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Principle of Formation of a Redundancy Parameter of the Information Stream from Analog Sensors of Slowly Changing Parameters and the Algorithm of its Implementation

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Abstract. The article justifies and sets the task to develop the algorithms of information processing in onboard radio telemetry systems (RTS), which will define:

- the presence of redundancy of information from the sensors and its reduction;
- the redistribution of information packets from the sensors in transfer frames of onboard RTS in case of emergency.

The redundancy indicator of the information stream in onboard RTS is described. Based on the offered earlier adaptive difference algorithm (ADA) [1, 2], which allows one to eliminate redundancy resulting from the erroneous choice of measurement scale, an adaptive difference algorithm with decimation (ADAD) is developed. This algorithm makes it possible to reduce redundancy caused by the increased sampling frequency. The ADAD cumulative maximum redundancy reduction factor is formed by multiplication of the compression factor of the ADA and the maximum decimation factor.

Keywords: onboard processing of measurement results, reduction of data redundancy, information packet, onboard radio telemetry system

Introduction

Any type of time-division multiplex system and pulse-code modulation (PCM) telemetry systems, in particular, according to their definition, require the discretization of the original signal before its transmission. The assumed model of the sampling process comes down to quantizing an analog signal by duration with a uniform frequency that is defined by the duration considered to be short in comparison with the amplitude-modulated signal sampling frequency.

The discretized function (discrete original signal) de facto exists only at moments in time that coincide with the moment of analog signal quantizing. For this reason, the function cannot be ideally restored by linear approximation of selected points. If the repetition frequency of sampling values is high enough when compared to parameter dynamics, then it is possible to accurately restore the waveform and preserve its essential characteristics.

Moreover, the advantage of transmitting band-limited signals lies in the possible usage of the theorem known as the discrete representation theorem, which defines the conditions for determining the correct sampling frequency for sensor output signals. The theorem is also known as the Nyquist theorem, Kotelnikov theorem, sampling theorem.

According to this theorem, limited bandwidth signals (*B*) in the case of their discretization every t_s seconds can be correctly restored using the following inequality: t_s £ *1/(2B),* where B is the signal bandwidth limit. [3]

In other words, if a function in interval T does not contain frequencies exceeding 2W Hz, then it is completely determined by its instantaneous values of the 1/(2W) period with [4].

In telemetry, redundancy of the quantity of samples during data transmission is embedded at the time of parameter sampling frequency assignment, taking into account the a priori information regarding the signal intended for transmission through a communication link.

Initially, the so-called "compression ratio" (calculated as the ratio of the amount of original samples to the amount of samples at the output of the data compression device) was chosen to characterize the efficiency of the data compression algorithm in question. Nevertheless, soon it was understood that the data compression ratio is not solely dependent on algorithm efficiency — it is determined by the initially assigned parameter sampling frequency and by the waveform in the given time interval. In other words, the compression ratio, calculated as stated above, does not unambiguously characterize the data compression algorithm, as well as the choice of an efficient data compression algorithm and the classification of compression algorithms by efficiency.

Another condition for the study and comparison of data compression algorithms: the assumption that the analytic representation of the signal subject to the procedure of compression is a priori known — which is not the case when solving practical problems of rocket telemetry. Moreover, during emergency phases of flight the behavior of telemetry parameters is not stationary, which curtails the implementation of the statistical test method for choosing an effective data compression algorithm. [4]

Sampling rate of analog sensors of slowly changing parameters (SCP)

In [5] is noted that the sensors of the propulsion system are usually sampled with a 50 Hz and 100 Hz frequency. Yet, in order to receive information on the behavior of the engine in an emergency, the sampling frequency of the corresponding sensors should be increased up to 200400 Hz.

For increasing the sampling frequency of some sensors, parallel connection of one sensor output to several inputs of the message collection subsystem [6] can be used. In this case, the sensor measurement samples may be non-uniform. This is conditioned by the fact that the sampling cycle of the local switch (LS) is 5 ms and the framing cycle is 10-20 ms. This should be accounted for in the system operation algorithm when inserting information into the output frame from the buffer ("mirror") of the message collection subsystem in accordance with the measurement program.

