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Method and Device for Image Coding and Transferring Based on Residue Number System

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Abstract: The method and device for multimedia data encoding in wireless sensor networks were developed. It provides the increase of the total communication channel bandwidth, data flow adaptive distribution, depending on the channel characteristics, it increases the reliability of the transmission through the usage of corrective properties of the residue number system. Conversion of pixels in the developed device is carried out once per cycle using parallel-serial multi-bit adders and incomplete encoders based on the direct addition method. Selected co-prime modules provide conversion of 24-bit images. The resulting balances are transferred in parallel channels with multipath routing. *Copyright © 2013 IFSA.*

Keywords: Wireless multimedia sensor networks, Residue number system, Image coding, Multipath routing.

1. Introduction

Interest in the wireless sensor network (WSN) technologies has been rapidly growing in recent years, both from the researchers' side, a vivid proof of which is a significant number of publications, and from the huge corporations' side, that invests a considerable amount of money in the research and development of these technologies [1].

Environmental monitoring systems, security systems, monitoring of mechanical products and living organisms that carry out the measurement of different physical parameters, such as temperature, pressure, humidity, light intensity, location and other facilities are built on the basis of WSNs [2, 3].

An integration of low-power wireless network technologies with an inexpensive hardware such as CMOS cameras and microphones currently contributes to the development of wireless multimedia sensor networks (Wireless Multimedia Sensor Network - WMSN). It allows a transfer of video and audio streams, stationary object images and scalar sensor data [4]. Multimedia data are characterized by a significant size of information and sensitivity to the transfer delay.

Taking into consideration functional limitations of the wireless sensors (transmission speed, computing power, self-power, etc.), an urgent task of multimedia data transfer is set to reduce the load upon the nodes-repeaters and time of the message delivery.

Video surveillance systems are widely used in: technical Security, traffic control, machine vision and other.

Among the factors that significantly limit the application of the existing video surveillance systems can be identified:

– using wire communication channels;

– the need for continuous power supply;

– fixed architecture.

Wireless Multimedia Sensor Networks (WMSN) can transmit video and audio streams, still images, and sensor data.

Integration of video surveillance systems WMSN will provide the system with the following benefits: mobility, reduction of installation time, the ability to set on objects of historical and cultural heritage, as well as objects of high complexity.

WMSN consist of miniature video cameras (VC) with battery-powered, low-power wireless ZigBee modules that are able to process, transmit and receive data. In existing systems, image sensor is directly connected to a wireless module.

For an effective usage of the whole bandwidth of communication channels the authors offer such type of WMSNs, which splits multimedia data into parts and transfers them by different routes (Fig. 1).

One of the most effective approaches to improve the reliability of data transmission in WMSNs is the usage of multipath routing. In multipath routing algorithms several paths are calculated for each destination. This allows an optimal usage of communication channels and an increase in the overall bandwidth.

In the usage of threshold secret sharing scheme for coding messages was proposed. The threshold secret sharing scheme (T, N) (where N is the number of shared secret parts, T is the number of parts required for the secret's recovery) divides the message into the optimal number of parts. An advantage of the threshold schemes is that the message can be recovered only if T or more pieces are present, otherwise the message can't be recovered. A disadvantage of using of threshold secret sharing schemes is a significant increase of the message.

