An Efficient Image Processing on Sensor Networks

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***Abstract*—The power consumption rate and bandwidth gain are the two major design criterions considered in the sensor networks, since the sensor nodes in the network are usually with limited capabilities in terms of processing power and bandwidth availability. These two criterions are usually contradictory to each other. However, the efficiencies of power consumption rate and bandwidth gain are achieved simultaneously in the image processing on sensor network proposed in this paper. This is made possible by a technique innovation: image processing in the compressed form. It is noted that in the conventional approach the compressed image must be decompressed first to be processed. This innovation makes the compression and processing a joint design not two separate processes as before.**

Keywords- morphological image processing; quad tree; sensor network

I. INTRODUCTION

Signal processing and data compression should be considered together as a whole to make totally efficient. More specifically, we propose in this paper to have signal processing and data compression suitable for being aware, reasoning and thus convenient for the sensor network [1-2] to make a decision. We accomplish this purpose by making data compressed and signal processed both functionally, i.e., being able to be accessed and processed to a specific interest. More clearly, the data is compressed in the hierarchical data structure processed by morphological image processing. Most importantly, we implement our morphological image processing on the hierarchical data structure [3-4] instead of on the pixel matrix. Therefore, the signal processing and compression are joined together. To our knowledge, this joint processing concept is newly proposed.

The morphology processing has long been applied successfully to industry auto-inspection and medical image processing [5-6]. There are many efforts on hardware implementation to facilitate the morphological processing [7-10]. Neural network consideration was also investigated in [11]. Morphological processing has recently been applied to video coding in sensor network by shape compensation [12], and cognitive sensing [13-14]. The quad tree data structure has been well applied to the field of computer vision such as image segmentation and compression [15-16]. The quad tree with its hierarchical data structure is computationally efficient. The quad tree is based on the principle of recursive decompositions of space. The technique of recursive call has been further developed to extend to the imbedded system [17-18] applications.

The conventional morphological image processing is processed by a pixel vs. pixel basis with the pictures stored in the matrix form. In contrast, the proposed morphological processing in the quad tree data structure can be processed by a block vs. block basis. The pyramid approach can be also classified as fast block basis processing but without the compression consideration due to the pyramid layer of every resolution in matrix form. The proposed approach is novel to achieve fast morphological processing jointly with image compression.

The power consumption rate and bandwidth gain are the two major design criterions considered in the sensor networks, since the sensor nodes in the network are usually with limited capabilities in terms of processing power and bandwidth availability. These two criterions are usually contradictory to each other. However, the efficiencies of power consumption rate and bandwidth gain are achieved simultaneously in the image processing on sensor network proposed in this paper. This is made possible by a technique innovation: image processing in the compressed form. It is noted that in the conventional approach the compressed image must be decompressed first to be processed. This innovation makes the compression and processing a joint design not two separate processes as before.

II. IMPLEMENTATION CONCEPTS WITH WORKING EXAMPLE

It is noted that by the quadtree decomposition, any binary image can be decomposed into black and white square blocks with some fixed size of power of 2. Thus, dilation of the whole image can be accomplished by dilating individual decomposed square blocks. White square blocks do not need dilation, black square blocks take a simple dilation by the tree pattern copy operations. The tree patterns are the dilation results of black square blocks and can be computed as patterns in advance for preparation. It is common for very many dilated block to share the same tree patterns. Therefore, the implementation concepts can be summarized as two strategies: block vs. block processing using pattern method and efficient transformation from sequential access string format to direct access pointer format. A working example is illustrated in Fig. 1.