The research set forth in [7] demonstrated that the sampling rate in LSs of analog sensors (LSA) could be increased by 2-4 times by way of selection of elements in the buffer cascade for reducing the time of the channel-switching transient. Thus, the maximum sampling frequency for analog sensors may be increased to 400 Hz or 800 Hz.

Still, with existing methods of placing sensor status information in transfer frames, for most sensors, increased sampling rates are useless because framing cycle duration is already longer than the LSA sampling cycle by fourfold. In other words, the cumulative information content of all of the LSs is considerably higher than that of the radio channel. Currently for coordinating the information content of the message collection subsystem (MCS) (i.e., the aggregate of all of the LS) and the information content of the radio channel only a limited amount of interrogation programs is used. These programs determine the location in the frame and the sampling rate (repetition rate in frame) of every sensor. However, in the case of abnormal item operation, a higher sampling rate may be required for a sensor with a low frequency specified in the interrogation program because, after all, it is impossible to foresee every situation. Thus, arises the necessity to develop information-processing algorithms for onboard RTS that are to determine:

- the presence of redundancy of information from the sensors and its reduction;
- the redistribution of information packets from the sensors in transfer frames of onboard RTS.

The principle of forming the information stream redundancy parameter in onboard RTS

The telemetry system collects information from many sensors. Analog sensors make up the largest part (53% - 84%) of the information content of the information stream from the onboard RTS to the Earth. [1] An analog sensor switch usually has one analog-to-digital converter (ADC) for 64 sensors and all of them are sampled in turn with an equal frequency. The received data is transmitted to the buffer memory of the system central unit. The unit, in accordance with the programmed interrogation program, generates the output frame of the onboard RTS. When such a data generation method is implemented, information redundancy will be present in some channels, considering that not all channels require the same sampling frequency. Partially, this redundancy can be compensated for by decimating the information incoming into the buffer from some sensors at the time of system output frame generation.

In [1, 2] for reducing information redundancy from analog sensors the use of the adaptive difference algorithm (ADA) is suggested. It is a cumulative algorithm with packet data transmission. Fixed-sized packets are transmitted. Data is compressed by transmitting not the measurements themselves but by transmitting the differences between adjacent samples. At the same time, value Δ is formed, which is the maximum amount of bits that the difference between adjacent samples occupies within one packet during algorithm operation.

This value Δ is the information redundancy factor for inputs with less dynamic signals. Due to this, it is possible to implement selective decimation of information for inputs with less dynamic signals from sensors and use the newly available information content to transmit information from sensors with higher signal dynamics. This will lead to a proportional to the decimation factor increase of the maximum compression ratio.

Adaptive difference algorithm with decimation

As it can be seen from [1], the ADA eliminates redundancy when sampling a sensor at one frequency with a compression ratio of no more than four (4). The decimation algorithm eliminates redundancy with a factor equal to the ratio of the maximum and minimum sampling frequencies. Combining these algorithms will give an even higher redundancy elimination factor. Now, we turn our attention the adaptive difference algorithm with decimation (ADAD).

Assuming that the sampling frequency is always equal to 200 Hz, the minimum frequency of information output from sensors during decimation is equal to 12.5 Hz, i.e., the decimation factor is taken to be 16. The size of the data portion of a packet is equal to 16 bytes; ADC capacity – 8. The results of ADAD algorithm implementation are as shown in Table 1. Nine steps comprise a full ADAD cycle.

The first seven steps correspond to the full cycle of the ADA algorithm, coefficient Δ is calculated with respect to two adjacent measurements of a single parameter that are carried out with the frequency of 200 Hz. At first, 16 measurements are accumulated, the condition $\Delta_{\max n} < 7$ bits is checked. If the condition is not met, then 16 measurements without compression are placed into the information packet. If the condition is met, then the accumulation of measurements continues.