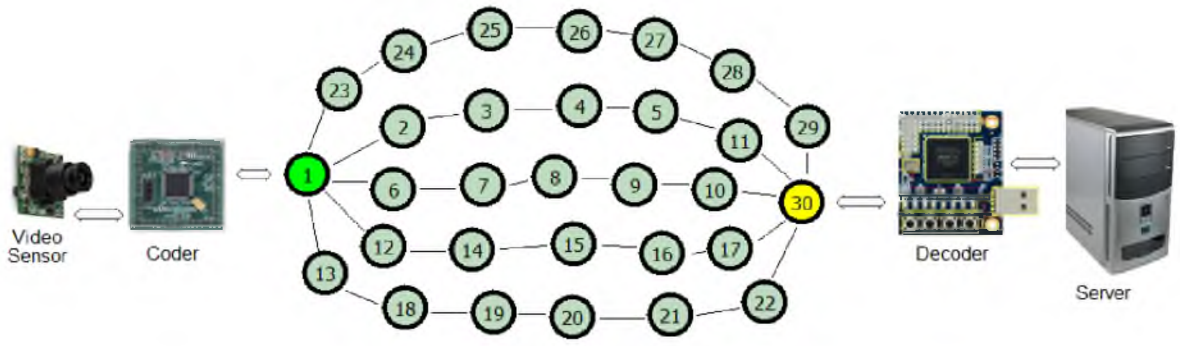

Fig. 1. Transmitting the message using multipath routing: 1 ÷ 30 wireless nodes of multimedia sensor network.

2. Image Coding Method

It is proposed by the author to use the Chinese remainder theorem as an algorithm for splitting the images. The splitting of the message is carried out using the following formula:

$$b_i = A\,(\mathrm{mod}\, p_i), \tag{1}$$

where A is the image for splitting, p_i is the co-prime modules.

Co-prime modules are chosen from the condition $p_i < p_{i+1}$.

Image recovering (decryption) is carried out using the formula:

$$A = \left(\sum_{i=1}^{n} b_i \cdot B_i\right) \mathrm{mod}\, \wp, \tag{2}$$

where $\wp = \prod_{i=1}^{n} p_i$, B_i is the orthogonal basis, n is the number of modules,

$$B_i = \frac{\wp}{p_i} \cdot \delta_i \equiv 1(\mathrm{mod}\, p_i), i = \overline{1, n} \tag{3}$$

where $1 \le \delta_i \le p_i - 1$ is the weight of the orthogonal elements.

Internal parallelism of the residue number system provides a set of advantages for data encoding and transmission in wireless sensor networks. One of them is the independence of digits' positions. It creates an opportunity for the parallel information processing that will increase the overall performance of a computing system. Also, a small number of digits' positions in residuals of the residue number system causes the reduction of computation resources in the whole computing system. Another advantage is the possibility to detect and correct errors during the arithmetic operations and data transmission.

The converter module that splits image into parts (Fig. 2) is placed between the video sensor and the wireless microcontroller.

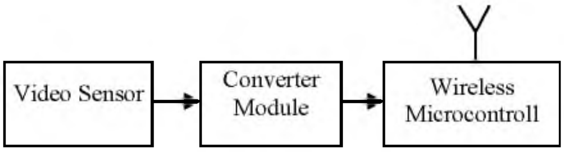

Fig. 2. The block diagram of a node for wireless multimedia sensor network.

Let's take, for example, the image coding (Fig. 3). The value of modules is chosen according to the rule, which predicts that the modules should be bigger than the maximum pixel value. Most video sensors use 24-bit binary code to represent a single pixel of the image. In the 24-bit representation, the maximum decimal value is 2^{24}. Therefore to convert one pixel into the residue number system were selected the following modules $p_1=7$, $p_2=23$, $p_3=29$, $p_4=59$, $p_5=61$, whose product is $\wp = 16803731$. Using provided modules, the n is the bit number, where $n = \log_2(\prod_1^5 p_i)$, can be presented.

It is obvious that the image splitting (15-30 frames per second) in the real-time environment requires significant computational resources of wireless microcontroller (see Fig. 3). Therefore, to reduce the load of the wireless microcontroller, author proposed to implement a hardware conversion of 24-bit binary code into a residue number system code using the method of direct addition.

