposed system show a good quality of reconstructed image at the low bit rate.

References

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(a)

Figure 4. Subjective results of the proposed system at (a) stage 1, (b) stage 2, (c) stage 3, (d) stage 4, (e) stage 5.

(b),(c)

(d),(c)