After accumulating 18 measurements in the second step, the condition $\Delta_{\max n} < 7$ bits is checked first. If the condition is not fulfilled, the packet formed during the first step is issued and the algorithm returns to step one. If the condition is fulfilled, then the specifying condition $\Delta_{\max n} = 6$ bits is checked. If it is met, then an

Table 1. Example of the ADAD algorithm

Sampling frequency	**Stage No.**	**Step No. (action)**	**Action for measurement collection buffer**	**Analysis of $\Delta_{\max n}$ – maximum amount of bits required for representing the measurement value differences in binary form**
200 Hz	0	1	Accumulation of 16 measurements	$\Delta_{\max n}$ = 8 or 7 bits, 16 measurements in a packet $\Delta_{\max n}$ < 7 bits, transition to action 2
		2	Accumulation of 18 measurements (MEAS) (+ 2 MEAS)	$\Delta_{\max n}$ = 8 or 7 bits, issue of 1 packet with 16 measurements, transition to action 1 $\Delta_{\max n}$ = 6 bits, issue of 1 packet with 18 measurements, transition to action 1 $\Delta_{\max n}$ < 6 bits, transition to action 3
		3	Accumulation of 21 measurements (+ 3 MEAS)	$\Delta_{\max n}$ = 8, 7 or 6 bits, issue of 1 packet with 18 measurements, transition to action 1 $\Delta_{\max n}$ = 5 bits, issue of 1 packet with 21 measurements, transition to action 1 $\Delta_{\max n}$ < 5 bits, transition to action 4
		4	Accumulation of 25 measurements (+ 4 MEAS)	$\Delta_{\max n}$ = 8, …, 5 bits, issue of 1 packet with 21 measurements, transition to action 1 $\Delta_{\max n}$ = 4 bits, issue of 1 packet with 25 measurements, transition to action 1 $\Delta_{\max n}$ < 4 bits, transition to action 5
		5	Accumulation of 31 measurements (+ 6 MEAS)	$\Delta_{\max n}$ = 8, …, 4 bits, issue of 1 packet with 25 measurements, transition to action 1 $\Delta_{\max n}$ = 3 bits, issue of 1 packet with 31 measurements, transition to action 1 $\Delta_{\max n}$ < 3 bits, transition to action 6
		6	Accumulation of 41 measurements (+ 10 MEAS)	$\Delta_{\max n}$ = 8, …, 3 bits, issue of 1 packet with 31 measurements, transition to action 1 $\Delta_{\max n}$ = 2 bits, issue of 1 packet with 41 measurements, transition to action 1 $\Delta_{\max n}$ < 2 bits, transition to action 7
		7	Accumulation of 61 measurements (+ 20 MEAS)	$\Delta_{\max n}$ = 8, …, 2 bits, issue of 1 packet with 41 measurements, transition to action 1 $\Delta_{\max n}$ = 1 bit, transition to action 8
100 Hz	1	8	Accumulation of 62 measurements with a frequency of 200 Hz, decimation by a factor of 2 (equivalent of sampling frequency reduction), acquisition of 31 measurements with a frequency of 100 Hz	$\Delta_{\max n}$ analysis analogous to step 5 for 31 decimated measurements $\Delta_{\max n}$ = 8, …, 3 bits, issue of 1 packet with 61 measurements with a frequency of 200 Hz, transition to action 1 $\Delta_{\max n}$ < 3 bits, transition to action 9
		9	Accumulation of 82 measurements with a frequency of 200 Hz, decimation by a factor of 2 (equivalent of sampling frequency reduction), acquisition of 41 measurements with a frequency of 100 Hz	$\Delta_{\max n}$ analysis analogous to step 6 $\Delta_{\max n}$ = 8, …, 3 bits, issue of 1 packet with 61 measurements with a frequency of 200 Hz, transition to action 1 $\Delta_{\max n}$ = 2 bits, issue of 1 packet with 41 measurements with a frequency of 100 Hz, transition to action 1 $\Delta_{\max n}$ < 2 bits, transition to action 10
		10	Accumulation of 122 measurements with a frequency of 200 Hz, decimation by a factor of 2 (equivalent of sampling frequency reduction), acquisition of 61 measurements with a frequency of 100 Hz	$\Delta_{\max n}$ analysis analogous to step 7 $\Delta_{\max n}$ = 8, …, 2 bits, issue of 1 packet with 41 measurements with a frequency of 100 Hz, transition to action 1 $\Delta_{\max n}$= 1 bit, transition to action 11