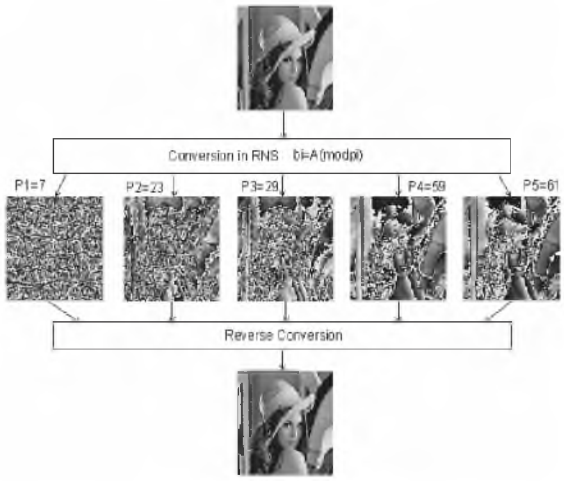

Fig. 3. Decomposition of the image by modules: 7, 23, 29, 59, 61.

Conversion of a 24-bit binary code into the residue number system was implemented using the method of direct addition:

$$A = \sum_{j=0}^{k} a_j \cdot 2^j \equiv b_i(\mathrm{mod}\, p_i) = \left(\sum_{j=0}^{k} a_{ij} \right) \mathrm{mod}\, p_i ,$$

where k is the number of binary digits,

$$a_{ij} \equiv \left(a_j \cdot 2^j \right) \mathrm{mod}\, p_i ,$$
$$a_{ij} = 0(\mathrm{mod}\, p_i), \text{ when } a_j = 0, \tag{4}$$
$$a_{ij} = 2^j (\mathrm{mod}\, p_i), \text{ when } a_j = 1.$$

3. Co-processor Implementation

Splitting the image into parts by modules $p_1=7$, $p_2=23$, $p_3=29$, $p_4=59$, $p_5=61$ is implemented as a separate co-processor (Fig. 4). Image binary code (24 bit) is entered to the input register RG. The information that was read from the registry is entered to the encoder inputs (EC1 - EC5). When "1" is present in the register place n then a binary code that corresponds to the coefficients according to Table 1 is formed at the encoder output. The binary code enters from the encoder outputs to the adders by base p_i inputs (AD).

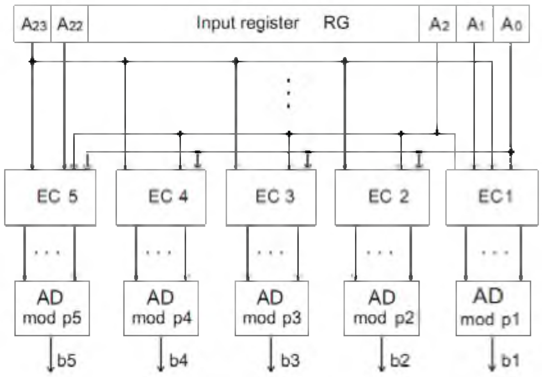

Fig. 4. Block diagram of the co-processor for binary code conversion into the residue number system

The encoder work for module $p_1=7$ is described by the following logical equations (Fig. 5):

$$f_{p1\_0}[0] = E0 \wedge a_0 ;$$
$$f_{p1\_1}[1..0] = E0 \wedge (a_1 \vee a_0) ;$$
$$f_{p1\_2}[2..0] = E0 \wedge (a_2 \vee a_1 \vee a_0) ; \tag{5}$$
$$\ldots$$
$$f_{p1\_23}[2..0] = E0 \wedge (a_2 \vee a_1 \vee a_0) ,$$

...

for module $p_5 = 61$:

$$f_{p5\_0}[0] = E0 \wedge a_0 ;$$
$$f_{p5\_1}[1..0] = E0 \wedge (a_1 \vee a_0) ; \tag{6}$$
$$\ldots$$
$$f_{p5\_23}[3..0] = E0 \wedge (a_3 \vee a_2 \vee a_1 \vee a_0) ;$$

where a_0, a_1, a_2, a_3 are the bits coefficients; $E0$ is the enabling input, when $E0$=1 a code is formed in the encoder output according to Table 1.

A multi-digit parallel-serial adder was developed by modules p_i (i = 1, ,5) to reduce the conversion time of 24-bit binary numbers into the residue number system code (Fig. 6).