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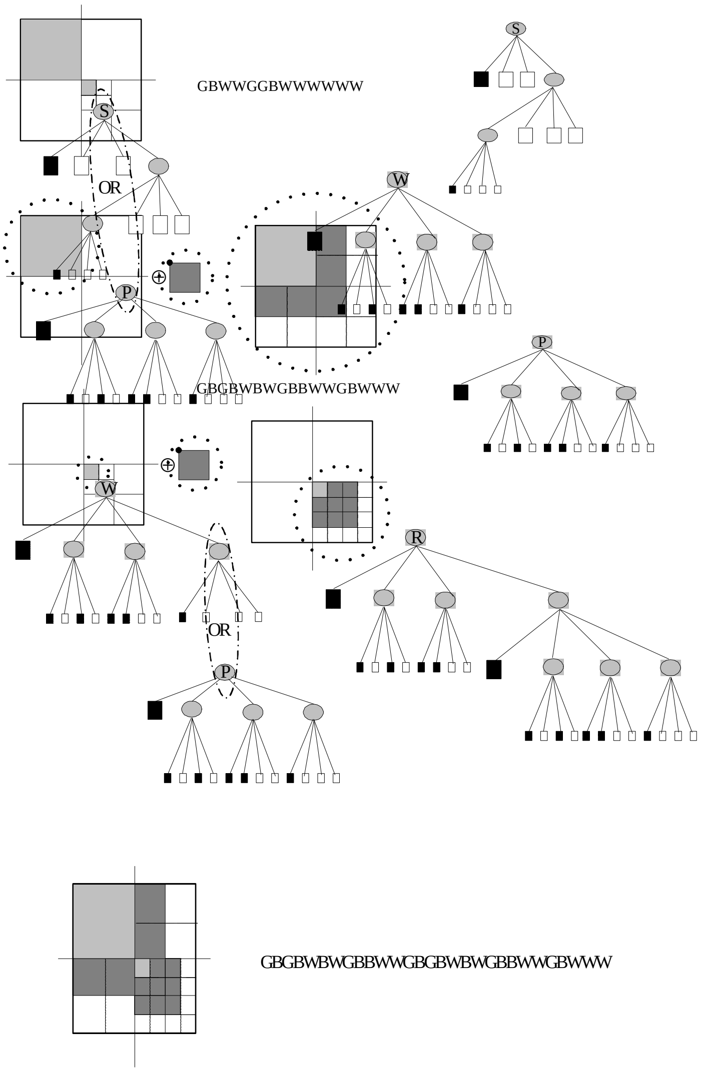


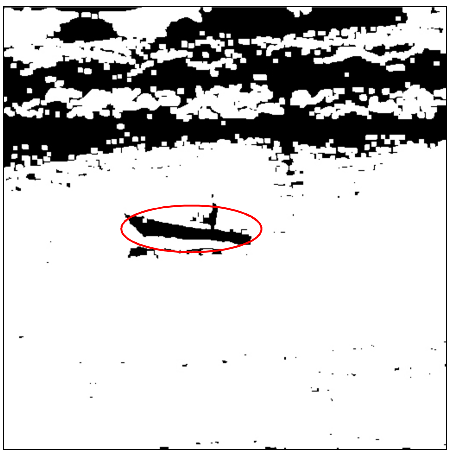
Fig. 1. Working example of dilation by the tree pattern copy operations.

III. Experiments On Sensing Application

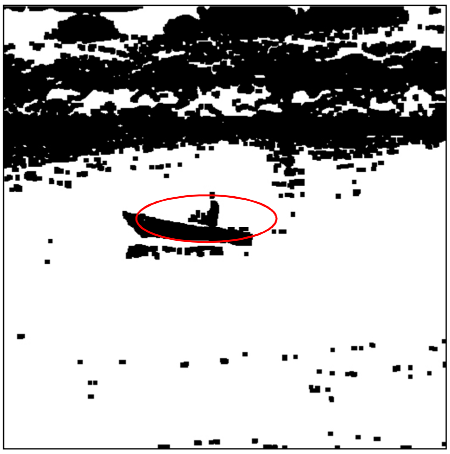
For sensing need, the workout example is a continuation to our research on low bit-rate video coding for sensor network. This continuation extends video coding to target tracking. The goal of this working example is to find object "boat", which is also set for the performance comparison. The boat obtained from the best resolution is regarded as the benchmark as in Fig. 2. The boats obtained from the lower resolutions appear image quality degradation as shown in Fig. 3. Accordingly, the quality degradation can be interpreted as "distortion", which is further numerically defined as the error count from the error image referenced to the benchmark for every resolution. The error images are shown in Fig. 4.

