About an adapted image compression algorithm for surveillance flying systems

Ciprian Răcuciu, Nicolae Jula, Florin-Marius Pop

***Abstract*—**Flying surveillance systems have become a priority in every modern army. The prove is the investments involved that are growing every year. A special category is the small systems known as UAV (Unmanned Air Vehicle) that embed only the highest technology because of the dimension limits imposed. The goal of this paper is to present an image compression module and its algorithm based on Discrete Cosines Transform that can be used on a UAV for a real-time transmission of the images captured to the ground. This paper focuses on low complexity techniques used in image compression that are combined to develop a full image compression algorithm that use low resources but with high compression ratio, flexibility for developing further options or characteristics and a medium quality. All the parameters can be changed for different requirements.

***Keywords*—** flying surveillance system, full image compression algorithm based on discrete cosines transform, real-time image transmission, UAV.

I. Introduction

THE most used and required informational products transmitted from a surveillance flying system, UAV type, are the captured aerial images of certain areas with high interest from the ground surface. Those images will be analyzed, storaged, indexed and interpreted to obtain very important information based on those images.

Complementary, in the aero spatial satellite records, these types of images has an important role in the concept of decisions regarding to defense, weather induced calamities, terrorists activities, humanitarian missions or undercover actions. Nowadays, there are a large variety of UAVs with particular characteristics, like physical dimensions, operational area, and the maximum altitude of flight, flight duration and speed.

Thus, the development of an image compression algorithm adapted for small UAVs, where physical dimension and energetically limits are required start an interest us.

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Fig. 1 An UAV built by Professor Nicolae Jula [9]

The technical module developed was adapted with a low physical dimension UAV, helicopter type, based on electrical energy [9], with a 1.3 meters length of the main rotor, able to fly in areas where the combustion is perturbed or in areas where the thermo combustion UAVs can not be used.

Image compression offers advantages for real time transmitting but also for future processing, and for an UAV this is a requirement, thanks to the low resources that can be used on a UAV. For every modern army, using an UAV become a priority mostly for their reduce size, low costs involved and the protected human life. The goal of this paper is to develop a module based on a real time image compression algorithm used for missions such as transmitting the images to the ground. The criteria imposed are:

- low processing resources;
- low bandwidth used for transmitting a high number of frames per second;
- portability on different platforms and the facility to be imported on hardware platforms (DSP, FPGA, etc).

II. Problem Statement

Here is the perspective: there is a battlefield and we need to track from a neutral area the enemy's movement, or in retreat situation, from an under siege city we need to analyze the number of the enemy troop's shifts. Thus, we need a surveillance system to transmit, without frequencies limitations and using low resources, images captured from that area and in the case the system is mobile, this is a high advantage. Such a system can be an UAV equipped with an image acquisition device remotely operated (with help from the transmitted images) or by a GPS with an initially map defined.

An UAV, helicopter type was built by Professor Nicolae JULA [9] and can be used in such situations. A picture of that UAV is presented in Fig.1. The flow chart of the situations is described in Fig.2. This paper will deal with the grey block that means the image processing block.

The situation shown in Fig.2 can be described as bellow: A mobile monitoring system, in this example an UAV equipped with image acquisition and radio transmitting devices, capture the images, processing it for the transmission (synchronous, compression, encryption) and transmit it to the ground using a radio channel with low energy and processing resources. On the ground, at a medium distance, the user with a laptop, is viewing the images and save it for further processing. Using the same radio channel, the user will remotely control the UAV helped by the images received in real time, thus the radio channel will be duplex [11].

III. Hardware Platform

The first step was to analyze a platform that will be used on the UAV. For that, firstly we try to use an all in one solution, such as a router that can be reprogrammed. A cheap but "smart" model is Asus WL 500G that costs only 130$. The advantages of the router are the modules included, such as encryption or radio communication because the model mentioned previously has included these modules: AES for the encryption and IEEE 802.11 b/g for the radio communication.

