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포터블 임베디드 시스템을 위한 웨이블릿 영상 부호화기

(An Efficient Wavelet Image Coder for Portable Embedded System)

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요 약

본 논문에서는 제한된 자원을 가지는 포터블 임베디드 시스템을 위하여, 작은 메모리 사용으로 효율적으로 영상 부호화가 가능한 웨이블릿 영상 부호화기를 제안하였다. 제안된 방법은 부호화 과정시 요구되는 메모리 사용량을 줄이기 위해 웨이블릿 계수들의 비트 레벨 정보를 가지는 2차원 중요 계수 배열을 사용한다. 제안된 방법은 중요 계수에 대한 부호화 과정과 계수들의 비트 레벨 정보의 부호화 과정을 한 번에 수행할 수 있다. 실험 결과 기존의 부호화 방법보다 화질 면에서 비슷하거나 우수한 성능을 보였으며, 2차원 중요 계수 배열을 이용한 최소의 메모리 사용으로 다양한 비트율에서 영상의 일그러짐 없이 안정적으로 동작함을 확인하였다.

Abstract

In order to provide an efficient way to processing with limited resources, we propose a wavelet coder that operates with little memory usage on the portable embedded system. In order to reduce redundancy in coding process caused by repetitive scanning of wavelet coefficients, the proposed coder uses a 2D significance coefficient array (SCA) which records the bit-level information of wavelet coefficients. The 2D SCA improves memory usage and processing speed required for image coding because it can perform significance check and bit coding of coefficients simultaneously

Keywords : Portable Embedded System, Wavelet Image Coder

Ⅰ. Introduction

In recent years, embedded systems have gained much momentum in both research and engineering, and portable digital devices have become popular. Image processing capability of embedded systems is highly favorable and issues such as providing efficient coding methods into small portable embedded digital systems are under study.

The design of the portable embedded system tends to restrict its performance in order to reduce cost and power consumption. Although portable embedded systems are required needs to process and transmit image data through wired or wireless communication channels, there are limitations on the memory size and computational capabilities due to their structural characteristics. To overcome these constraints, more efficient video coding methods are necessary.

Among many image coding methods, the wavelet transform-based coding method can eliminate blocking artifacts, which appear in block-based coding systems such as JPEG. Also, wavelet transform-based coding has higher compression rates than block-based coding systems. These

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forementioned advantages have encouraged engineers to research wavelet-based image coding methods[1-5].

The embedded zero-tree wavelet (EZW) algorithm uses successive approximation quantization (SAQ) method that utilizes self-similarity among between subbands on the same direction in wavelet transformed images[6]. Set Partitioning in Hierarchical Trees (SPIHT) algorithm is more efficient than EZW because it codes only significant subbands after determining significance of each subband through examining its coefficient set.

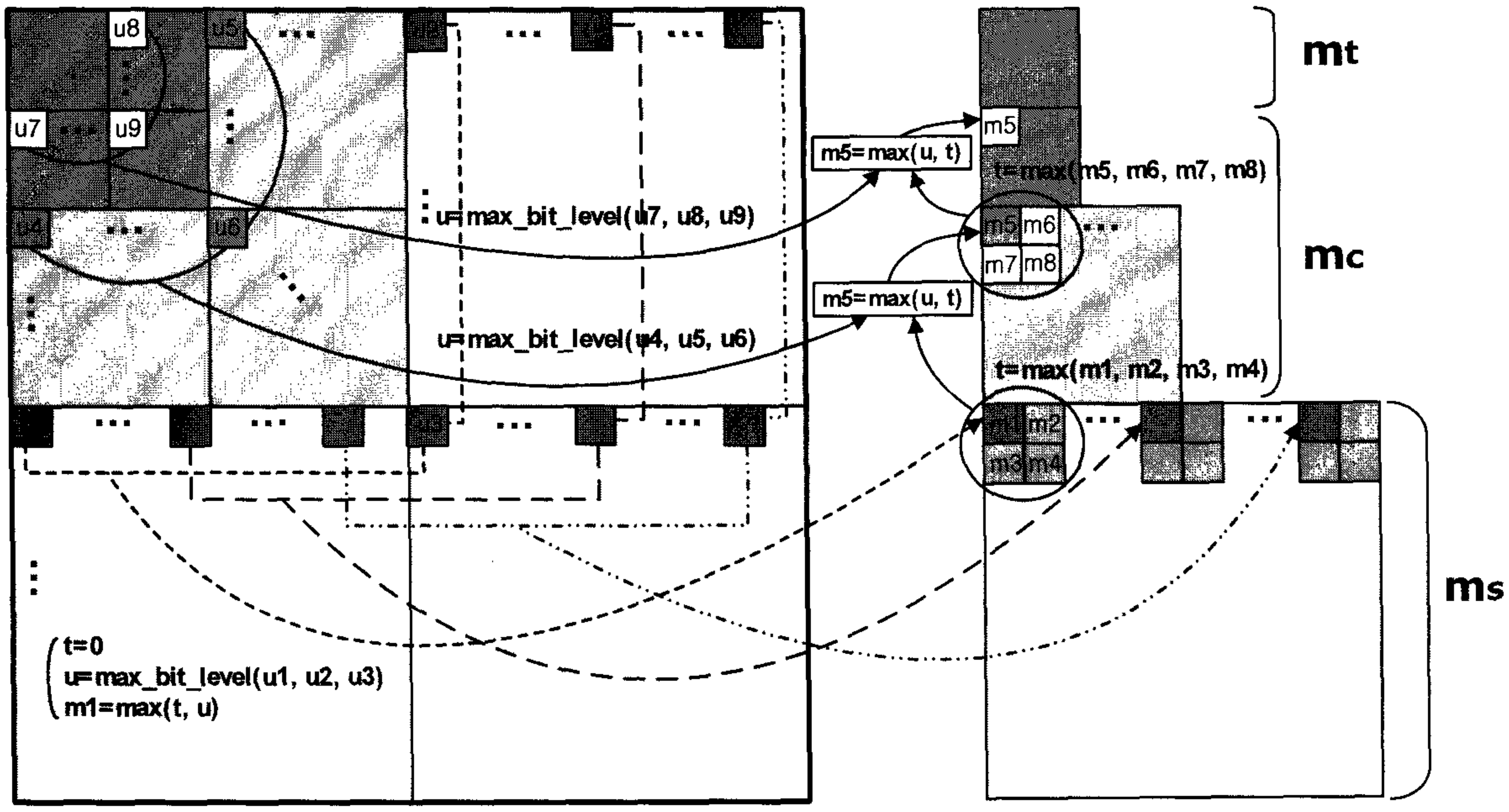
We propose wavelet transform based image coder that requires less memory and performs more efficient coding in restricted environments such as portable embedded systems. The proposed method can perform zero-tree coding more effectively by using a 2D SCA which has bit-level information of wavelet coefficients, and can improve redundancy of the coding process caused by repetitive scanning of wavelet coefficients. Both memory usage and processing speed benefit since the significance checking and coefficient scanning are done simultaneously.