Table 1. Example of the ADAD algorithm

Sampling frequency	**Stage No.**	**Step No. (action)**	**Action for measurement collection buffer**	**Analysis of $\Delta_{\max n}$ – maximum amount of bits required for representing the measurement value differences in binary form**
50 Hz	2	11	Accumulation of 124 measurements with a frequency of 200 Hz, decimation by a factor of 4 (equivalent of sampling frequency reduction), acquisition of 31 measurements with a frequency of 50 Hz	$\Delta_{\max n}$ analysis analogous to step 8 $\Delta_{\max n}$ = 8, …, 3 bits, issue of 1 packet with 61 measurements with a frequency of 100 Hz, transition to action 1 $\Delta_{\max n}$ < 3 bits, transition to action 12
		12	Accumulation of 164 measurements with a frequency of 200 Hz, decimation by a factor of 4 (equivalent of sampling frequency reduction), acquisition of 41 measurements with a frequency of 50 Hz	$\Delta_{\max n}$ analysis analogous to step 9 $\Delta_{\max n}$ = 8, …, 3 bits, issue of 1 packet with 61 measurements with a frequency of 100 Hz, transition to action 1 $\Delta_{\max n}$ = 2 bits, issue of 1 packet with 41 measurements with a frequency of 50 Hz, transition to action 1 $\Delta_{\max n}$ < 2 bits, transition to action 13
		13	Accumulation of 244 measurements with a frequency of 200 Hz, decimation by a factor of 4 (equivalent of sampling frequency reduction), acquisition of 61 measurements with a frequency of 50 Hz	$\Delta_{\max n}$ analysis analogous to step 10 $\Delta_{\max n}$ = 8, …, 2 bits, issue of 1 packet with 41 measurements with a frequency of 50 Hz, transition to action 1 $\Delta_{\max n}$ = 1 bit, transition to action 14
25 Hz	3	14	Accumulation of 248 measurements with a frequency of 200 Hz, decimation by a factor of 8 (equivalent of sampling frequency reduction), acquisition of 31 measurements with a frequency of 25 Hz	$\Delta_{\max n}$ analysis analogous to step 11 $\Delta_{\max n}$ = 8, …, 3 bits, issue of 1 packet with 61 measurements with a frequency of 50 Hz, transition to action 1 $\Delta_{\max n}$ < 3 bits, transition to action 15
		15	Accumulation of 328 measurements with a frequency of 200 Hz, decimation by a factor of 8 (equivalent of sampling frequency reduction), acquisition of 41 measurements with a frequency of 25 Hz	$\Delta_{\max n}$ analysis analogous to step 12 $\Delta_{\max n}$ = 8, …, 3 bits, issue of 1 packet with 61 measurements with a frequency of 50 Hz, transition to action 1 $\Delta_{\max n}$ = 2 bits, issue of 1 packet with 41 measurements with a frequency of 25 Hz, transition to action 1 $\Delta_{\max n}$ < 2 bits, transition to action 10
		16	Accumulation of 488 measurements with a frequency of 200 Hz, decimation by a factor of 8 (equivalent of sampling frequency reduction), acquisition of 61 measurements with a frequency of 25 Hz	$\Delta_{\max n}$ analysis analogous to step 13 $\Delta_{\max n}$ = 8, …, 2 bits, issue of 1 packet with 41 measurements with a frequency of 25 Hz, transition to action 1 $\Delta_{\max n}$ = 1 bit, transition to action 17

