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Research paper

Design of DWT based Image Compression Technique for Wireless Sensor Network Applications

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Abstract

In this paper, we propose an efficient image compression strategy exploiting the multi-resolution characteristic of the wavelet transform. We use MATLAB simulation to evaluate the image compression technique called "Discrete Wavelet Transform Skipped High Pass Sub-band (DWT-SHPS). Furthermore, we have implemented an image compression using DWT-SHPS technique on a low-cost single board computer. The evaluation is performed under the wavelet compression framework from the view point of quality of image and data compression ratio. Different combinations of parameters and transformation levels have been compared against the JPEG compression standard. The experimental results indicate that the SHPS technique is close to the performance of JPEG standard. It efficient and has low complexity with less memory requirements in the hardware implementation.

Keywords: *Wireless sensor networks; Image compression; Wavelet transform*

1. Introduction

Wireless sensor network (WSN) has become one of the most interesting networking technologies since it can be deployed without communication infrastructures, Kumsawat et al. (2015). The development of such networks was originally motivated by military applications such as battlefield surveillance. Currently, wireless sensor network play an important role in agriculture production. It has been widely used as a tool for precision agriculture. Nowadays, Wireless Sensor Network has been gaining popularity in the research community and development of Internet of Things (IoT). WSN can capture multimedia content from the environment. However, the large number of data generated by the image sensor remains as a challenging problem, because the power consumption and finite processing of WSN is strongly affected by the number of data to be processed and transmitted. For these reasons, power consumption is a critical issue in WSN. In this paper, a low computational complexity image compression scheme is proposed. This approach is based on DWT-SHPS and run-length encoding (RLE). It can reduce the energy requirement in transmitting minimal bits of image data.

This paper is organized as follows: Section 1, the wireless sensor networks are introduced. In Section 2, the literature review is shown. The proposed method both DWT image compression algorithm and hardware implementation are described in Section 3. In Section 4, the experimental results are shown. The conclusions of our study can be found in Section 5.

2. Literature Review

In recent years, people have done a lot of research work on data compression algorithm and proposed many compression algorithms for WSN. Chew, L.W., Ang, L.M. & Seng, K.P. (2008) proposed survey of image compression algorithms for wireless sensor networks. The result is 8 popular image compression algorithms; it is found that SPIHT wavelet-based image compression is most suitable image compression algorithm for implementation in a hardware constrained environment. Paek, J., & Ko, J. (2017) developed an image compression scheme using K-means clustering on low-power embedded devices for image-based WSNs. More specifically, they use the similarity of pixel colors to group pixels and compress the original image. Their findings show that the transmission overhead of these images can be reduced significantly. Nasri, M., Helali, A., Sghaier, H., & Maaref, H. (2010) proposed technique for image compression called "SHPS" based on Discrete Wavelet Transform and distributed processing and compression technique. Mostefa, B., & Sofiane, B.H., (2016) proposed an efficient adaptive image compression technique called "background subtraction" that can significantly minimize the energy required for wireless image communication. Patel, N., & Chaudhary, J. (2017) described the various image compression techniques, which can be used to aid energy efficient wireless multimedia sensor network. Comprehensive reviews and comparisons various types of image compression techniques were also performed. Chaudhari, R.E., & Dhok, S.B. (2014) proposed wavelet transform based fast fractal image coding. FFT based fractal image coding with variable quadtree partition is applied to the approximation subband and three detail subbands of the transformed image. Wu, M.S. (2014) proposed the fractal encode algorithms to overcome the problem of the time-consuming drawback. First, a FIC using DWT. Second, embedding the DWT technique into the genetic algorithm (GA). The proposed GA method is faster than the full search method.

3. Proposed Method

In this section, we first give a brief overview of the wavelet-based image compression algorithm. We then describe the implementation of an image compression node for wireless sensor network applications.

3.1 DWT Image Compression Algorithm

The discrete wavelet transform (DWT) is a time-scale analysis. The signal is analyzed at multiple frequency ranges with different resolutions by decomposing the signal into a coarse approximation and detail information.