This paper is organized as follows. Section 2 describes the 2D SCA for bit-level information preservation of the wavelet coefficients. Section 3 describes our proposed coding method. Section 4 includes the test results on our proposed method, and Section 5 concludes this paper.

Ⅱ. 2D Significance Coefficient Array

Large amount of time is needed to check significance of wavelet transformed coefficients. We propose a 2D SCA to store bit-level information which is essential for faster and effective significance checks of coefficients. As shown in Fig. 1, each element of the 2D SCA has level information of bits that are required represent the greatest coefficient value of each subband in the same position at the same level of a wavelet pyramid.

To generate a 2D SCA, let's assume the height of wavelet coefficient pyramid is H and the width of wavelet coefficient is W. If the number of pyramid level is S, excluding the scaling coefficient level L which represents low-resolution image information, the height and width of scaling coefficients are $H_L=H/2^S$ and $W_L=W/2^S$ respectively.



(a) Wavelet coefficient pyramid (b) 2D SCA

그림 1. 중요 계수 배열의 생성

Fig. 1. Generation of significant coefficient array.

Each level in the 2D SCA is defined as follows.

$$W_{x,y} = W_L 2^{\left\lfloor \log_2(\max(1, \frac{y}{H_L})) \right\rfloor}$$

$$H_{x,y} = H_L 2^{\left\lfloor \log_2(\max(1, \frac{y}{H_L})) \right\rfloor} \tag{1}$$

And, $m_{x,y}$ the element of the 2D SCA, is defined to $m_t(x,y)$, $m_c(x,y)$ and $m_s(x,y)$ as described in Eq. 2.

$$\begin{aligned} m_t(x,y) &= \max\left\{m_{x,y+H_s}, \left\lfloor \log_2(\left|c_{x,y}\right|) \right\rfloor + 1\right\} \\ m_c(x,y) &= \max\{m_{2x,2y}, m_{2x+1,2y}, \\ &\qquad m_{2x,2y+1}, m_{2x+1,2y+1}\} \\ m_c(x,y) &= \left\lfloor 1 + \log_2\left(\max\left\{ \left|c_{x,y}\right|, \left|c_{x+W_{x,y},y}\right|, \right.\right.\right. \\ &\qquad \left.\left.\left. \left|c_{x+W_{x,y},y-H_{x,y}}\right| \right\}\right) \right\rfloor \end{aligned} \tag{2}$$

where *x* and *y* has range of $0 \le y < H$ and $0 \le x < W_L 2^{\left\lfloor \log_2\left(\max\left(1, \frac{y}{H_L}\right)\right)\right\rfloor}$ respectively. As shown in Eq. 2, $m_t(x,y)$ has significant coefficient information of the highest subband level(*L*). $m_s(x,y)$ has the coefficient information of the lowest subband level(Level 1) and $m_c(x,y)$ has the coefficient information of the other subband levels. Therefore, the 2D SCA array $m_{x,y}$ stores the coefficient information of the greatest value in the same position of the same level of each subband. According to Eq. 2, the flow of the 2D SCA generation is shown in Fig. 2.

