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The development of modern automated image processing and transfer systems for agriculture unmanned aerial vehicles

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Abstract. The paper contains results of analytic research of unmanned aerial vehicles using in agriculture. The main problems arising in the creation and subsequent large volumes of high-resolution images real time transfer in unmanned aerial vehicles are highlighted. The Automated image processing and transfer system using new methods of information compression on unmanned aerial vehicles board is proposed. The paper considers the issues of consider the problems of constructing new orderings of Walsh functions and constructing fast compression algorithms in synthesized systems of discrete Walsh functions. For processing and subsequent transmission of information from UAVs recommended to use the fast DWT procedure, it allows for a hardware implementation capable of the real-time conversion performing due to its simplicity. The introduction of the proposed solutions for UAVs in agriculture allows to increase accurasy of electronic cartographic material, to keep electronic records of agricultural operations, to carry out operational monitoring of the crops state and to respond quickly for violations and deviations, to predict crop yields and plan their activities for short-term and long-term prospects.

1 Introduction

Automation is one of the most important areas of scientific and technological progress in agriculture. The maximum effect in agriculture can be achieved only by possessing up-to-date and accurate information about the area, specificity and relief of the field ground. Using the unmanned aerial vehicles (UAVs) is the most optimal and effective way to obtain such information [1-7]. Modern unmanned systems solve such agriculture problems as assessment of the crops quality and detection of damage or loss of crops; detection of sowing defects and problem areas; analysis of the plant protection activities effectiveness; monitoring of structure compliance and plans of crop rotation; detection of deviations and irregularities during agricultural works, et.

One day of shooting gives data for examination and analysis of the area of up to 5 thousand hectares. Technologically equipped UAVs can perform the following operations (Fig.1, 2): aerial photography, video photography, 3D simulation, thermal imaging, laser scanning and spraying.

The key requirements of the UAV application for the tasks described above are the possibility of real-time visual analysis of information, high quality of transmitted images and transmission speed. The latter characteristic is largely determined by the interference situation and the communication channel bandwidth. However, it is often not possible to transfer high quality bitmap images with insufficient throughput.

Fig. 1. UAVs performing spraying.

Fig. 2. UAVs performing thermal imaging procedure.

This task is currently being accomplished by means of the development of appropriate automated communication systems using the data compression technologies on the UAV board [8-11]. The current large data amounts processing and real-time control points transmitting methods have limited operational and technical capabilities.

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Among image compression techniques, data redundancy reducing technologies play a very important role. It compresses large amounts of transmitted or stored information, which makes it possible to unload communication channels and data processing and storage systems, which is equivalent to the data collection, transmission and processing systems or the storage devices capacity increasing.

JPEG and JPEG-like algorithms, as well as compression methods based on Fourier transform, iscrete cosine transform (DCT), discrete Walsh (DWT) and Haar transform are used most often for data reduction and transmission in automated control systems[12-17]. If the situation requires the extreme analysis, it is also recommended to use the fast DWT procedure in sensors, it allows for a hardware implementation capable of the real-time conversion performing due to its simplicity [16].

Efficient using of DWT in applied problems lies in the possibility of calculating them using fast algorithms that have significantly less computational complexity compared to direct (classical) conversion algorithms, which increases the speed of processing and data transfer [16-18].

The disadvantage of DWT is that they are inferior in compression efficiency to the DCT. However, there is a way to further optimize the Walsh transform. For example, it is possible to increase the efficiency of data compression and transmission using DPA by additional processing of the spectrum elements with extrapolation methods and by implementing new orderings of discrete Walsh functions (DWF) [19].

Next, we consider the problems of constructing new orderings of Walsh functions and constructing fast algorithms in synthesized systems of discrete Walsh functions.

2 Construction and study of the properties of difference-ordered systems of discrete Walsh functions

Well-known orderings in the DFU system such as: Walsh-Kachmazh, Walsh-Paley, Walsh-Hadamard are used in data processing and transmission systems. The new proposed fixed methods for ordering DFU in the system are obtained by a certain permutation of the basis functions of the reference matrices [19]. Moreover, the Walsh-Hadamard and Walsh-Paley matrices are used as reference matrices.

A new approach to the fixed ordering of DWF dimensions is as follows:

1. A partition of the set of serial numbers of the original system's Walsh functions is being constructed.

$I = \{0, 1, \ldots, N-1\}$ to $(n+1)$ subsets, each of which includes function numbers with the same differential orders.

2. The formed subsets are arranged in increasing order of the differential orders of the corresponding functions.

The resulting difference-ordered system of DWF will be characterized by the fact that the functions in it are arranged in groups in increasing order of their differential orders. For a permutation sequence vector, we stick to the designation $P_n = (p_0, p_1, \ldots, p_{N-1})$, where $p_i = j_i$, $i = \overline{0, N-1}$.