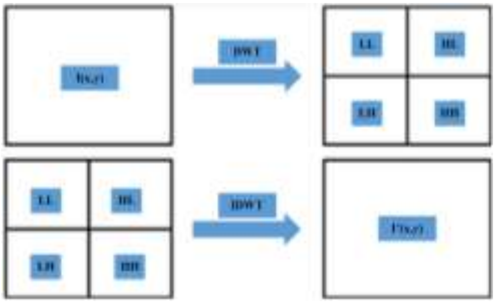

Figure 1: 1-Level DWT and Inverse DWT

Figure 1 illustrates the diagram of 1-level DWT image decomposition. The 1-level DWT can be used to decompose an image into four-subband images. It compose of low-pass coefficients (LL) and high-pass coefficients (LH, HL and HH) after applying 1-level DWT to the image. The low-pass coefficients represent approximation of the original image whereas the high-pass coefficients represent detail information of the original image. Indeed, we notice that the high-pass coefficients values are very small. Based on the numerical distribution of DWT coefficients, we can estimate the high-pass coefficients to be zeros and hence avoid computing them. In order to save computation energy, we propose a wavelet-based image compression approach in WSN which does not require computation of certain high-pass coefficients of the DWT. This technique is called "Skipped High Pass Sub-bands; DWT-SHPS". Following the same process given by M. H. Nasri et al. (2010), we use Haar's wavelet to implement the DWT. In this paper, Run-Length encoding is applied to reduce the length of the DWT coefficient sequences. The DWT image compression process is shown in Figure 2.

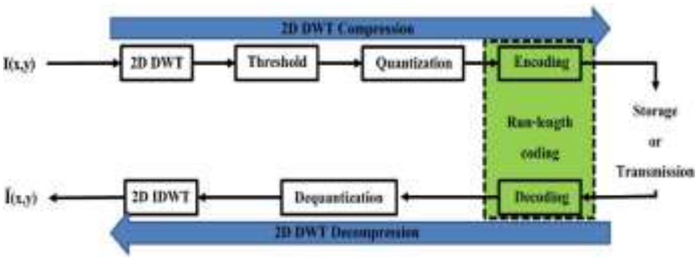

Figure 2: DWT image compression and decompression

3.2 Hardware Implemation of DWT-SHPS Image Compression Algorithm

Figure 3 shows the implementation of an image compression node for wireless sensor network applications. The 2D-DWT SHPS image compression algorithm was implemented on a low-cost single board computer called Raspberry Pi 3 Model B running Ubuntu Linux. The Raspberry Pi camera image sensor is connected to the microcontroller unit through the I2C interface. The image compression and decompression nodes are powered by solar panel with 20 Watts. The wireless communication module is ZigBee, and takes responsibility of transferring data in the networks. The image compression node has the facility of data logging (SD-card) for saving the original image.

The image decompression node or base station is illustrated in Figure 4. It can be uploaded the decompressed image over Internet for further investigation via wireless access point (3G Aircard). In this experiment, we demonstrate the efficiency of this scheme under real-world applications. The compression node and decompression node were deployed in a farmland environment at Suranaree University of Technology (SUT). The installation of image compression node for WSN is shown in Figure 5.