Table 1. Example of the ADAD algorithm

Sampling frequency	**Stage No.**	**Step No. (action)**	**Action for measurement collection buffer**	**Analysis of $\Delta_{\max n}$ – maximum amount of bits required for representing the measurement value differences in binary form**
12.5 Hz	4	17	Accumulation of 496 measurements with a frequency of 200 Hz, decimation by a factor of 16 (equivalent of sampling frequency reduction), acquisition of 31 measurements with a frequency of 12.5 Hz	$\Delta_{\max n}$ analysis analogous to step 14 $\Delta_{\max n} = 8, \dots, 3$ bits, issue of 1 packet with 61 measurements with a frequency of 25 Hz, transition to action 1 $\Delta_{\max n} < 3$ bits, transition to action 18
		18	Accumulation of 656 measurements with a frequency of 200 Hz, decimation by a factor of 16 (equivalent of sampling frequency reduction), acquisition of 41 measurements with a frequency of 12.5 Hz	$\Delta_{\max n}$ analysis analogous to step 15 $\Delta_{\max n} = 8, \dots, 3$ bits, issue of 1 packet with 61 measurements with a frequency of 25 Hz, transition to action 1 $\Delta_{\max n} = 2$ bits, issue of 1 packet with 41 measurements with a frequency of 12.5 Hz, transition to action 1 $\Delta_{\max n} < 2$ bits, transition to action 19
		19	Accumulation of 976 measurements with a frequency of 200 Hz, decimation by a factor of 16 (equivalent of sampling frequency reduction), acquisition of 61 measurements with a frequency of 12.5 Hz	$\Delta_{\max n}$ analysis analogous to step 16 $\Delta_{\max n} = 8, \dots, 2$ bits, issue of 1 packet with 41 measurements with a frequency of 12.5 Hz, transition to action 1 $\Delta_{\max n} = 1$ bit, issue of 1 packet with 61 measurements with a frequency of 12.5 Hz, transition to action 1

18-measurement packet is issued and packed into 16 bytes. If the specifying condition ($\Delta_{\max n}$ < 6 bits) is not fulfilled, then measurement accumulation is continued, and the transition to the third step of the algorithm is made.

Upon accumulation of 21 measurements in step three, first, the condition for transitioning from the second step is checked: $\Delta_{\max n}$ < 6 bits. If the condition is not met, the packet formed during step two is issued and the algorithm is returned to step one. If the condition is met, the specifying condition $\Delta_{\max n}$ = 5 bits is checked. If it is fulfilled, then a packet, packed in 16 bytes, with 21 parameter measurements is issued. If the specifying condition ($\Delta_{\max n}$ < 5bits) is not met, then measurement accumulation continues and transition to the fourth step of the algorithm takes place.

After accumulating 25 measurements in step four, first, the condition for transitioning from step three $\Delta_{\max n}$ < 5 bits is checked. If it is not met, the packet formed in step 3 is issued and the algorithm returns to the first step. If the condition is fulfilled, then the specifying condition $\Delta_{\max n}$ = 4 bits is checked. If it is met, then a packet with 25 parameter measurements packed in 16 bytes is issued. If the specifying condition ($\Delta_{\max n}$ < 4 bits) is not met, then measurements continue to be accumulated and the transition to the fifth step of the algorithm is made.

After accumulating 31 measurements in step five, the transition from step four condition $\Delta_{\max n}$ < 4 bits is checked. If the condition is not met, the packet, which was formed in step four, is issued and the algorithm returns to the first step. If the condition is fulfilled, the $\Delta_{\max n}$ = 3 bits specifying condition is met. If the specifying condition is fulfilled, then a packet with 31 measurements is issued that is packed in 16 bytes. If the specifying condition is not fulfilled ($\Delta_{\max n}$ < 3 bits), measurement accumulation is continued and the transition to the sixth step of the algorithm is made.

Upon accumulation of 41 measurements in step six the condition for transitioning from step five is checked: $\Delta_{\max n}$ < 3 bits. If the condition is not fulfilled, the packet, which was formed during step five, is issued and the algorithm returns to step one. If the condition is met, then the specifying condition $\Delta_{\max n}$ = 2 bits is checked. If it is fulfilled, a packet with 41 measurements is issued. The packet is packed in 16 bytes. If the specifying condition ($\Delta_{\max n}$ = 1 bit) is not met, the measurement accumulation is continued and the transition to step seven of the algorithm is carried out.