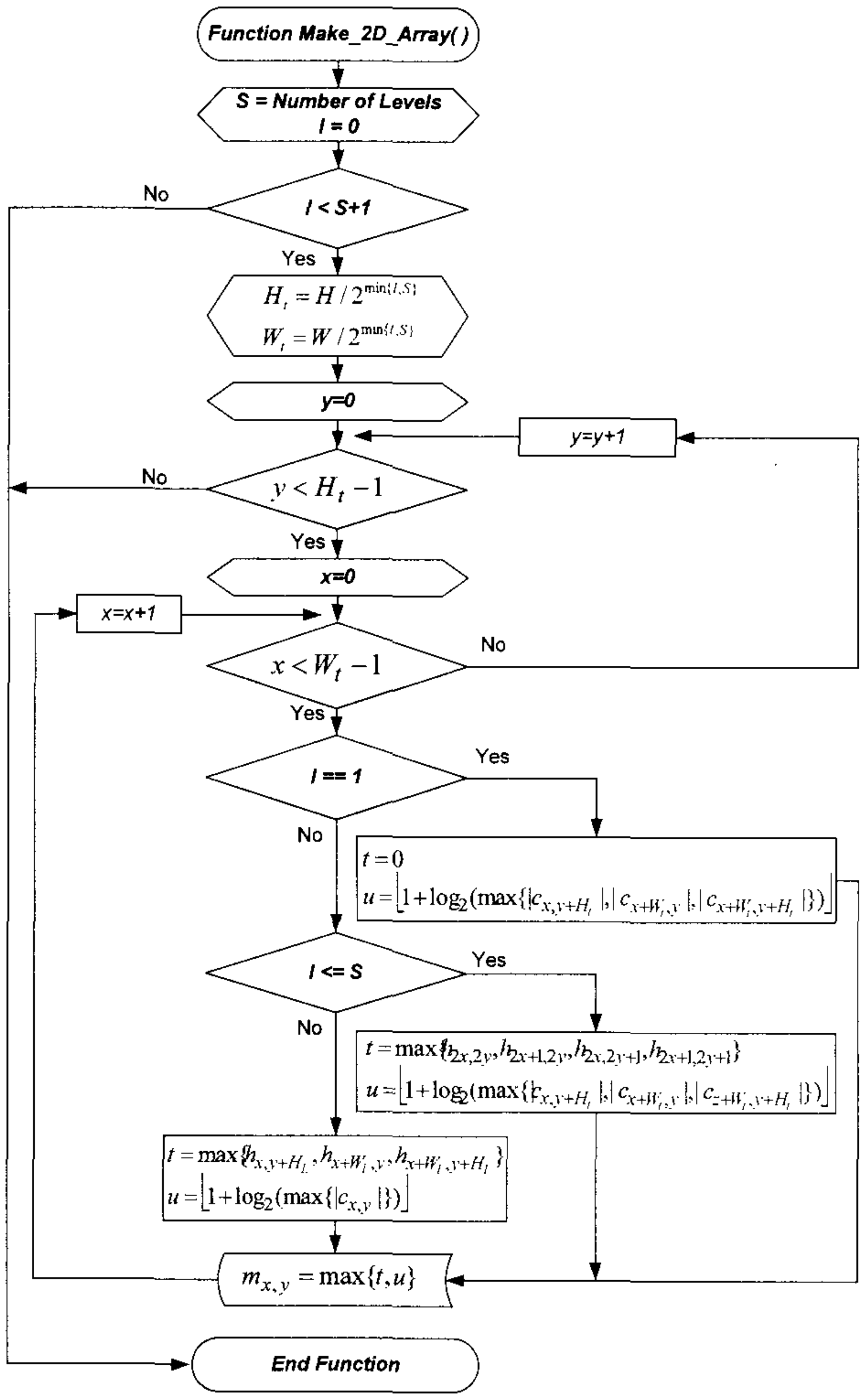


그림 2. 2차원 중요 계수 배열 생성 흐름도
Fig. 2. Flow chart of 2D significant coefficient array generation.

Ⅲ. Proposed Coding Algorithm

The block diagram of proposed wavelet image coder is shown in Fig.3.

Image is transformed into wavelet space by 2D wavelet decomposition. 2D SCA is generated to store bit-level information of wavelet coefficients, and adaptive arithmetic coder(QM-Coder) is initialized for binary symbol coding. Wavelet transformed coefficients are scanned bit by bit from most significant bit(MSB) with bit scanning algorithm, and the output values are arithmetically coded by QM-Coder. Decoding process is performed by opposite order of encoding. The flow chart of overall proposed coding algorithm is shown in Fig.4

Fig. 5. shows the bit-level scanning algorithm of wavelet coefficients. Scanning algorithm firstly checks coding stopping condition. Stopping condition is specific bit-rate that is required to represent desired image quality. Termination of coding algorithm is determined by function *Continue_Coding()*. This function returns true or false value by calculating bit-rate that is produced during encoding. Encoding continues when the returned value from function *Continue_Coding()* is true, and is stopped when the returned value is false. And, the result values are coded after searching 2D SCA to check whether zero-tree is started from current position. In the case that the current coefficient is started by