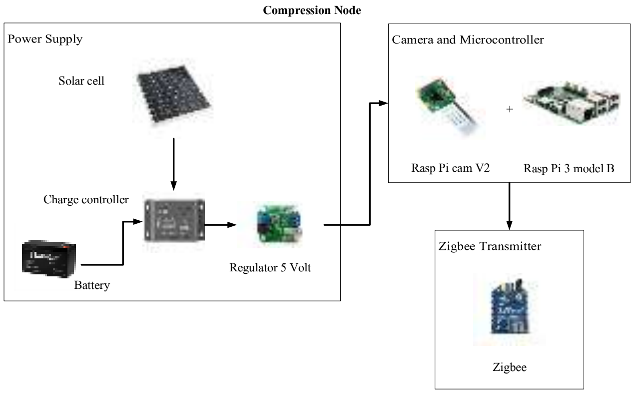

Figure 3: Image compression node

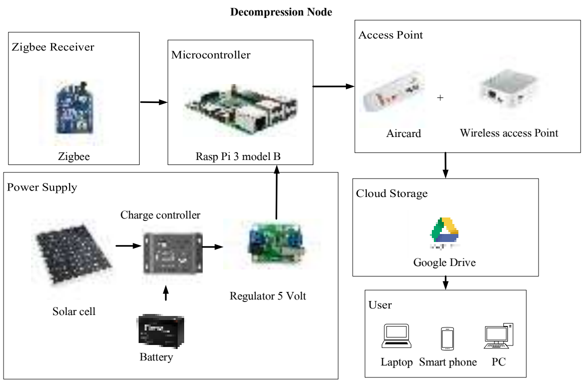

Figure 4: Image decompression node

Figure 5: The compression and decompression node installation at SUT farm

4. Experimental Results and Discussions

To demonstrate the effectiveness of our proposed method, a series of experiments have been conducted. The gray-scale standard test images are Lena, Tiffany, Baboon and Airplane (F16). The size of each image is 512×512 pixels. The compression ratio (CR) and peak signal to noise ratio (PSNR) are used as performance measures to quantify the difference between the original image and the reconstructed image. The CR and PSNR can be represented as follows:

$$CR = \frac{\text{Total number of bits in original file}}{\text{Totle number of bits in compressed file}} \quad (1)$$

$$\text{PSNR (dB)} = 20\log_{10}\frac{2^{B}-1}{\sqrt{MSE}} \quad (2)$$

,where B and MSE denote the number of bits per pixel (bpp) of the raw image and mean square error, respectively. The mean square error is defined as:

$$\text{MSE} = \frac{1}{m \times n}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - \bar{I}(i,j)]^2 \quad (3)$$

,where m and n denote number of rows and number of columns, respectively. I denote the pixel values of the original image and $\bar{I}$ denote the pixel values of reconstructed image.

4.1 Software Simulation Results

To evaluate the performance of the DWT-SHPS technique, we used JPEG compression with quality factors (QF) varying from 10% to 90% and measured the PSNR and CR between the original image and the reconstructed image. Figure 6 shows the average of PSNR as a function of CR. We can see that the DWT-SHPS technique is close to the performance of JPEG compression between QF = 10 to QF = 60. Its PSNR is around 3 dB lower than JPEG compression. However, it efficient and has low complexity with less memory requirements, and is particularly suited for highly resource-constrained wireless sensor networks node. The visual comparison of files between JPEG compression and DWT-SHPS techniques are illustrated in Figure 7.

4.2 Hardware Implementation Results

To evaluate the proposed scheme in terms of its efficiency and energy saving, experiments are carried out on resource-constraint embedded system. First, the input image has been compressed by using 2D-DWT SHPS image compression algorithm. Then, the sequences of information are encoded using a lossless encoding technique called run-length encoding for further compression. The compressed data are sending to the base station by ZigBee wireless module. The compressed data is recovered at the base station and the performance metrics are applied. After decompression, the recovered image is transmitted to the Google drive cloud storage for further investigation. However, the transmission to the cloud storage can be wired or wireless based on the application and necessity. However, because there are errors in transmission image packet of other sub-bands, the quality (measured by PSNR) of the reconstructed image at the base station has also been reduced. Figure 8-9 show the PSNR and CR of the 1-level DWT-SHPS and 2-level DWT-SHPS techniques, respectively. The original image and reconstructed image are also shown in the Figure 10. It can be seen that the 2-level DWT-SHPS is higher CR than 1-level DWT-SHPS with almost the same of PSNR.