A permutation using this vector is called a permutation on the differential orders of basis functions (briefly D-permutation).

An analysis of the differential orders of the Walsh-Hadamard functions showed that the vector P_n can be represented as a combination of a number of subvectors:

$$P_n = (P_n^{(0)}, P_n^{(1)}, P_n^{(2)}, \ldots, P_n^{(n)}) \quad (1)$$

where $P_i^{(0)} = (0)$, $P_i^{(i)} = (2^i - 1), i = \overline{1, n}$;

$P_n^{(k)}, k = \overline{1, n-1}$, – are subvectors, defined by recurrence relations:

$$P_i^{(k)} = \begin{cases} (2^i - 1), & i = k, \\ (P_{i-1}^{(k)}, 2^{i-1} + P_{i-1}^{(k-1)}), & i = \overline{k+1, n}, \end{cases} \quad (2)$$

where $i = \overline{k, n}$.

Based on the obtained vector of permutation sequence values, difference-ordered systems of DWF $\{hdd_N(i)\}_{i=0}^{N-1}$ can be described like this:

$$hdd_N(i) = had_N(p_i), \quad i = 0, 1, N-1, \quad (3)$$

where $had_N(i)$ – are, respectively, the i Walsh-Hadamard functions.

The matrix entry for the introduced DWF systems has the following form:

$$HDD_N = S_N^D HAD_N \quad (4)$$

where $S_N^D = [s_{ij}]_{i,j=\overline{0,N-1}}$ – is the matrix of D-permutations, which elements are formed like that:

$$s_{i,j} = \begin{cases} 1, & if\ j = p_i, \\ 0, & in\ other\ cases. \end{cases} \quad (5)$$

The spectra of discrete power polynomials of low orders in the difference-ordered DWFs bases are characterized by a greater degree of localization of nonzero components in their initial sections (Fig.3).

Let us illustrate the nature of the distribution of nonzero components of the spectra of discrete power polynomials of the first and second degree for N = 16 in the bases of various systems of DWF (Fig. 3).

We introduce the indicator vector of the spectrum $S = (s_0, s_1, \ldots, s_{N-1})$, by defining its elements so

$$S_i = \begin{cases} 1, & F(i) \neq 0, \\ 0, & F(i) = 0, \end{cases} \quad (6)$$

where $F(i)$ - is the *i*-th conversion coefficient.

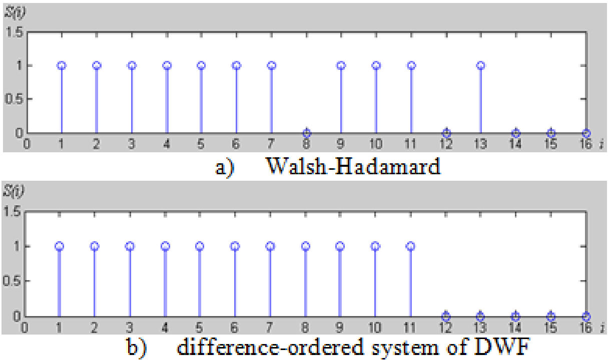

Fig. 3. Indicator spectra in the bases of various systems of DWF.

The spectra of discrete power polynomials of low orders in the bases of difference-ordered DWF are characterized by a greater degree of localization of nonzero components in their initial sections. The obtained property of transformations by difference-ordered systems of DWF is very important for their applications in the problems of digital processing of signals and images from primary sensors and video cameras UAVs.

3 Captions/numbering Fast algorithms building for one-dimensional and two-dimensional transformations in difference-ordered systems of DWF

The calculation of the spectral coefficients of a two-dimensional DWT is possible in several ways. For example, the calculation can be reduced to two sequentially performed operations of multiplying three matrices:

$$F = HAD_N^{T} \, f \, HAD_N \quad (7)$$

where f – is the source data matrix; F – is the matrix of spectral coefficients; HAD_N - matrix of DWHT.

The classical way of calculating the operation of multiplying 8×8 matrices requires: $N^2(N-1) = 448$ addition and subtraction operations. Accordingly it will be required 896 addition and subtraction operations for calculating a two-dimensional DWT of 8×8 dimension.

There is also a line-by-column method for implementing fast two-dimensional DCS requiring only $2(N^2 \log_2 N) = 384$ operations of addition and subtraction. The number of operations reduction is achieved by factoring the Walsh matrix into sparse factors in the form, like:

$$HAD_N = \prod_{i=0}^{n-1} HAD_N^{(i)} \quad (8)$$

where *n* – number of factorization matrices ($N = 2n$);
$HAD_N^{(i)}$ - weakly filled matrix of the form like

$$HAD_N^{(i)} = (I_{2^{n-i-1}} \otimes HAD_2 \otimes I_{2^i}) \quad (9)$$

where I_k - identity matrix.