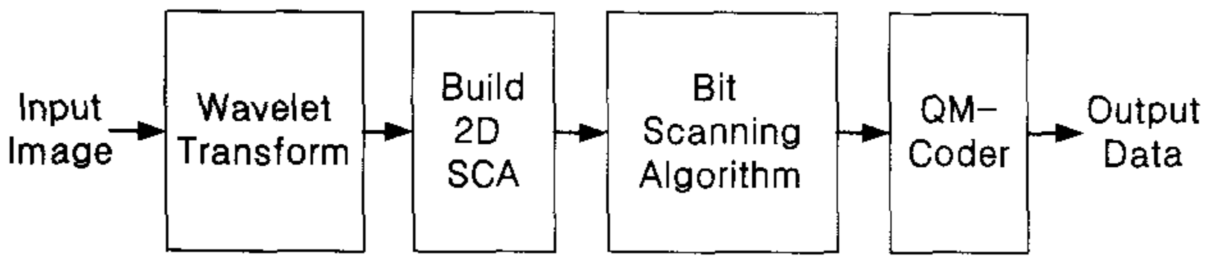


그림 3. 제안된 웨이블릿 부호화기의 블록도
Fig. 3. Block diagram of proposed wavelet coder,

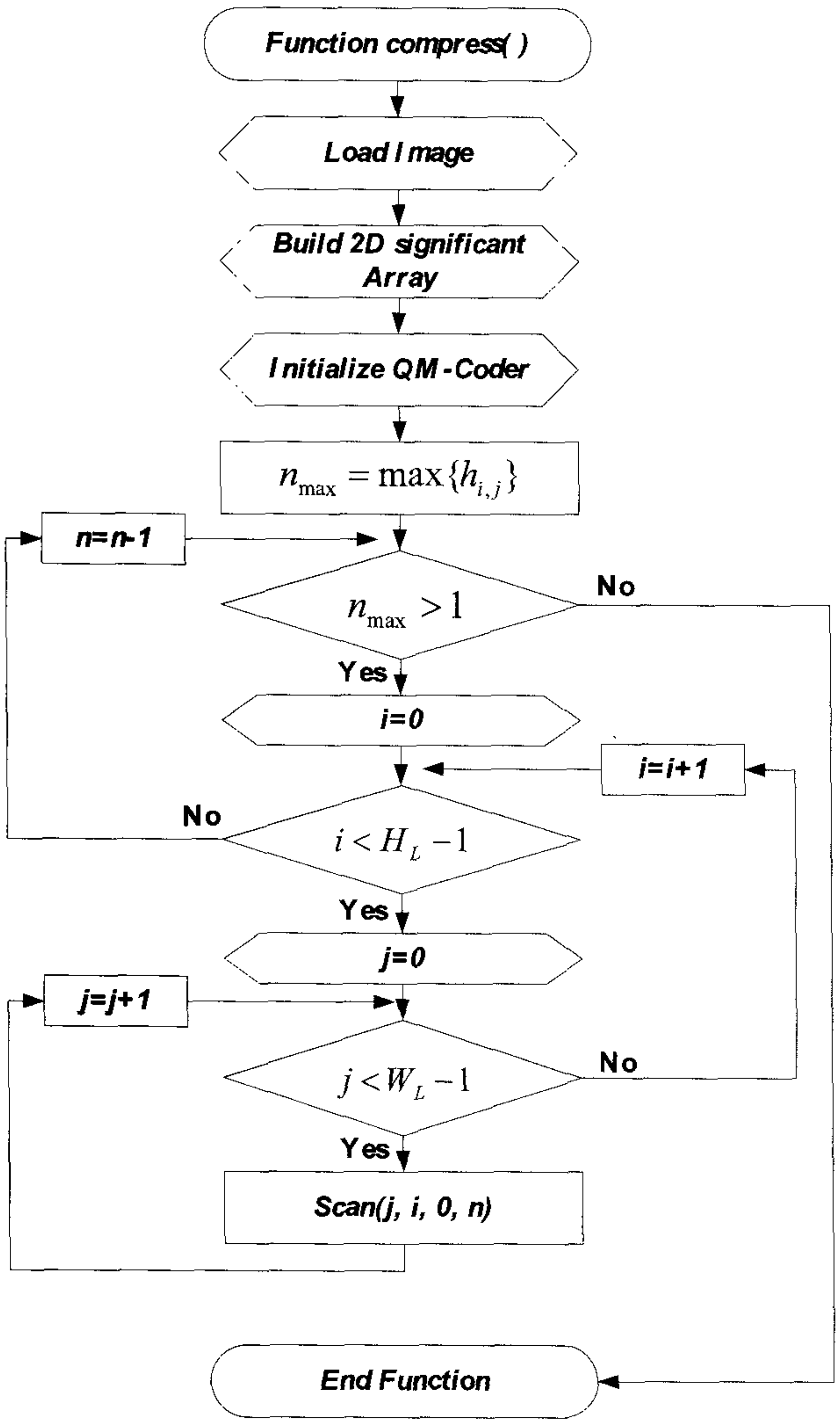


그림 4. 제안된 부호화 알고리즘의 흐름도
Fig. 4. The flow chart of proposed coding algorithm.

zero-tree, bit coding on the coefficients in lower level of current pyramid level can be omitted. Because scanning algorithm is recursive structure, the coefficients of same position in the next lower level of current pyramid level are scanned recursively. In the case that the coefficients in lower level are encoded, all the coefficients in subbands of every direction are processed. If there is another next lower level, descendant coefficients in that level are searched recursively