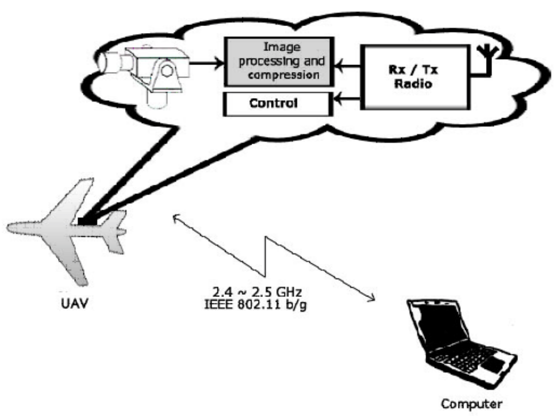

Fig. 2 Diagram of a perspective

The first problem appeared from the processor included on the router: it has only 266 MHz and because of that, the compression cannot be realized with a many number of the frames, thus another platform will be searched. Many solutions come from VIA Technologies Inc.: they developed many motherboards of low size, medium power and low energy requirements. The motherboard that can be achieved is LEX CV700C and cost 550$. A web link to the technical description of LEX CV700C is http://www.lex.com.tw:8080/product/spec/CV700C.pdf.

This is a more expensive solution than the router but has the advantages that the processor has the frequency of 1 GHz. As we have told, the solution is not unique and another better solution from VIA exists but it could not be acquired. Let us now develop an algorithm and test it on the VIA platform mention previously.

IV. Image Compression Algorithm

A. General Overview

Firstly, the block scheme contains the following: starting from the original uncompressed image that is represented in the numerical field in a RGB format, it will be converted to YUV representation, the chrominance will be reduced and the values remained will be centered to zero. After it, block of 8*8 sizes will be extracted. For every 8*8 block, the Discrete Cosines Transform will be applied, the coefficients resulted will be quantified, a zigzag follow-up will be applied and after that the Run Length Encoding and the Huffman Encoding will reduce the size of the quantified coefficients.

B. Uncompressed Image

Because the goal of the paper is to explain the image compression algorithm implemented on the module that can be used on real time transmitting with low processing resources, we won't insist on the capture from the optical sensor, thus the frames will be considered BMP images. The BMP images are uncompressed images with maximum 24 bit depth and use the RGB color system [2]. The explanation will be followed by the image presented in Fig.3 which is an 8*8 block extracted from the uncompressed image.

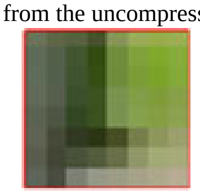

Fig. 3 An 8*8 block extracted

The values of the RGB components extracted from the uncompressed image will be between 0 and 255.

C. RGB to YUV Conversion

The conversion is realized using simple linear operation. For that, the equations that are used are presented bellow. As can be seen, the operations use a low complexity step, as we proposed at the beginning of the paper.

RGB to YUV conversion offers many advantages: for example, if there are problems with the radio communication, it can be selected for transmitting, only the Y components, which represent a grayscale image. This will offer a compression without any effort [6].

The advantage of the YUV conversion can be seen on the example analyzing the values.

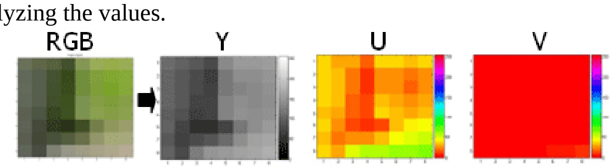

Fig. 4 YUV representation

D. Chrominance reduction

The reduction is based on the human eye property that is more sensitive to the luminance than to the chrominance, thus for that, instead of blocks of n size for every component, it will result 3 blocks such as: n size for the luminance and n/2 size for U and V components that are chrominance components [6]. From now, only the Y block will be analyzed to simplify the explanation. The steps for the U and V components follow the same principles.

E. Center to Zero the Values

The values for the Y, U and V blocks are between 0 and 255 based on the fact that for every block it will be used 8 bits for the bit depth. For a faster computation on the Discrete Cosines Transform (it will be explained later in the paper), a representation between -128 and 127 is preferred [8].