The complexity of logic equations writing has considerably increased along with the increase of the module number of bits, therefore the work of adders by modules p_1=7, p_2=23, p_3=29, p_4=59, p_5=61 can be described using VHDL (Fig. 7).

Table 1. Coefficients generated by an encoder, when a single information bit is entered on input.

mod	$2^j (\mathrm{mod}\ p_i)$													
	2^{23}	2^{22}	2^{21}	2^{20}	2^{19}		2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
mod7	4	2	1	4	2	...	2	1	4	2	1	4	2	1
mod23	2	1	12	6	3	...	13	18	9	16	8	4	2	1
mod29	10	5	17	23	26	...	12	6	3	16	8	4	2	1
mod59	47	53	56	28	14	...	10	5	32	16	8	4	2	1
mod61	10	5	33	47	54	...	6	3	32	16	8	4	2	1

An adder for 24-bit binary numbers processing is implemented in a CAD Max + Plus II (see Fig.8).

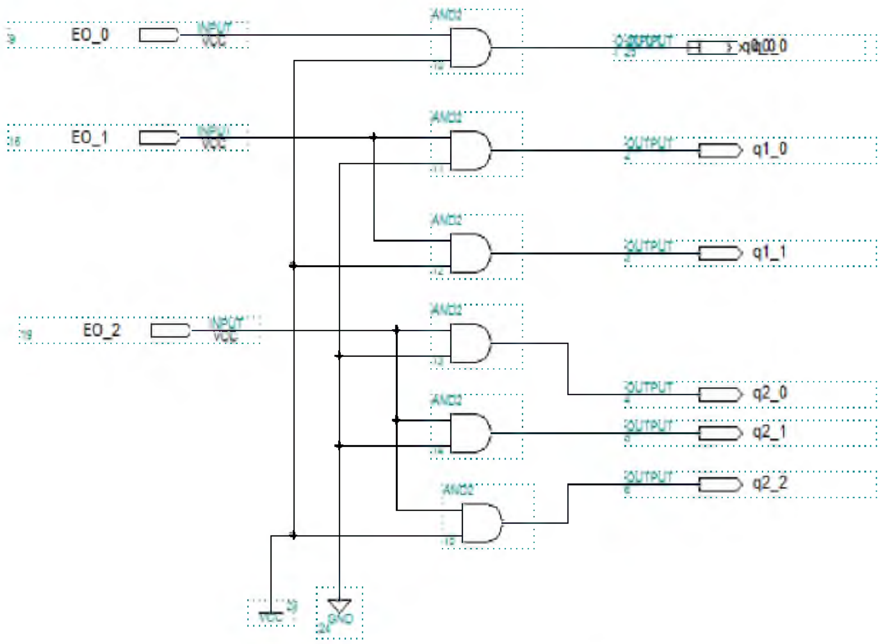

Fig. 5. Coefficients generation encoder circuit for module p_1=7.

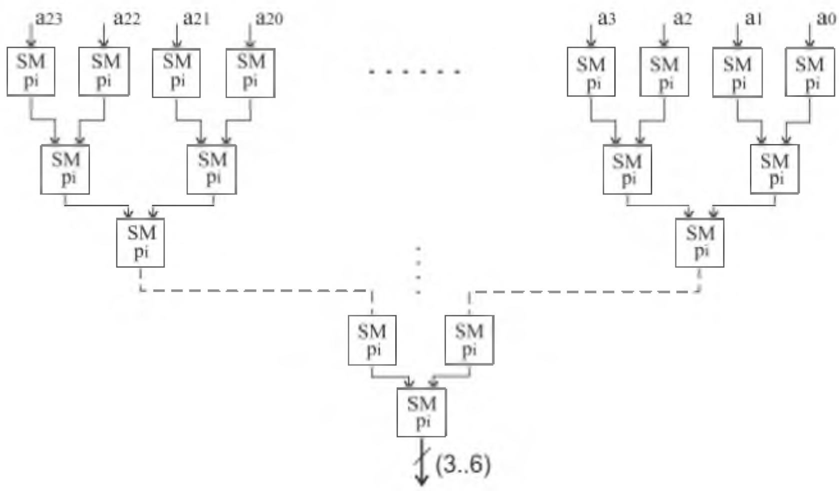

Fig. 6. Block diagram of multi-digit adder by module p_i: $a_0 \div a_{23}$ - coefficients of expression $a_{ij} = 2^j \bmod p_i$ (see Table 1.)