(a)

(b)

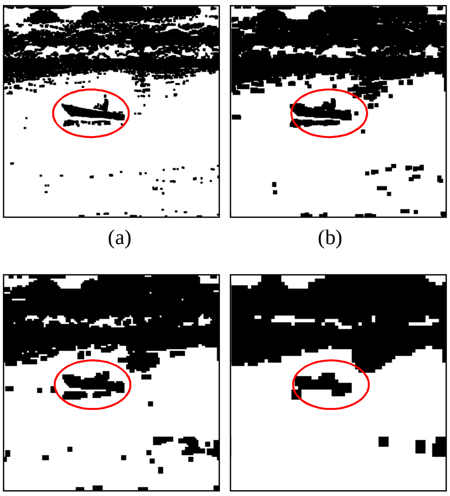


(c)



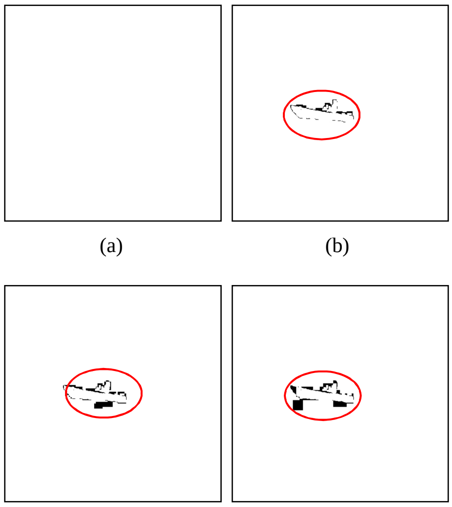
(d)

Fig. 2. Intermediate results of working example for target tracking using four resolutions: only the highest resolution is shown in this figure (a) the original 512*512 grey picture (b) the 512*512 binary picture (c) eroding b by structuring element 4*4 square (d) dilating c by structuring element 4*4 square



(a) (b) (c) (d)

Fig. 3. Final results of working example: eroding, dilating using different resolutions compared to Fig. 5 (but Fig. 5d repeated here as Fig. 6a) (a) the highest resolution: 512*512 original picture with 4x4element (b) the second resolution: 256*256 original picture with 4x4 element (c) the third resolution: 128*128 original picture with 2x2 element (d) the fourth resolution: 64*64 original picture with 2x2 element



(a) (b) (c) (d)

Fig. 4. Error results of working example: The target error is referenced to the target obtained by the highest resolution in Fig. 6a as the benchmark (a) the first resolution is a blank picture because there is no error at all (b) the second resolution (c) the third resolution (d) the fourth resolution.

As a summary of our experiments, three procedures are applied in our signal processings: (I) binarized quantization, (II) down sampling in resolution (III) shape compensation by morphological operations. It is noted that the error results are compared for different resolutions in procedures II and III.

IV. Rate–Distortion Performance Analysis

Rate–distortion theory is a major branch of information theory about source coding, which provides the theoretical foundations for lossy data compression; it addresses the problem of determining the smallest compression rate R to encode the source signal without exceeding a given distortion D when reconstructed by the coded data bits. The compression rate corresponds to the cost of data bits and the distortion represents the performance. To apply the rate-distortion theory to our work, we first define the distortion as the error counts from the error images referenced to the target image computed by the best resolution. Secondly, we interpret the rate as the power consumption rate instead of the original data rates.

TABLE I

NODES INFORMATION FOR THE PICTURE "BOAT"

	Gray	Black	White
Level 9	1	0	0
Level 8	4	0	0
Level 7	16	0	0
Level 6	64	0	0
Level 5	247	8	1
Level 4	886	67	35
Level 3	2861	281	402
Level 2	7473	1277	2694
Level 1	13472	6795	9625
Level 0	0	26168	27720

TABLE II
SPEED EFFICIENCY COMPARISON

Methods	Direct Method	Propose Method
Structuring Element	time (msec)	Time(msec)
2 x 2 square	4468	375
4 x 4 square	10764	313
8 x 8 square	31640	406
distributed squares	13483	1172