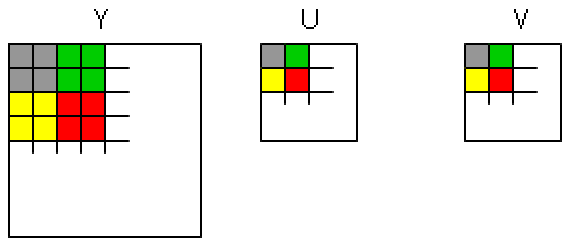

Fig. 5 Chrominance reduction

*F. Extracting 8*8 Blocks*

This is used for a low computation cost. The size of 8*8 is selected because for a smaller size than 8*8, a part of the correlation between pixels will be lost, and for a higher size, the computation cost will grow exponentially with only a small higher correlation that in the 8*8 situation [13]. In Fig.6 we illustrated the extracting step, the luminance block extracted and the representation of the values in a color system for an easy follows of the next steps.

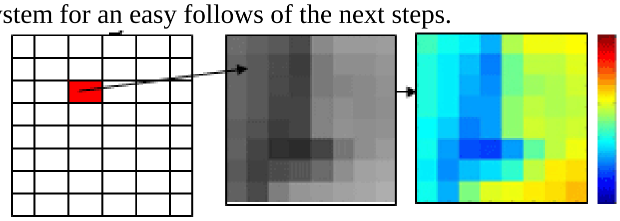

Fig. 6 A luminance block extracted from the image

G. Applying Discrete Cosines Transform

Discrete Cosines Transform (DCT) has the main property of compacting the energy of the image in low frequencies. In our case, it will be applied the DCT-2D, which is the two dimensional DCT applied, that has the formula:

$$F(u)=\sqrt{\frac{2}{N}}C(u)\left[\sum_{x=0}^{N-1} f(x)\cos\frac{(2x+1)u\pi}{2N}\right] \qquad (1)$$

where:

$$C(u)=\frac{1}{\sqrt{2}},\ for \qquad u=0;$$

$$C(u)=1, else.$$

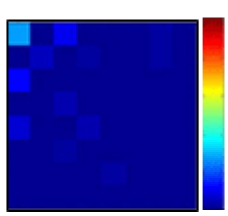

Fig. 7 DCT coefficients

Another way to express the effect of the DCT-2D on an image is that the coefficients resulted represent "how much vary the intensity [8]", and not the intensity value itself.

For the block extracted from the image, the DCT coefficients represented in a color scheme are illustrated in Fig.7.

H. Quantization

This step is used to establish the compression ratio and the quality of the image. The quantization is not scalar, but is a linear one. Thus, for every component (Y, U and V), another matrix of quantization will be applied [13]. For example, for the luminance block, the quantization matrix applied is presented in Fig.8 and the results are illustrated in Fig.9 and Fig.10.

4	3	2	4	6	10	13	16
3	3	3	5	7	14	15	14
2	3	4	6	10	14	17	14
4	5	6	9	13	22	20	16
6	7	10	13	17	28	26	19
10	14	14	22	28	26	28	23
13	15	17	20	26	28	30	26
16	14	14	16	19	23	26	25

Fig. 8 Quantization matrix

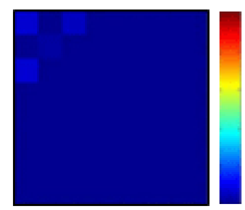

Fig. 9 Color representation of the quantized coefficients

The importance of this step is that here we can use many variance of the matrix, thus it can be established the compression ratio (and also the bandwidth necessary), and the quality of the image. The matrix proposed [7] follows that the quality of the image, measured with the PSNR (Peak Signal Noise Ratio) has to be all the time at least 30 dB (that means a good quality of the image).

17	24	13	0	0	0	0	0
-6	5	0	1	-1	0	0	0
16	-9	0	1	0	0	0	0
-2	0	1	0	0	0	0	0
3	-1	-1	1	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Fig. 10 Quantized coefficients

It can be seen that a lot of coefficients become zero values, thus the next steps will offer a better representation of the zero values.