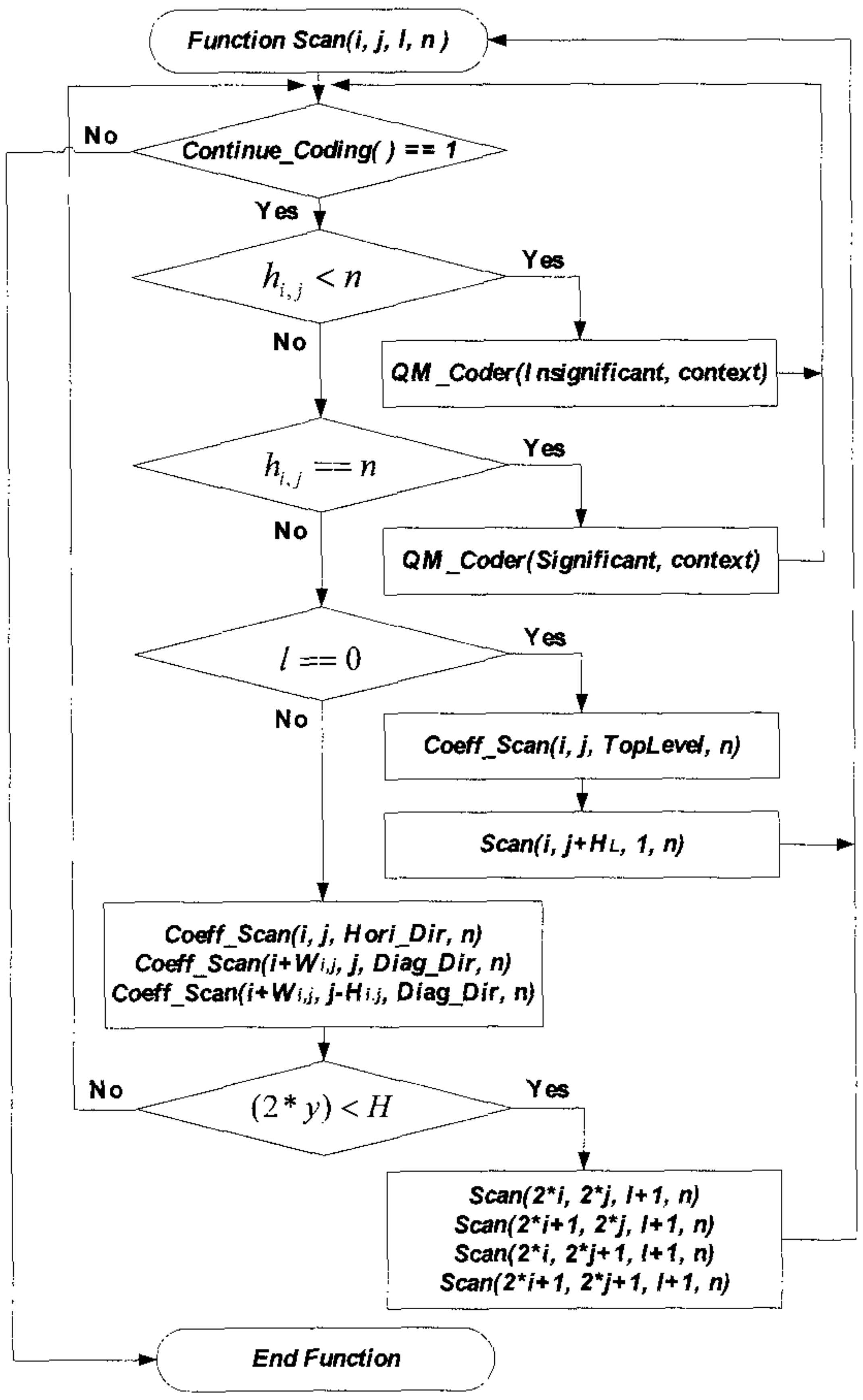


그림 5. 비트-레벨 스캐닝 알고리즘
Fig. 5. Bit-level scanning algorithm.

The bit-level coding algorithm of wavelet coefficients is shown in Fig.6. *Coeff_Scan()* checks whether coefficients are significant. If coefficients are significant, the bit-level of current coefficient is coded and bit-rate is calculated to determine whether produced bit rate satisfies desired bit-rate. If the coefficient is smaller than 2^n , MSB of coefficient should be checked. In the case that MSB is 1, the sign of coefficient is reflected in encoding and bit-rate is calculated to determine whether bpp is satisfied.

In this algorithm, function *Bit_Return(x, n)* returns *n*-th bit value of absolute value of *x*, $s_{i,j}$ is the sign of wavelet coefficient at position *(i, j)* and $c_{x,y}$ means wavelet coefficient at position *(x, y)*. Bits generated by *Bit_Return(x, n)* are arithmetically coded by *QM_coder(b, context)*. QM-Coder, which is one of the adaptive arithmetic coding method, is entropy encoder provided by JBIG(Joint Bi-level Image Experts Group)[7]. Where, argument *b* means bit that

