Image compression for WSN applied to the process supervision in Industry 4.0

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Abstract

Wireless Sensor Network (WSN) applications in the industrial sector are in permanent evolution due the emergence of the Industry 4.0 concept. Considering this context, Wireless Image Sensor Networks (WISN) appeared as a solution to supervise production processes. In this specific type of WSN, the size of the data to process and to transmit constitutes an important constraint that could cause network congestion and impact node lifetime. Thus, the goal of this paper is to study and evaluate a typical image compression algorithm as a solution to optimize the energy consumption and communication traffic in a WISN, dedicated to control a chemical industrial process.

1. Introduction

The concept of Industry 4.0 has emerged in the last years thanks to the full evolution of digital solutions, along with the raising of Cyber-Physical Systems, which could provide new knowledges to manufacturers concerning their production processes. These knowledges can be collected, among other techniques, by means of distributed wireless sensors. Considering this context, specific Wireless Sensor Networks based on cameras, called Wireless Image Sensor Networks (WISN), are frequently deployed for process supervision purposes. In these WISN, one of the main challenges is to process and transmit images or videos, that represent high size data, ensuring, at the same time, the availability of the network and an acceptable network lifetime.

Therefore, to reduce the impact of this high quantity of data on the overall WISN performances, many research works are being carried out about the image processing and compression. As an example, one way considered in the scientific literature to reduce the communication network congestion is to execute image processing tasks at the WISN level, and to transmit only the labelled features to the server, as proposed in [1]. In this case, the energy consumption due to data transmission decreases, while the energy consumption related to computation in the node increases. Other research works have opted to reduce the images size before transmitting them through the network. In [2], the reduction of the energy consumption has been achieved using image compression before transmission. Considering the state of the art, image compression can be considered an appropriate solution to optimize both energy consumption and communication network availability in WISN.

Therefore, the aim of this work is to propose and evaluate solutions to improve data compression algorithms regarding the performance required for the supervision, in a chemical industry process, of a liquid-liquid interface using WISN. The JPEG standard is one of the most widespread data compression algorithms in the literature [3], and its performance is evaluated using the MATLAB environment. As in future work experiments will be conducted to test the proposed solutions for data compression, an overview of the physical prototype architecture is also described.

2. JPEG standard evaluation by simulations

2.1. Applied methodology

To evaluate its performance using the MATLAB environment, the JPEG compression is applied considering the following steps: a) decomposition of the image in blocks of 8x8 pixels; b) application of the Discrete Cosine Transform (DCT) for each block in order to pass from the spatial to the frequential domain, resulting in a matrix containing the high and low frequencies separately; c) quantification, which is a multiplication with decreasing weights to eliminate the high frequencies which are invisible for the human eye. The result of this quantification gives a matrix containing positive values on the top left corner, and zeros or almost zeros values elsewhere. Therefore, the information on the image is finally concentrated in the top left corner. The size of the top left corner to be considered is determined by the details of the original image to be conserved.

Then, to reproduce more precisely the considered context, the compression phase is applied to an image composed of horizontal layers with different grey levels, representing the liquid-liquid interface to be supervised, and followed by a simulation of a noisy wireless transmission. For that, Zigbee frames are considered in which the data field size is equal to 80 bytes. In this scenario, one of the worst situations is considered: due to the noise, one random bit is changed in each packet sent through the WISN.

2.2. Evaluation criteria

In the considered context, the tradeoff to reach applying a compression method is to reduce the quantity of data while ensuring the image quality. Therefore, to validate our results, the Compression Ratio (CR) is firstly used to verify the information quantity gain. On the other hand, the Peak Signal to Noise Ratio (PSNR) and the Structural SIMilarity (SSIM) are used to confirm the compressed data quality allowing their interpretation [4]. PSNR, a mathematical metric and SSIM, a human visual system-based metric, are used both to measure the similarity between an image and a reference image. When this similarity increases, PSNR value goes towards $+\infty$, and SSIM goes towards 1. Otherwise, the two metrics go towards 0. In our case, PSNR and SSIM values greater than 16 and 0.7 respectively, are considered satisfying.

2.3. Simulation results

Figure 1 presents the original image (a) along with the decompressed images obtained without transmission (b) and with noisy transmission (c).

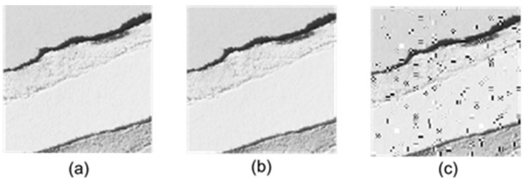

Figure 1. Visual results of JPEG compression

The obtained values of CR, PSNR and SSIM for JPEG compression (JC) and decompression (JD), with and without noisy transmission (NT), are exposed in Table 1. Thanks to the JC, the quantity of data sent in the transmission channel is reduced to 25% of the initial quantity. Moreover, even with NT, PSNR and SSIM values are still within the acceptable limits. These results confirm that, in our context, data compression constitutes a solution to reduce the amount of data to be transmitted while ensuring the usability of the decompressed image.

Table 1. JPEG evaluation results.

Result	CR	PSNR	SSIM
JC + JD	75%	31.54	0.87
JC + NT + JD	75%	17.21	0.62

3. Proposed physical prototype

To test improvements of compression method, a node prototype, based on a Raspberry Pi 4 (RP) as processing and transmission unit, is in preparation. The capacity to program RP using source languages, such as Python [5], and to interface it to other nodes using different communication technologies explains this choice. As illustrated in Figure 2, this prototype is also composed of:

- RP Camera Module V2.1 to perform image capture,
- WS2812 LED-based light source with configurable colors to enhance the details of the image,
- PIC18F1320 nano-Watt technology microcontroller to activate periodically the DC/DC converter and the RP but also to control the light source,
- Real Time Clock (RTC) to keep date and hour of the RP when the DC/DC converter is stopped.

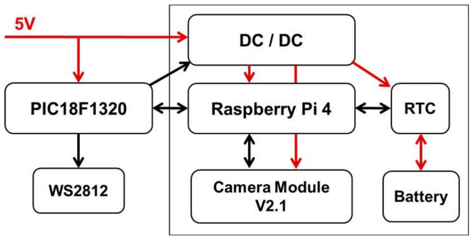

Figure 2. Prototype architecture

4. Conclusion

This paper proposed an optimization way, by using data compression methods, to reduce the network congestion and energy consumption in WISN dedicated to process supervision. Considering CR, PSNR and SSIM criteria, simulation results have validated, using JPEG, data quantity reduction and acceptable image quality after compression and noisy transmission. The last section described the prototype that will be used in future work to experimentally validate our improvement proposals.

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