http://dx.doi.org/10.5755/j01.eie.23.3.18334 ELEKTRONIKA IR ELEKTROTECHNIKA, ISSN 1392-1215, VOL. 23, NO. 3, 2017

Impact of Complexity and Compression Ratio of Compression Method on Lifetime of Vision Sensor Node

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***Abstract*—The energy budget is limited in remote applications of Wireless Vision Sensor Network (WVSN). It imposes strict constraints on both the processing energy consumption and transmission energy consumption of the Vision Sensor Nodes (VSN). Transmitting the raw images to the Central Base Station (CBS) consume substantial portion from the energy budget of each of the VSN. The consequence of greater transmission energy consumption due to transmitting raw images is the reduced lifetime of the VSN. Image compression standards effectively reduce the transmission energy consumption by compressing the images. But the computational complexity of a compression method has also a significant effect on the energy budget and lifetime of each of the VSN. This paper investigates the impact of the computational complexity and communication energy consumption of three chosen compression methods on the lifetime of the VSN. Both statistically generated images and the real captured images are used for evaluating the energy consumption of the three chosen image compression methods. We have determined the improvement in the lifetime of the VSN based on the computational complexity and compression ratio of the three selected binary image coding methods.**

***Index Terms*—Energy consumption; embedded system; image compression; lifetime; wireless vision sensor network.**

I. INTRODUCTION

The inaccessible applications of the Wireless Vision Sensor Network (WVSN) imposes strict constraints on both the execution and transmission energy consumption of the Vision Sensor Nodes (VSNs). Hardware components of the typical VSN includes a camera, onboard processing unit, memory and a radio transceiver. The energy budget of WVSNs is limited because of their deployment in inaccessible zones where it is difficult to change the position of the node or to regularly update the batteries.

One application of WVSN is sky surveillance for the detection of birds/bats which fly towards wind mills/turbines [1], [2]. Other applications includes automatic meter reading [3]–[5] and target detection/tracking [6]–[8]. Our intended application is the automatic monitoring of hydraulics systems for failure detection [9]. We can predict the health of the hydraulic system based on the number and dimensions of the magnetic particles in the images captured and processed by the VSNs.

This diverse set of applications demand a significantly large number of VSNs for continuous and persistent monitoring. Cabling the sensor network for powering the VSNs and for communication with the server for such remote applications is difficult and costly. Hence, for remote applications of WVSN, the placement of battery operated VSN is essential.

The image processing flow from image capturing up to feature extraction includes many complex algorithms including filtering, background-frame subtraction, segmentation, morphology, labelling, object dimension/features extraction and image compression. The VSNs must be able to perform these complex tasks using onboard processing unit and needs to be able to communicate (wirelessly) the final results. However, unluckily, they have inadequate energy budget in the form of batteries initially installed at deployment time. A lesser energy resource in the form of batteries put hard restrictions on the kind of the hardware apparatuses used and the algorithms for the various image-processing tasks. Typically, the preference is for hardware components with low power consumption and algorithms, which have low computational complexity. The energy budget and wireless communication are the major constraints of remote applications of WVSN.

Both in-node processing and transmission (wireless) to server consume a huge share from the energy budget of the VSN. Communicating the images from the node without in-node processing decreases the processing energy but its consequence is greater transmission energy because of communicating the huge information contained in images.

On the contrary, performing the entire processing using on-board processing unit and communicating the end results does reduce the transmission energy consumption. But, its drawback is greater execution energy consumption based on the longer processing time at the VSN. Figure 1 shows these two extremes of processing at the VSN. We have previously concluded in [10] and [11] that the choice of an appropriate strategy for Intelligence Partitioning (IP) between the server and VSN does reduce the over-all node's energy consumption.

Manuscript received 15 October, 2016; accepted 14 April, 2017.
The authors extend their appreciation to the Deanship of Scientific Research at King Saud University for funding this work through research group NO (RG-1438-034).