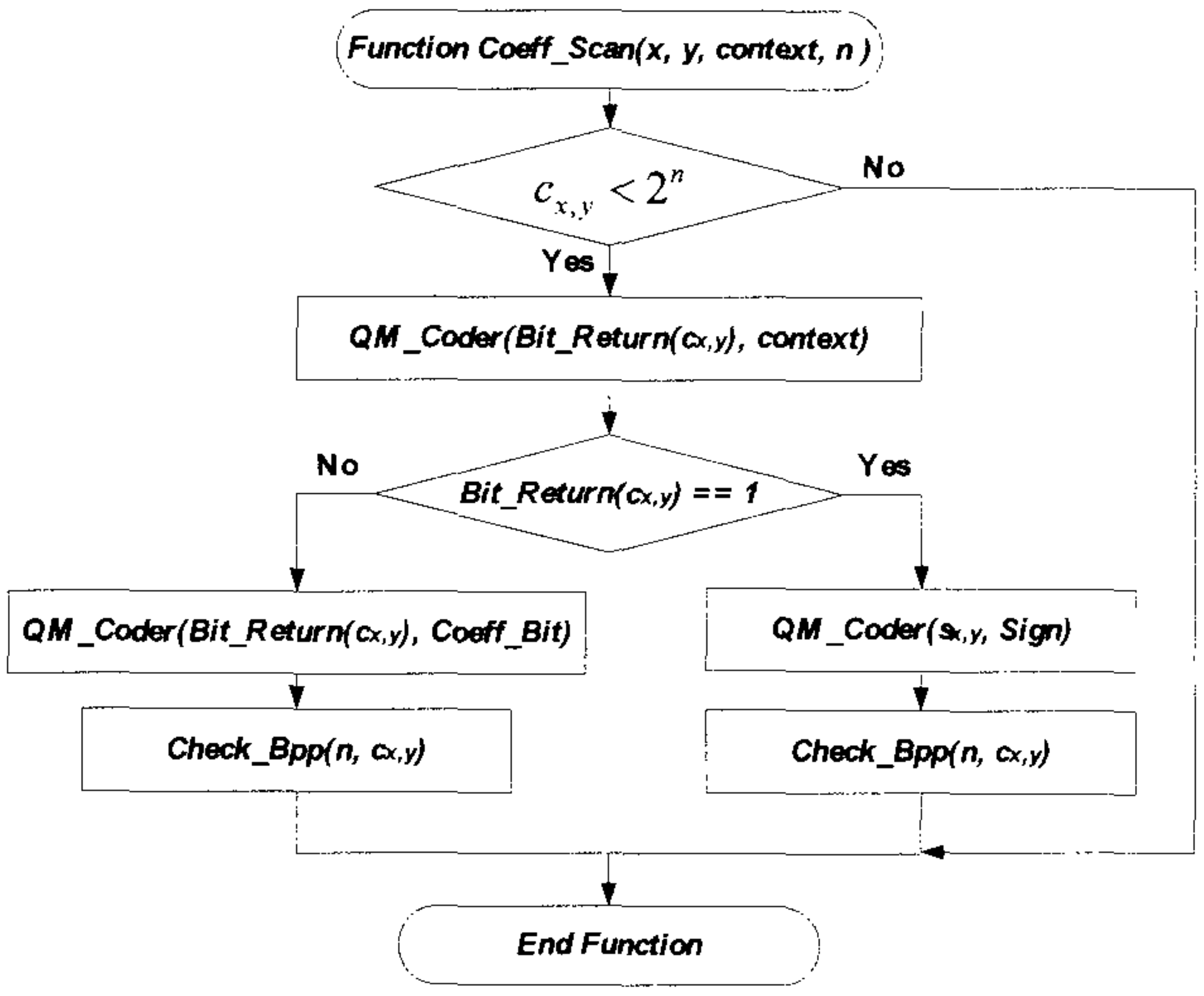


그림 6. 비트-레벨 코딩 알고리즘
Fig. 6. Bit-level coding algorithm.

are being coded and context means the pattern for probability estimation of the symbol that are being coded. Coefficient coding algorithm calculates approximated image quality of current coding stage by using MSE to determine stopping condition. It is performed by calling function *Check_Bpp()* whenever n-th bit of coefficient x is being coded.

Ⅳ. Experiments and Result

Embedded system shown in Fig. 7 is used to test performance of proposed coder[8]. The system consists of Xscale PXA250, which is the Intel's low power 32-bit RISC processor, 32MB flash ROM and 64MB SDRAM. PXA250 processor is embedded type RISC processor that operates at 400Mhz of clock speed and has 150MIPS of processing capability. Linux 2.4.5 Kernel is used for operating system. C language is used for software and its compilation is done on ARM Linux gcc 2.95.3 compiler. All tasks are performed by serial communication and telnet through serial port and ethernet port on Linux Redhat 6.0 based host PC.

Lena and Barbara images of 515x512 resolution are used for experiments and Daubechies 9/7 wavelet filter is used for wavelet transform. PSNR values produced by EZW, SPIHT, Baseline JPEG, EZDCT[9] and ZTE of MPEG-4 methods[10] are compared for

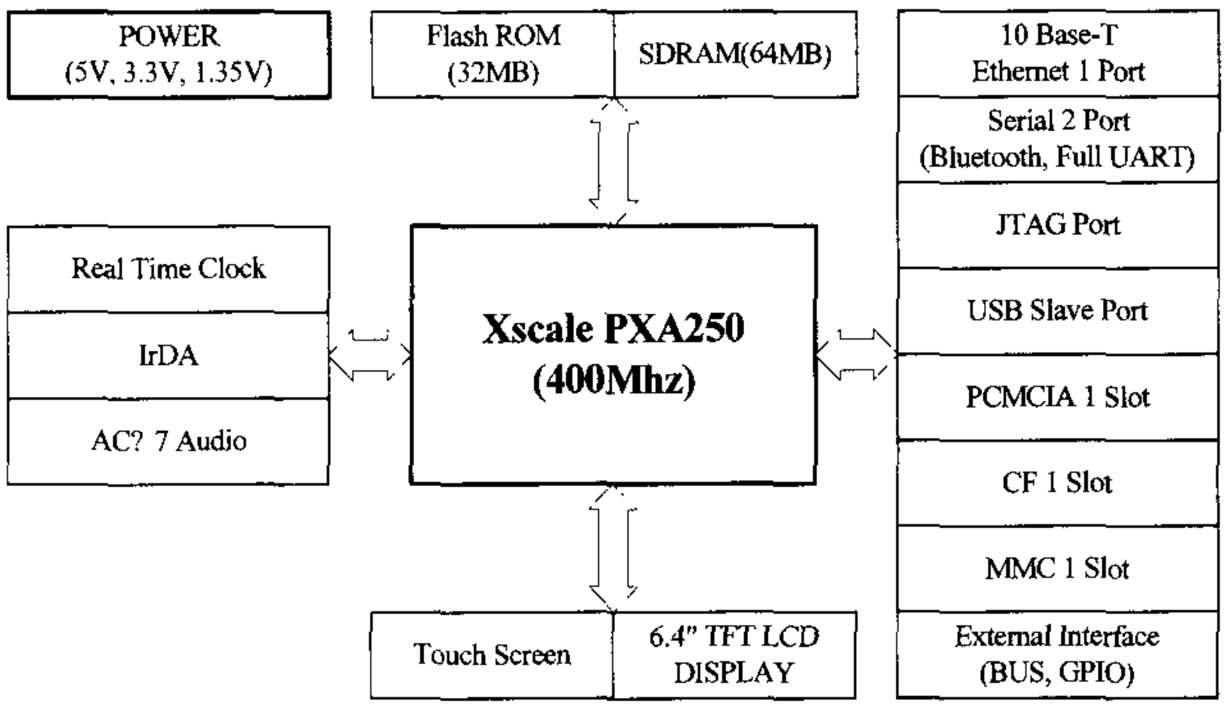


그림 7. 임베디드 시스템 블록 다이어그램
Fig. 7. The block diagram of embedded system.