I. Zigzag Follow-up

By this follow-up of the 2D dimensional vector, it will result a 1D dimensional vector, useful for Run Length Encoding (RLE) coding. The advantage appears after DCT, because the nulls coefficients are mostly under the secondary cross-bar of the matrix. The 1D dimension vector will be easy to code with a high compression ratio using RLE (we will present it in the next step).

J. Run Length Encoding

RLE is based on constitute pairs (number of zeros before the non-zero x value, value x) [13]. The compression ratio obtained for this code is 2:1 or 3:1 because the image contains a uniform area like the sky, the grass. The last bits of zeros are noted (0, 0). An example of an 8*8 RLE coded matrix is shown bellow:

(0,17) (0,24) (0,-6) (0,16) (0,5) (0,13) (2,-9) (0,-2) (0,3) (2,1) (0,30

(1,-1) (0,1) (0,1) (0,-1) (2,-1) (0,0)

It is visible that instead of 64 elements, we will have 34 elements, after a simple operation.

K. Huffman Encoding

The Huffman encoding follows the classical algorithm [1] with a few changes: it will be applied on the image, not on the blocks but for 256 coefficients for one coder.

TABLE I
HUFFMAN'S DICTIONARY

Symbol	0	1	2	-1
Code	0	1111	1110	1101
Symbol	3	17	24	-6
Code	1100	10101	10100	10111
Symbol	16	5	13	9
Code	10110	10001	10000	10011
Symbol	-2			
Code	10010			

For that, many matrix of Huffman coding are built before and adapted for all situations by other research centers. Thus, the Huffman encoding is an entropic encoding and for images offers usually a compression ratio equal with 3:1. For that, it will be used dictionaries [2]. For the example presented, the dictionary is illustrated in Table I.

The binary code for this dictionary is:
0101010101000101110101100100010100001110100110100100110
011101111101100111111010110101111101101111000

V. The Application

The algorithm presented previously is implemented on the platform from Section III and the decoder is an application used on the ground not only to receive the images captured but to control the UAV based on the images received. A preview of the application menu and functionality is presented in Fig. 11.

Other options of the software are to control the compression depending of the transmission state [12]. For example, for a low bandwidth transmission the images can be sent at lower quality or in grayscale, instead of color images. The transmission in grayscale can be achieved using only the Y field from Section IV.C and the quality can be changed by changing the quantization matrix from Section IV.H.

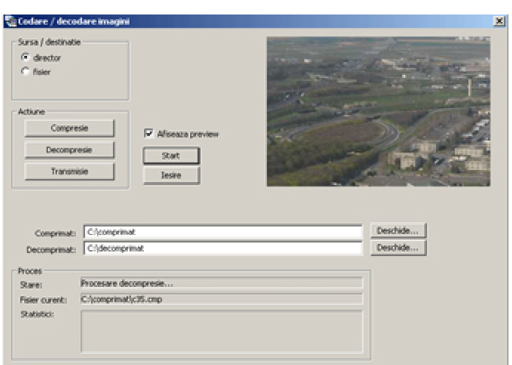

Fig. 11 The interface of the software

VI. Optimization of the Algorithm

As mentioned previously, the algorithm can be optimized by offering a high flexibility [12]. The optimization of the algorithm follows three major ways:

- optimization of the frames per second: for low processing platform, to achieve a higher number of frames per second, the complexity of the algorithm can be reduced by changing the Huffman coding from the compression blocks with "a more practical version of the Huffman coder named the trunked Huffman coder [17]". The cost of this step is that the compression ratio becomes lower.
- optimization of the quality: as mentioned previously, the quality can be adjusted by changing the quantization matrix for Y, U and V fields presented in Section IV.C. A library of quantization matrix can be found at [7];
- the compression ratio (or the necessary bandwidth): an option presented in Section V is the flexibility of the compression ratio, depending on the transmission. We will not insist on the method, even if is an important characteristic of the algorithm.