Summarizing the actions for all of the ADA steps (except for the first and the last ones): every step presumes that the condition for transition from the previous step ($\Delta_{\max n}$ < Y– (n – 1), where *Y* is the ADC capacity and *n* is the number of the step) is checked after the required amount of measurements is assumed. Should the condition not be met, the packet that was formed during the previous step is issued and the algorithm returns to step one. If the condition is fulfilled, then the following specifying condition is checked: $\Delta_{\max n}$ = Y – n. If this condition is met, then a packet, which was generated during the current step, is issued. In the event of the specifying condition ($\Delta_{\max n}$ = Y – n) not being fulfilled, the condition for transitioning to the next step is fulfilled ($\Delta_{\max n}$ < Y – n), measurement accumulation is continued and a transition to the following step of the algorithm is carried out.

After the accumulation of 61 measurements in step seven (which corresponds to the last step of the ADA algorithm), the transition from step six condition ($\Delta_{\max n}$ < 2 bits) is checked first. If it is not fulfilled, the packet, which was formed during the sixth stage, is issued and the algorithm returns to step one. If the condition is met, that means that $\Delta_{\max n}$ = 1 bit. In the ADA algorithm a packet is issued with 61 measurements packed into 16 bytes and the algorithm returns to step one, i.e., the cycle starts over again. As for the ADAD algorithm – a transition to the information cycle is made, i.e., to step eight.

The accumulation of 62 measurements in step eight is carried out with a frequency of 200 Hz. The value Δ is calculated by the ratio of two adjacent sampling measurements, carried out with a frequency of 100 Hz. Thus, every other measurement from the original is taken – 31 measurements, in total, with a frequency of 100 Hz, which corresponds to the fifth step of the ADA algorithm. Further processing is carried out in a manner analogous to the fifth step; only measurements decimated by two-fold are processed.

Following the accumulation of 31 measurements with a 100 Hz frequency in step eight, a condition analogous to the one for transitioning from step five to step six is checked: $\Delta_{\max n}$ < 3 bits. If this condition is not met, the packet, generated in step seven (containing 61 measurements obtained with a frequency of 200 Hz and packed in 16 bytes) is issued. If the condition is fulfilled, the accumulation of measurements is continued and the transition to step nine of the ADAD takes place.

Table 2. Generalized ADAD algorithm

Sampling frequency, Hz	**Frequency decimation stage**	**Step No. (action)**	**Action for measurement collection buffer**	**Analysis of $\Delta_{\max n}$ – maximum amount of bits required for representing the measurement value differences in binary form**
f_{max}	0	1	Accumulation of X/У measurements	$\Delta_{\max n}$ = У or (У – 1) bits, X/У measurements per packet $\Delta_{\max n}$ < (У – 1) bits, transition to action 2
		2	Accumulation of ((X – У) / (У – 2) + 1) measurements	$\Delta_{\max n}$ = У or (У – 1) bits, X/У measurements per packet, transition to action 1 $\Delta_{\max n}$ = (У – 2) bits, issue of 1 packet with (X – У) / (У – 2) measurements, transition to action 1 $\Delta_{\max n}$ < (X – У)/(У – 2) bits, transition to action 3
		3	Accumulation of ((X – У) / (У – 3) + 1) measurements	$\Delta_{\max n}$ = У, …, (У – 2) bits, issue of 1 packet with (X – У) / (У – 2) measurements, transition to action 1 $\Delta_{\max n}$ = (У – 3), issue of 1 packet with (X – У) / (У – 3) measurements, transition to action 1 $\Delta_{\max n}$ < (У-3) bits, transition to action 4
		…		
		n	Accumulation of ((X – У) / (У – n + 1) + 1) measurements	$\Delta_{\max n}$ = У, …, (У – (n – 1)) bits, issue of 1 packet with ((X – У) / (У – (n – 1)) + 1) measurements, transition to action 1 $\Delta_{\max n}$ = (У – n) bits, issue of 1 packet with ((X – У) / (У – n) + 1) measurements, transition to action 1 $\Delta_{\max n}$ < (У – n) bits, transition to action (n + 1)
		…		
		У – 1	Accumulation of ((X – У) / 2 + 1) measurements	$\Delta_{\max n}$ = У, …, 2 bits, issue of 1 packet with ((X – У) / 3 + 1) measurements, transition to action 1 $\Delta_{\max n}$ = 1 bit, issue of 1 packet with ((X – У) / 2 + 1) measurements, transition to action У