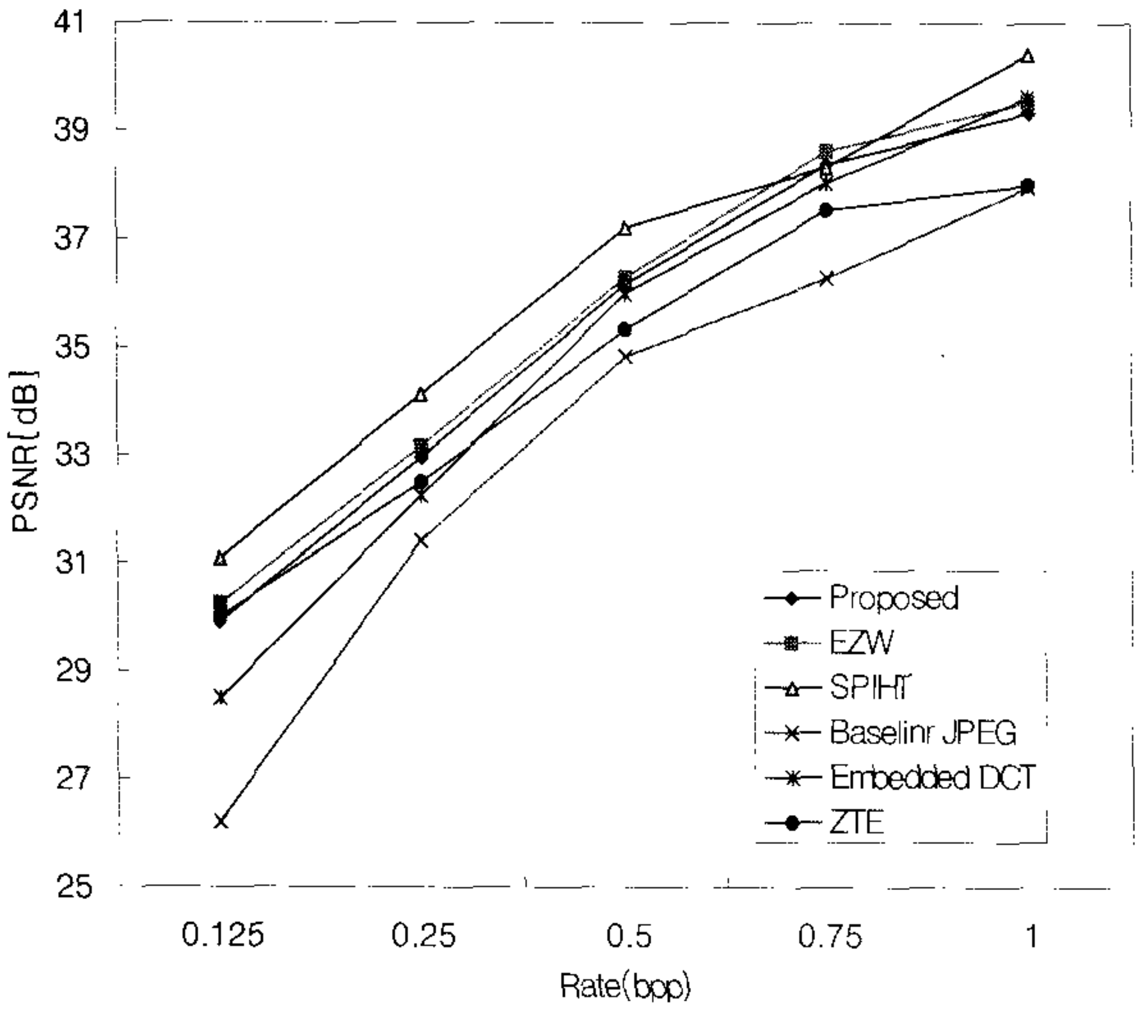
image quality test.

The PSNR at each bit-rate are shown in Table 1 and Fig. 8. Performance for both Lena and Barbara images is not better than SPIHT, however it is much better than JPEG and similar to EZW. Our algorithm shows performance as good as other algorithms at bit-rate lower than 0.5bpp. The original and reconstructed images processed by proposed algorithm are shown in Fig.9. The reconstructed image at low bpp shows good quality without distortion between adjacent blocks.