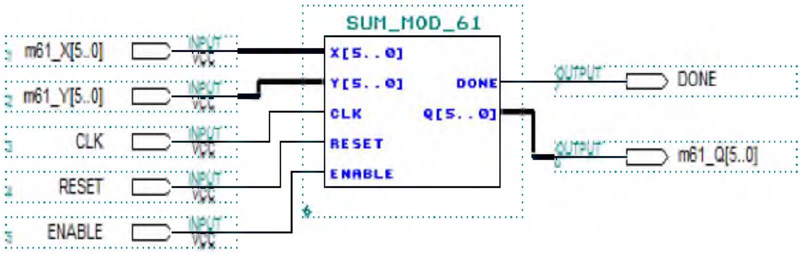

Fig. 7. The adder by module 61.

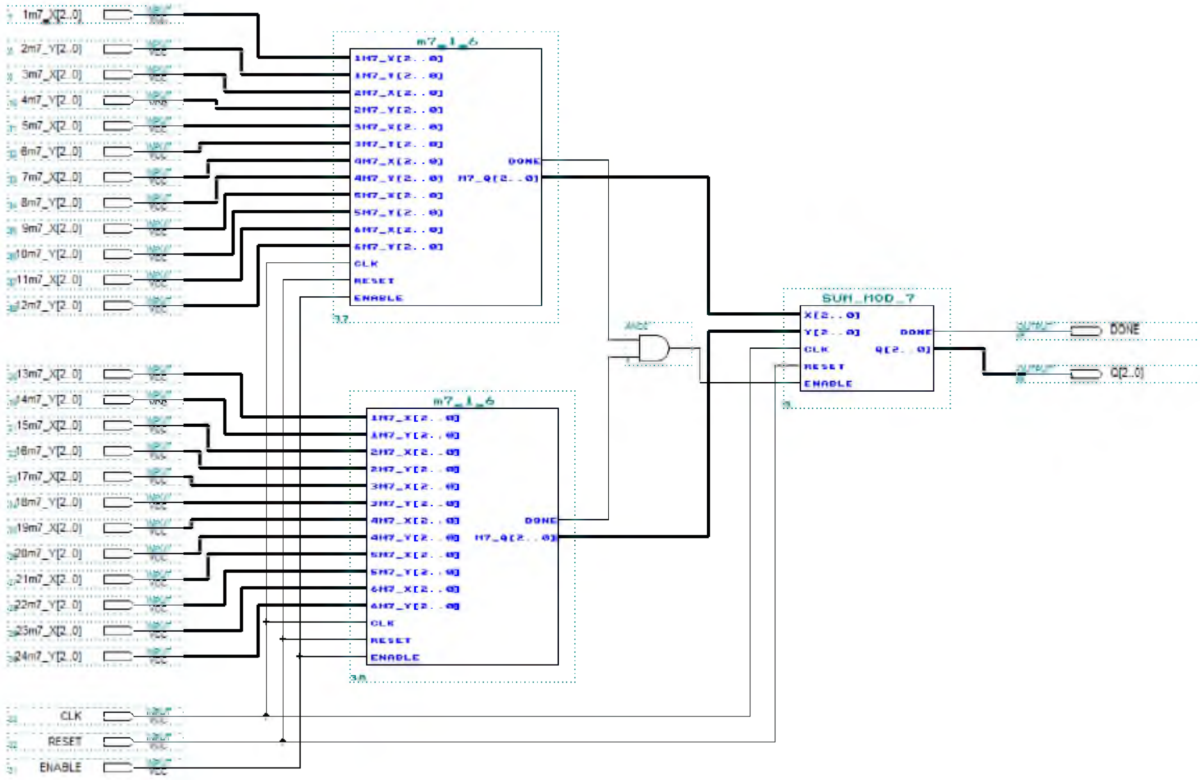

Fig. 8. Multi-digit adder by module 7.