Table 2. Generalized ADAD algorithm

Sampling frequency, Hz	Frequency decimation stage	Step No. (action)	Action for measurement collection buffer	Analysis of $\Delta_{\max n}$ – maximum amount of bits required for representing the measurement value differences in binary form
$f_{max}/2$	1	У	Accumulation of ((X – У) / 4 + 1) x 2 measurements with $f_{max\ n}$, frequency decimation by a factor of 2 (equivalent of sampling frequency reduction), acquisition of ((X – У) / 4 + 1) measurements with $f_{max\ n}/2$ frequency	$\Delta_{\max n}$ analysis analogous to step У – 3 for ((X – У) / 4 + 1) decimated measurements $\Delta_{\max n}$ = У, …, 3 bits, issue of 1 packet with ((X – У) / 2 + 1) measurements with $f_{max\ n}$ frequency, transition to action 1 $\Delta_{\max n}$ < 3 bits, transition to action У + 1
		У + 1	Accumulation of ((X – У) / 3 + 1) x 2 measurements with $f_{max\ n}$ frequency, decimation by a factor of 2 (equivalent of sampling frequency reduction), acquisition of ((X – У) / 3 + 1) measurements with $f_{max\ n}/2$ frequency	$\Delta_{\max n}$ analysis analogous to step У – 2 $\Delta_{\max n}$ = У, …, 3 bits, issue of 1 packet with ((X – У) / 2 + 1) measurements with $f_{max\ n}$ frequency, transition to action 1 $\Delta_{\max n}$= 2 bits, issue of 1 packet with ((X – У) / 3 + 1) measurements with $f_{max\ n}/2$ frequency, transition to action 1 $\Delta_{\max n}$ < 2 bits, transition to action У + 2
		У + 2	Accumulation of ((X – У) / 2 + 1) x 2 measurements with частотой $f_{max\ n}$, decimation by a factor of 2 (equivalent of sampling frequency reduction), acquisition of ((X – У) / 2 + 1) measurements with $f_{max\ n}/2$ frequency	$\Delta_{\max n}$ analysis, analogous to step У – 1 $\Delta_{\max n}$ = У, …, 2 bits, issue of 1 packet with ((X – У) / 3 + 1) measurements with $f_{max\ n}/2$ frequency, transition to action 1 $\Delta_{\max n}$= 1 bit, transition to action У+3
…				