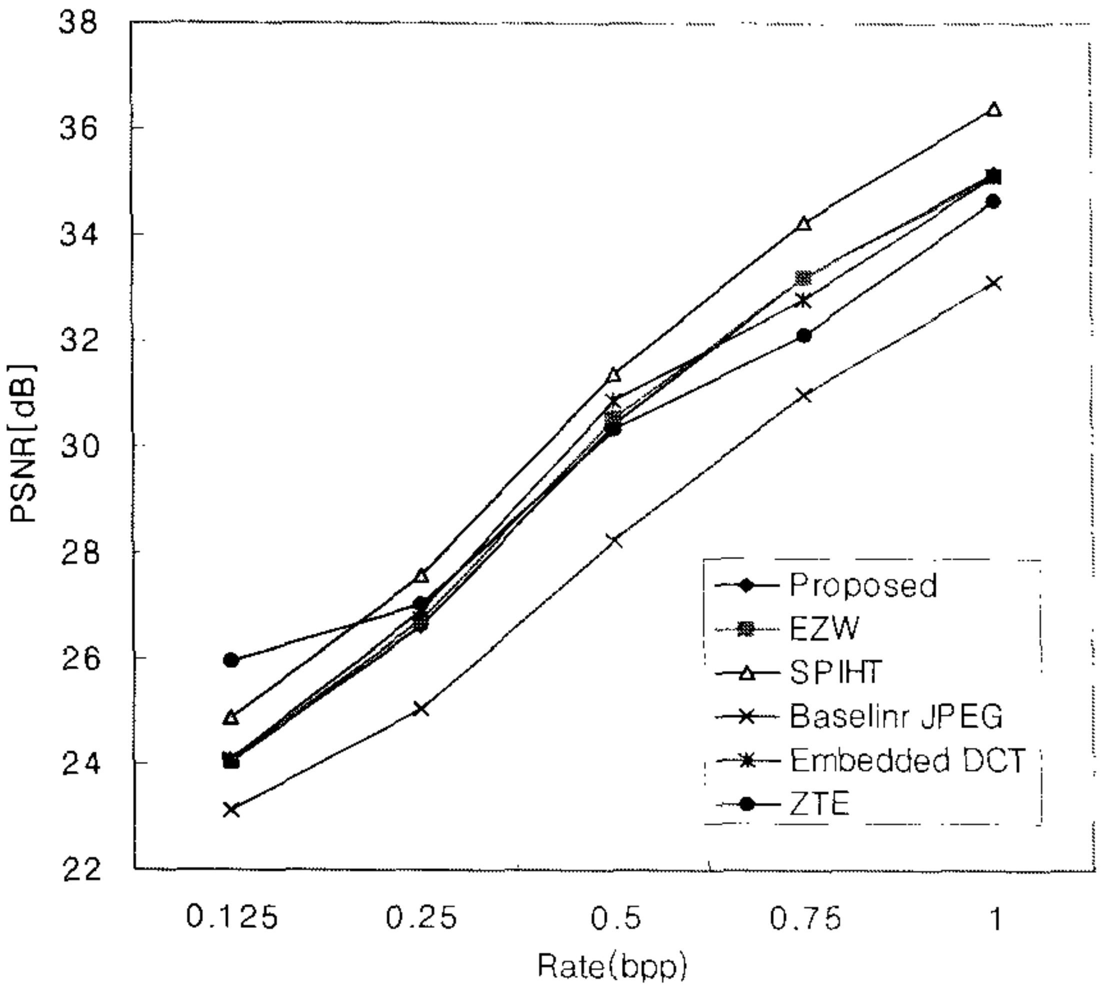
We could not calculate exact memory usage of encoding due to experimental difficulties. But, if data type would be 16-bit integer, theoretically EZW or SPIHT requires approximately $16 \times N$ bits memory size for coding, however proposed coder requires only $(16 \times N)/3$ memory size. Where, N is the number of coefficient. If we code $2^n \cdot 2^n$ resolution image, which has $16(2^4)$ bit size of data type, other coders require $2^n \cdot 2^n \cdot 2^4$ bit size of memory, but proposed coder requires $\left[\left(\sum_{m=4}^{n} 2^{m-1} \cdot 2^{m-1}\right) + \left(2^3 \cdot 2^3\right)\right] \cdot 2^4$ bit size of memory. For example, in the case that 512x512 resolution Lena image is coded by 6-level wavelet transform, other coders use $2^9 \cdot 2^9 \cdot 2^4$(524,288byte) size of memory, but proposed coder use only $\left[\left(2^8 \cdot 2^8 + \cdots + 2^3 \cdot 2^3\right) + (2^3 \cdot 2^3)\right] \cdot 2^4$ (174,848byte) size of memory. Therefore, proposed coder can encode images with only 33.35% of memory usage compared to other coders, and 66.65% of memory usage is reduced.

표 1. 다양한 비트율에서의 PSNR 결과
Table 1. PSNR result according to various bit-rates.

algorithm \ bpp		0.125	0.25	0.5	0.75	1.0
Lena	Proposed	29.93	32.97	36.15	38.36	39.34
	EZW	30.23	33.17	36.28	38.64	39.55
	SPIHT	31.09	34.11	37.21	38.32	40.41
	JPEG	26.21	31.42	34.84	36.6	37.95
	EZDCT	28.5	32.27	35.98	38.04	39.61
	ZTE	30.01	32.51	35.32	36.75	37.95
Bar-bara	Proposed	24.04	26.61	30.41	33.19	35.15
	EZW	24.03	26.77	30.53	33.2	35.14
	SPIHT	24.86	27.58	31.39	33.51	36.41
	JPEG	23.11	25.05	28.27	31.01	33.11
	EZDCT	24.07	26.93	30.87	32.81	35.13
	ZTE	25.97	27.04	30.34	32.12	34.68



(a) Lenna image



(b) Barbara image

그림 8. 각 알고리즘의 PSNR 그래프
Fig. 8. PSNR graph for each algorithm.

표 2. 부호화 복호화 알고리즘의 수행 시간(초)
Table 2. Running time (sec) of the different components in the proposed encoding and decoding algorithm. (256x256 Lena image)

algorithm \ bpp		0.125	0.25	0.5	0.75	1.0
Enco-ding	DWT	2.18	2.18	2.19	2.19	2.18
	Build 2D Array	0.02	0.02	0.02	0.02	0.02
	Zerotree Encoding	0.03	0.07	0.13	0.18	0.23
	Total	2.29	2.32	2.4	2.45	2.49
Deco-ding	Zerotree Decoding	0.05	0.09	0.15	0.2	0.26
	IDWT	2.21	2.21	2.21	2.21	2.21
	Write Image	0.09	0.09	0.09	0.08	0.08
	Total	2.35	2.39	2.45	2.49	2.55

We can see from experimental results that our proposed coder is more effective in the case of processing high resolution images.

The required time to encode and decode 256x256 resolution Lena image are shown in Table 2. Zero-tree encoding and decoding speed increases as bit-rate increase, and inverse wavelet transform requires more time to process as bit-rate increases as well. Especially in the case of embedded system, wavelet transform and inverse wavelet transform consumed 93%~97% of total encoding and decoding time. The other parts, such as image read and write, arithmetic coding and 2D SCA, are performed at relatively fast speed.

Ⅳ. Conclusion

We proposed wavelet image coder that can perform image coding effectively on portable embedded system with low memory usage. Proposed coder can be stored bit-level information of wavelet coefficient into 2D significant coefficient array, and can be performed on significance check and bit scanning simultaneously. Therefore, repetitive coefficient scanning process is minimized and 66% of memory usage for encoding is reduced compared to other algorithms. By comparing performances to other algorithms, we verified that proposed algorithm is superior to others. Proposed coder is effective for portable embedded system with limited memory size and can be used on various applications for image transmission and archiving.

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