VII. Results

The algorithm implemented on LEX CV700C obtained for the still images from Fig. 12 the results presented in Table II. The image compression module was tested on a high number of images, practical ones captured from the UAV and theoretical from a image database.

For the results presented in Table II, the annotations mean are:

- resolution of an image: is measured in pixel*pixels;
- compression ratio: there are two ways to define it, one meaning the number of bits necessary to represent one pixel and the second one is by comparing the size of the original and the compressed image using the divider operator;
- quality of a image: a method to measure the quality of an image is using PSNR (Peak Signal Noise Ratio) and the measure unit is decibel (dB).

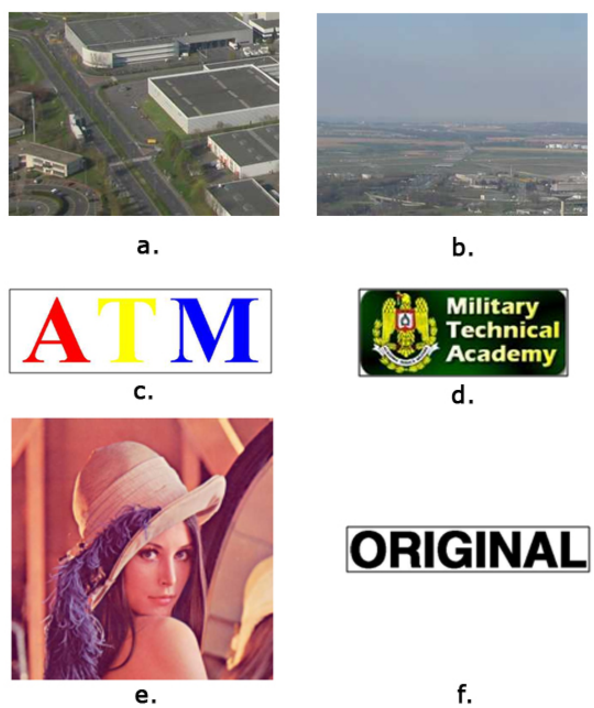

Fig. 12 Few images from the set tested

TABLE II
THE COMPRESSION'S RESULT

Images	a.	b.	c.	d.	e.	f.
Resolution (pixels*pixels)	640*480	640*480	539*171	211*86	512*512	547*99
Compression ratio (bpp)	0.72	0.38	0.8	2.66	0.75	1.36
Compression ratio (image1/image2)	33:1	63:1	30:1	9:1	32:1	9:1
Quality – PSNR (dB)	37	35.2	52	34	31.4	47

For a video transmission, a general overview on the results obtained with LEX CV700C shows the following:

- at the resolution of 320*240, color frames, LEX CV700C can compute 5 frames per second;
- at the resolution of 640*480, color frames, LEX CV700C can compute 1.5 frames per second;
- the compression ratio vary, depending of the content of the frames between 32:1 and 140:1 for color frames;
- quality of natural images: the quality is variable, depends of the quantization matrix used, but for the matrix previously proposed in the luminance situation, the PSNR is between 31.2 dB and 37 dB at the compression ration presented previously;
- the bandwidth necessary to transmit color frames at 320*240 is between 10 and 50 Kbytes/s;
- the bandwidth necessary to transmit color frames at 640*480 is between 9 and 39 Kbytes/s.

VIII. Conclusion

The goal of this paper is to present an image compression algorithm after analyzing compression techniques and selecting only low complexity steps to be embedded in a coder that can be used on a small UAV to be controlled from the ground without eye contact, and to transmit for storage at the ground the images captured.

Nowadays, the coder is limited by the technological resources, but for higher prices resources, the number of the frames per second can grow. A better solution, but with high computational costs is to use prediction between frames [3], and in this situation the compression ration can achieve values higher by 12 times, meaning a compression ratio between 384:1 and 1680:1!

All the results are presented in the worst cases, only color images, with high details, low resources, thus the results can be even better, depending on the parameters of the coder and the contain of the images.

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