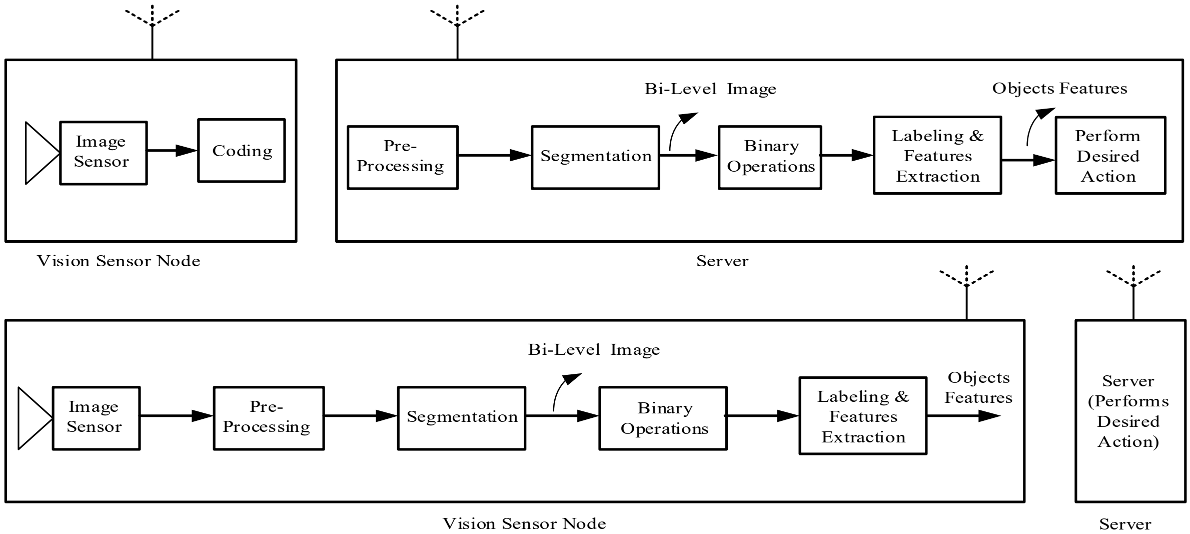

Fig. 1. The two extremes of image processing tasks in WVSN.

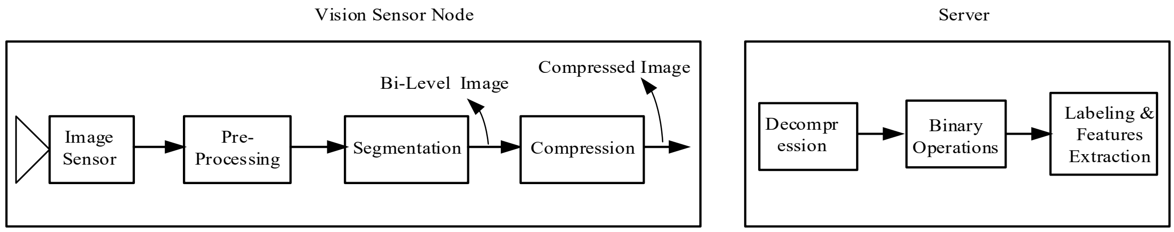

Fig. 2. Proposed architecture for the implementation of the VSN.

However, transmitting the uncompressed images to server will quickly drain the total node's energy.

Transmission energy consumption is largely reliant on the data that is being transmitted between the VSN and the server. Compressing the bi-level image after preprocessing and segmentation proves to be a decent alternative for achieving a general architecture for some applications of WVSN [12]. The general architecture from [12] is presented in Fig. 2 which show that the remainder of the operations, such as bi-level image processing operations, labelling and object features extraction are shifted to the server.

The size of the compressed image in Fig. 2 is dependent on the used compression method. Additionally, the VSN's energy consumption is dependent on the processing complexity of the underline compression algorithm. We determined in [13] that JBIG2 [14], CCITT Group 4 [15] and Gzip_Pack [16] are appropriate binary image compression standards for inaccessible applications of WVSN.

In the current work, we are interested in determining the improvement in lifetime of the VSN based on the reduction in communication energy consumption which can be achieved by using any of these three suitable image compression methods. Our analysis is based on NGW100 mkII which is an AVR32 based architecture. The NGW100 mkII kit uses the AT32AP7000 which has a 32-bit digital signal processor. The kit has 256 MB Random Access Memory (RAM) and 256 MB NAND flash. The AT32AP7000 operates at 150 MHz clock.

The rest of the article is planned as follows. Section II describes the related work and Section III presents the experimental setup. Section IV elaborates the execution time, the energy consumption and the improvement in the lifetime of the VSN based on the three compression methods. Finally, the conclusion is provided in Section V.