Considering the proposed fast DWTs algorithms, we restrict ourselves to the synthesis of direct transformation algorithms, since they uniquely determine the inverse transformation algorithms.

In matrix form, the formulas for the one-dimensional transformation in difference-ordered systems of DWF will have the form:

$$F = S_N^D HAD_N \, f \quad (10)$$

where *f* – source data vector; *F* – spectral coefficients vector; S_N^D – D-permutations matrix.

D-permutations matrices elements $S_N^D = [s_{ij}]_{i,j=\overline{0,N-1}}$ are formed as follows:

$$s_{i,j} = \begin{cases} 1, & if \ j = p_i, \\ 0, & in \ other \ cases. \end{cases} \quad (11)$$
$$s_{i,j} = 0, then \ s_{i,p_i} = 1.$$

where p_i - permutation vector elements (2).

For the source data vector at HAD_N the matrix can be represented as the product of three sparse factors:

$$\begin{aligned} &HAD_8 = HAD_8^{(2)} HAD_8^{(1)} HAD_8^{(0)}, \\ &HAD_8^{(0)} = I_4 \otimes HAD_2 = \\ &= diag(HAD_2, HAD_2, HAD_2, HAD_2); \\ &HAD_8^{(1)} = I_2 \otimes HAD_2 \otimes I_2 = \\ &= \begin{bmatrix} HAD_2 \otimes I_2 & \\ & HAD_2 \otimes I_2 \end{bmatrix}; \\ &HAD_8^{(2)} = 1 \otimes HAD_2 \otimes I_4 = \begin{bmatrix} I_4 & I_4 \\ I_4 & -I_4 \end{bmatrix}. \end{aligned} \quad (12)$$

Two-dimensional transformations in difference-ordered systems of DWF at a 8×8 dimension are realized on the basis of fast one-dimensional algorithms of DWT. First, we transform the input matrix of 8×8 size into a 64-dimension vector.

Write the formulas for calculating the one-dimensional transformation in difference-ordered systems of DWF of a 64-dimension vector:

$$F = S_{64}^{D(2)}\, HAD_{64}^{(2)}\, S_{64}^{D(1)}\, HAD_{64}^{(1)}\, f \qquad (13)$$

where $HAD_{64}^{(1)} = I_8 \otimes HAD_8$;

$$HAD_{64}^{(2)} = HAD_8 \otimes I_8;$$

$$S_{64}^{D(1)} = I_8 \otimes S_8^D =$$
$$= diag(S_8^D, S_8^D, S_8^D, S_8^D, S_8^D, S_8^D, S_8^D, S_8^D);$$

$$S_{64}^{D(2)} = S_8^D \otimes I_8.$$

This study also proposes a second variant of calculating a 64-point fast conversion in difference-ordered systems of DWF, in which the permutation of the spectral coefficients vector of 64 dimension is performed only at the last stage. The corresponding graphs of computational procedures are developed for each option.

4 Results

We performed an analysis of compression algorithms with conversion according to various DWF ordering systems in [20]. Using a difference-ordered system algorithms of DWFs showed 15% more compression ratios (CR) than algorithms based on other orderings of DWF on the test image set (Table 1).

Table 1. Comparison of Compression Algorithms.

Test image	compression ratio	winning rate, %
monarch	14,43	24
peppers	13,95	18
sail	8,08	6
serrano	6,86	10
tulips	9,74	11
lena	13,29	21
Mean		15

Figures 4 and 5 show the images that occur during aerial collection from UAV for operational monitoring of the crops condition and for the agricultural operations electronic accounting processed by algorithm using differential-ordered DFC system at different compression ratios.

a) initial image

b) fragment at compression ratio =36

Fig. 4. Image from UAV for operational monitoring of seeding condition.

a) UAV image for the agricultural operations automated recording: initial image

b) fragment at compression ratio =17

Fig. 5. UAV image for the agricultural operations automated recording.

Performing the proposed fast conversion algorithms in differential ordered DFC systems requires 384 addition and subtraction operations, as well as 64 permutations when executing the first variant of the algorithm and 48 when executing the second variant. The advantage of classical fast algorithms is achieved at the computing organizations level: there are no transposition operations and work with a one-dimensional array.

Note some of the obtained algorithms properties: a parallel data processing possibility, the progressive compression support , the simplicity of hardware implementation of algorithms in the form of specialized processors.

The proposed fast transformation algorithms in differential-ordered DFC systems can be effectively used in the development of appropriate automated image processing and data transmission systems using compression methods on board UAVs.

The introduction of the proposed solutions for UAVs in agriculture allows to increase accurasy of electronic cartographic material, to keep electronic records of agricultural operations, to carry out operational monitoring of the crops state and to respond quickly for violations and deviations, to predict crop yields and plan their activities for short-term and long-term prospects

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