A verification of the co-processor developed at Quartus II software of Altera Corporation confirmed its correct work.

The developed co-processor for image coding using the residue number system provides high performance while using incomplete encoders and parallel-sequential multi-digit adder by the relevant modules. Co-processor is implemented by CPLD series MAX-II of ALTERA Corporation, chip EPM240T100C5, conversion time of 24-bit binary code (one pixel) is 16.7 ns, respectively the transformation of one image frame (640×480) equals approximately to 5 ms.

The obtained images (residual) b_i are transmitted by different routes basing on multipath routing protocol.

Multimedia data is sensible to packet loss. Such loss leads to either discarding all the image or rapid decreasing of the image quality. Therefore multimedia content requires plenty of packets that should not be lost, so the requirement for high-quality image has been confirmed. That's why network protocol should assure packet transmission reliability that will conform to the multimedia characteristics.

Besides the total amount of memory there is another limiting factor: the bandwidth channels with wireless sensor networks. The bandwidth evaluates with the equation.

$$C = \frac{V \cdot n}{128} \text{ Mbit / s}$$

where V is the image volume in KB; n is the number of fps.

Corresponding calculations for the bandwidth sufficient for transmission of streaming video (rate 25 and 15 fps) that depends on image volume is represented on Fig. 9, where Full_25, Full_15 – uncompressed image at 25fps and 15 fps, High – image with high compression ratio (1:20), Low –

image with a compression ratio of 1:10, respectively for 25 fps and 15 fps.

Since the transmission rate according to the standard ZigBee modules IEEE802.15.4 is 250 kbit/s, the sensor network can transmit images up to 100 KB (Fig. 9), which follows the format QCIF (resolution 176×144) with a compression ratio (1:20).

The use of video surveillance systems based on WMSN will significantly expand the scope of their application, such as: vision systems, telemedicine systems, care for the elderly, an environmental and engineering control.

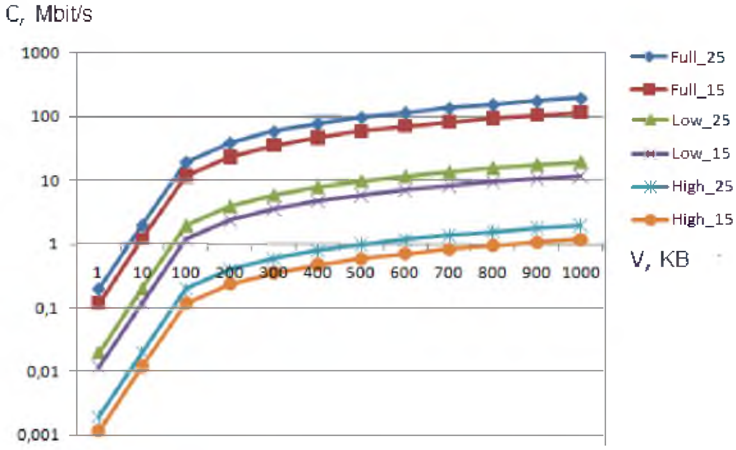

Fig. 9. Required broadband that depends on image size for 25 and 15 frames per second transmission

4. Conclusions

The image splitting into parts in residue number system and usage of multipath routing in the wireless sensor networks allow reducing the load on the nodes-repeaters and reduce the time of the message delivering up to 2-3 times, depending on the number of independent routes. In case that the message is splitting into the parts of different capacity (in illustrated example 3 ÷ 6 bits), its transferring can be done with route bandwidth and reliability allowance. The developed co-processor transforms one pixel of the image per one cycle, while the transformation of one image frame (640*480) need approximately 5 ms.

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