II. RELATED WORK

Representative examples of WVSNs are explained in [17]–[19]. The authors in [17] developed a mote for camera based wireless sensor network. They analysed the processing and memory limitations in current mote designs and have developed a simple but powerful platform. Their mote is based on a 32-bit ARM7 micro-controller operating at 48 MHz and reading up to 64 KB of on-chip RAM. The IEEE 802.15.4 standard has been used for wireless communication.

The authors in [18] presented a CMUcam3 which is a cheap, open-source, embedded computer vision platform. Their hardware platform composed of a frame buffer, a colour CMOS camera, a cheap 32-bit ARM7TDMI microcontroller and memory card.

The authors in [19] proposed and demonstrated a wireless camera network system which they named as CITRIC. Their hardware platform consists of a camera, a CPU (which supports up to 624 MHz clock speed), 64MB RAM and 16MB FLASH. Their designed hardware is capable of performing in-network processing of images in order to reduce the transmission energy consumption.

III. EXPERIMENTAL SETUP

Our intended application is magnetic particle detection in a flowing liquid in hydraulic system. The prototype hydraulics system and the proposed flow of the image processing tasks is shown in Fig. 3. The particles are categorized by the dimensions and number and our system is intended to be used for the detection of failure in hydraulic systems.

Image capture: The image of the magnetic particles from the round glass in Fig. 3 is captured in this step.

Pre-Processing: The current frame is subtracted from the stored background. A predefined threshold is used for segmenting the image into black and white image. In this thresholded image, the magnetic particles are the white objects while the background is black.

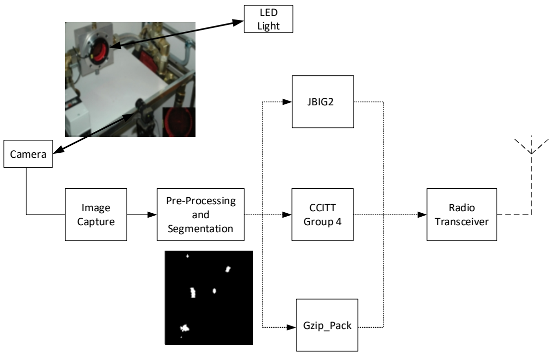

Fig. 3. The imaging flow for particle detection in hydraulic system.

Image Compression: Any of the three selected binary image coding methods can be used for the image compression. The dotted lines in Fig. 3 shows that any of the three binary image coding standards can be used. The goal is to analyse the impact of the three image compression methods on the energy consumption and eventually the lifetime of the VSN. The compressed images are transmitted to the server for performing the rest of the image processing tasks.

IV. THE PROCESSING TIME AND ENERGY CONSUMPTION

This section consists of the discussions related to the energy consumption and execution time of the three bi-level image coding methods. The execution file and respective libraries of all the three compression standards are downloaded to the target embedded platforms (NGW100 Mk II) and are used to compress the images. The mean compressed file size for the three selected binary image coding standards from seven analysed methods in [13] are shown in Table I.

The compressed file size is different for the various compression methods and the communication time of the radio transceiver is dependent on the size of the transmitted data. In our previous work [10]–[12], the data transmission time for the IEEE802.15.4 radio transceiver is determined using (1)

$$T_{IEEE802.15.4} = (X+19)\times 0.000032 + 0.000192. \qquad (1)$$

In our current work, IEEE802.15.4 is considered for the transmission of data from the VSN, thus, the same equation is used to calculate transmission time in Table I. The constants in (1) are based on CC2520 wireless transceiver. The packet structure is composed of 133 octets where 127 octets are for the frame length and 6 octets are the PHY header. The 0.000032 in (1) is the execution time of one byte while 0.000192 is the minimum Inter-Frame Separation (IFS) period. The size of the compressed image is more than the maximum available packet size of the wireless transceiver. So, the compressed bits stream of the compression methods is transmitted in several packets.

Table I shows that the transmission energy consumption is highest for transmitting segmented images and is lowest for JBIG2 compression. Though the transmission energy of JBIG2 is lowest but its compression time is highest due to high computational complexity of underline algorithm i.e. arithmetic coding. The Compression time and the total energy consumption of the compression methods is shown in Table II. The total processing time in third column of Table II includes the compression time as well as the time for capturing, pre-processing and segmentation.