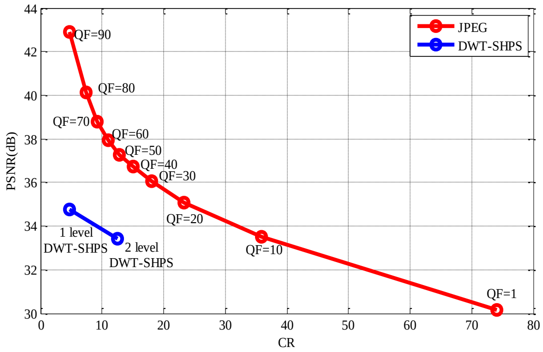

Figure 6: Comparison of JPEG compression with DWT-SHPS technique

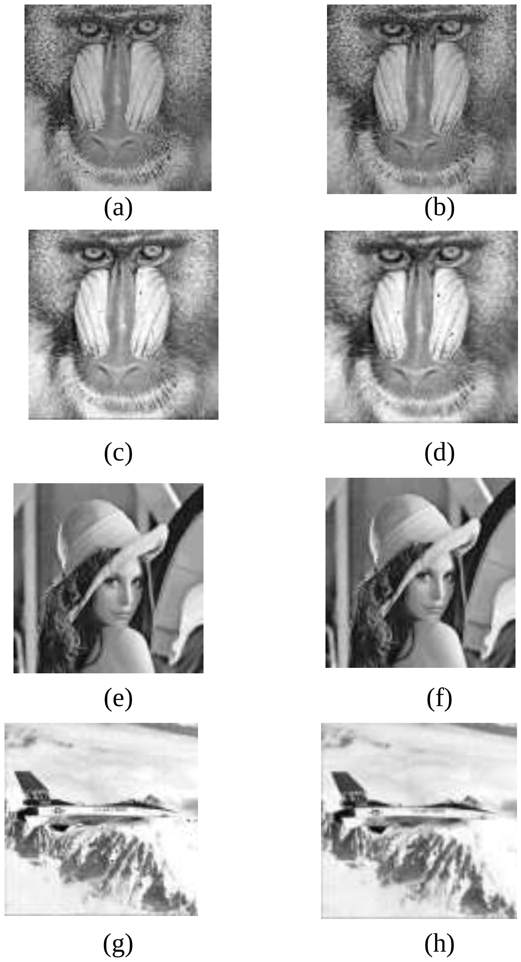

Figure 7: (a) Original Baboon image (b) JPEG QF = 70, Baboon (PSNR=34.13 dB), (c) 1-Level DWT-SHPS, Baboon (PSNR=31.20 dB), (d) 2-Level DWT-SHPS, Baboon (PSNR=30.04 dB) (e) 1-Level DWT-SHPS, Lena (PSNR=36.57dB) (f) 2-Level DWT-SHPS, Lena (PSNR=34.83dB) (g) 2-Level DWT-SHPS, Airplane (F16) (PSNR=36.28 dB) and (h) 2-Level DWT-SHPS, Airplane (F16) (PSNR=33.93 dB)

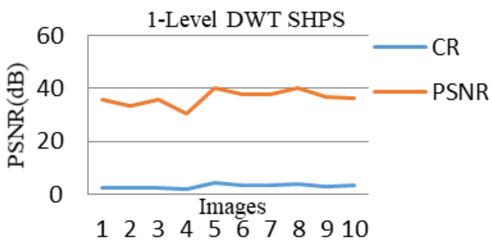

Figure 8: PSNR and CR of 1-level DWT-SHPS

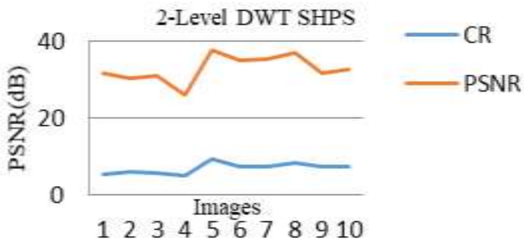

Figure 9: PSNR and CR of 2-level DWT-SHPS

(a)

(b)

(c)

Figure 10: The image of SUT farm (a) original image (b) reconstructed image of 1-level DWT-SHPS compression technique (CR = 3.3, PSNR = 36.79 dB) and (c) reconstructed image of 2-level DWT-SHPS compression technique (CR = 7.37, PSNR = 31.69 dB)

5. Conclusion

This paper describes software simulation and hardware implementation of Skipped High Pass Sub-bands image compression algorithm along with run-length encoding and decoding architectures for wireless sensor network applications. The main controller of an image compression node is ARM 64-bits Cortex–A53 processor on Raspberry Pi 3 Model B single-board computer. This image compression technique has low computational complexity, thus it can reduce the energy requirement in transmitting minimal bits of image data. We analyze the performance of this technique in terms of peak signal to noise ratio and compression ratio. The experimental results indicate that the Skipped High Pass Sub-bands technique is close to the performance of JPEG standard. It efficient and has low complexity with less memory requirements in implementation. Further research can be concentrated on the development of the optimization technique of color image compression algorithm by using the artificial intelligent techniques.

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