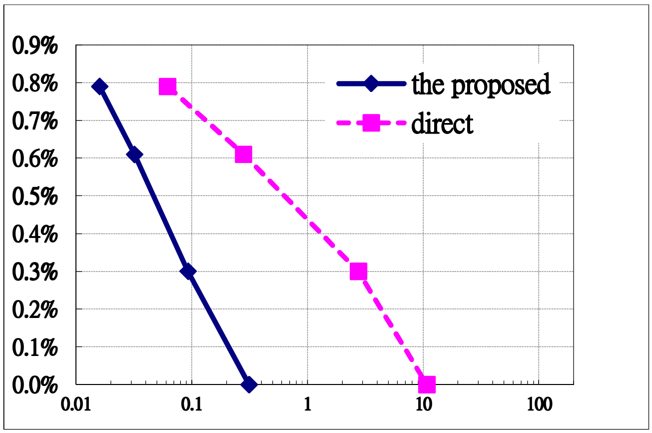


Fig. 5. The rate-distortion performance comparison in consumption power for two methods: the logarithm in the processing (horizontal) axis is also required because of too large deviation for the two processing power spent in the respective methods.

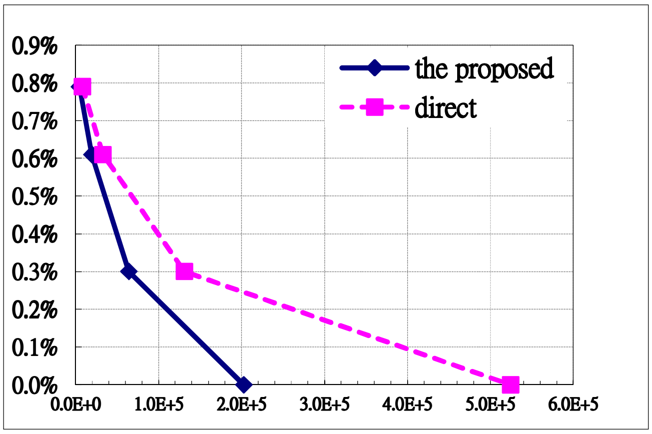


Fig. 6. The rate-distortion performance comparison in communication bandwidth for two methods.

The transmission bandwidth in our analysis is roughly computed by the data bits of the testing image because the bandwidth cost is proportional to the data bits transmitted in transmission. It is straightforward to count the data bits for the direct method, in which the picture is stored in the matrix form. In contrast, the data bits for the proposed method are computed from the node information in Table I. It is noted that the rate-distortion analysis for bandwidth can also be interpreted as the analysis for consumption rate for transmission power since the transmission power is usually proportional to the data rates. The processing power is approximated by the processing time, which is simply measured in average of 100 times and listed in Table II. As a summary, we can associate the processing time and data bits with the concepts of power cost and bandwidth cost respectively and have the corresponding two cost-distortion (rate-distortion) functions represented in Fig. 5 and 6.

V. CONCLUSIONS

In this paper, three strategies are proposed to improve the bit processing rate. First, utilizing the sensor's special feature, which emphasizes on decision not for visual aesthetics or entertainment purpose. Second, exploiting an appropriate functional image processing such as the morphological image processing, which provides the feature only (not the detail) for decision. Third, developing an image processing in the compressed form such as in the quadtree data structure, which is advantageous in the low resolution. Strategy 3 requires a technique innovation, image processing in the compressed form. It is noted that in the conventional approach the compressed image must be decompressed first to be processed. This innovation makes the compression and processing a joint design not two separate processes as before.

Morphological processing is suitable for fast module applications in sensor network because it is built upon simple logic operations with many extended functional interpretations such as erosion, dilation, thinning, and pruning. The processing efficiency can be further improved by being implemented in hierarchical data structure. With its hierarchical data structure, the morphological processing can be applied to be focus on any specific blocks. The conventional direct method for morphological image processing is processed by a pixel vs. pixel basis with the pictures stored in the array form. In contrast, the morphological processing with a hierarchical data structure can be processed by a block vs. block basis. This joint processing concept is first time proposed in this paper. The processing efficiency is also verified in our experiments.

The rate-distortion theory is applied to our bandwidth gain analysis by defining the distortion as the error counts from the error images referenced to the target image computed by the best resolution. Meantime, the rate-distortion theory is further modified by us to study the power consumption rate if the rate is simply interpreted as the power consumption rate instead of the original bit rates. As a summary, it is the efficiencies in both the compression and the speed performance to make the proposed method outperform the direct method significantly in the rate-distortion analysis.

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