TABLE I. TRANSMISSION ENERGY CONSUMPTION.

Method	Mean Data (Bytes)	Transmission Time (ms)	Transmission Energy (mJ)
Segmented Image	32000	1283	92
Group 4	455	97	7
JBIG2	302	91	6.5
Gzip_pak	598	103	7.4

Contrary to Table I, the total energy consumption of JBIG2 is high compared to Group 4 and Gzip_Pack and the reason for this is the high compression time. High total energy consumption of JBIG2 will result in reduced lifetime of the VSN.

TABLE II. TOTAL PROCESSING TIME AND ENERGY CONSUMPTION.

Method	Processing Time of Method (ms)	Total Processing time (ms)	Processing Energy (mJ)	Total Energy (mJ)
Capture+Pre_Proc+Seg	90	90	7	7
Group 4	140	230	11	18
JBIG2	349	439	26	33
Gzip_pak	160	250	12	19

The WVSNs are subject to data losses where the packet and sometimes the whole image could be lost. The acknowledgment of every packets must be received and in case of failure, the packets should be retransmitted otherwise the image will not be decompressed at the receiver side. As our goal in current paper is to explore the compression performance and energy consumption of the compression methods, which will help us to decide which compression, method is the most suitable for WVSNs. We have not tested all the compression methods in the actual physical deployment, which is not in the scope of the current work, so the discussion about the actual losses and their recovery is out of scope of the current work.

TABLE III. TOTAL TIME AND ENERGY CONSUMPTION (PROCESSING + TRANSMISSION).

Method	Total Time (ms)	Total Energy (mJ)
Capture+Pre_Proc+Seg	1373	99
Group 4	327	25
JBIG2	530	39.5
Gzip_pak	353	26.4

Table III shows the total time and total energy of the various compression methods. In Table III, the total time in the second column is the sum of processing time and transmission time from Table II and Table I respectively. Similarly, the total energy in the third column of Table III is the sum of the processing energy and transmission energy consumption from Table II and Table I respectively.

The lifetime of the VSN in Fig. 4 is calculated using 4 AA batteries. Figure 4 shows that the lifetime of the VSN is the lowest for the case when the segmented binary image is transmitted to the server. On the other hand, the lifetime of the VSN is highest for the case when segmented image is compressed using CCITT group 4 compression method. For high sampling time in Fig. 4, the lifetime of the VSN is not increased because of sleep energy dominancy.

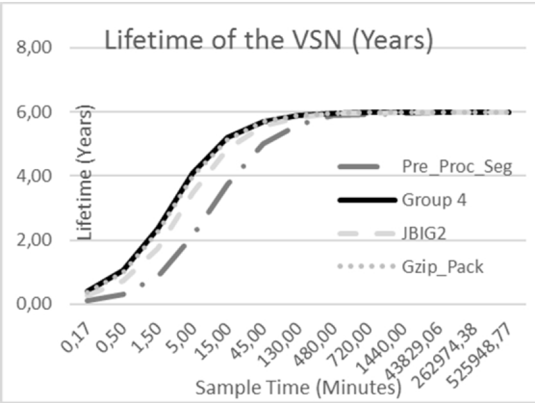

Fig. 4. The Lifetime of the VSN.

It is true that there may be fluctuations in the current during the compression process, but we have determined the average value and still the variation in the current is very small. Hence, the average value of the current is a good measure. The voltage will also vary with the passage of time, but as long as the node remains functional, the difference in the voltage will be very small and hence our measured energy consumption will provide a good analysis. The transmission energy is calculated using the transmission time and the power characteristics of the IEEE802.15.4 standard.

V. CONCLUSIONS

We have explored the influence of processing time, compression efficiency and energy consumption of the three binary image compression methods on the life time of the VSN. Though the compression efficiency of JBIG2 is the highest but due to its long compression time, the total energy consumption is high. Higher total energy consumption of JBIG2 resulted in reduced life time of the VSN. The life time of the VSN is comparable for Gzip_Pack and CCITT Group 4 compression methods. Reduced lifetime of the VSN is a characteristic that is not desirable for most applications of Wireless Vision Sensor Networks (WVSNs). Hence, CCITT Group 4 and Gzip_Pack are the suitable candidates for the energy constrained applications of WVSNs.

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