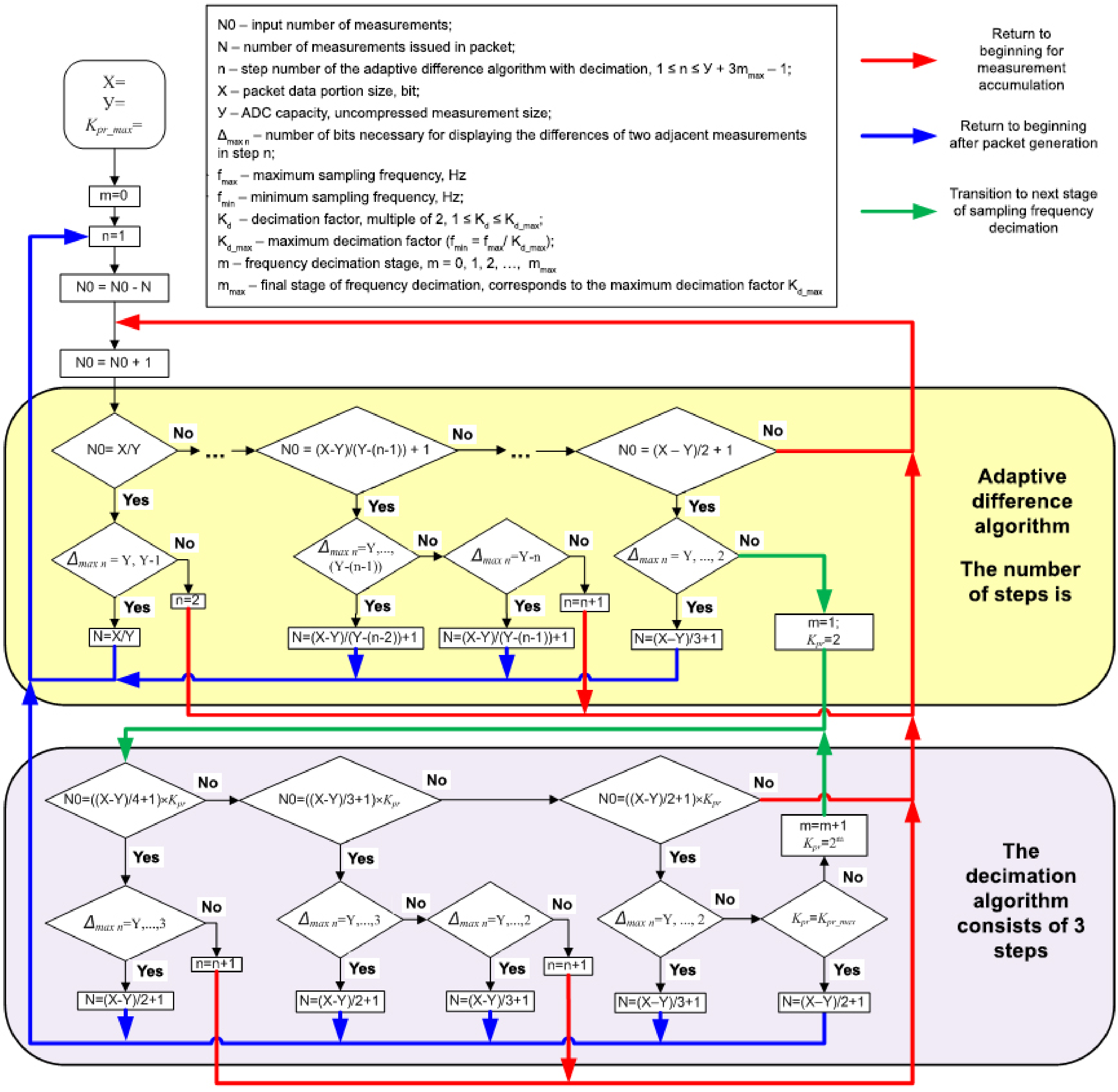
Table 2. Generalized ADAD algorithm

Sampling frequency, Hz	**Frequency decimation stage**	**Step No. (action)**	**Action for measurement collection buffer**	**Analysis of $\Delta_{\mathrm{max\,n}}$ – maximum amount of bits required for representing the measurement value differences in binary form**
f_{max}/K_d	m = $\log_2 K_d$	У + 3m – 3	Accumulation of ((X – У) / 4+1) x K_d measurements with $f_{max\ n}$ frequency, decimation by a factor of K_d (equivalent of sampling frequency reduction), acquisition of ((X – У) / 4+1) measurements with $f_{max\ n}/K_d$ frequency	$\Delta_{\mathrm{max\,n}}$ = У, …, 3 bits, issue of 1 packet with ((X – У) / 2+1) measurements with 2x $f_{max\ n}/K_d$ frequency, transition to action 1 $\Delta_{\mathrm{max\,n}}$ < 3 bits, transition to action (У + 3m - 2)
		У + 3m – 2	Accumulation of ((X – У) / 3 + 1) x K_d measurements with $f_{max\ n}$ frequency, decimation by a factor of K_d (equivalent of sampling frequency reduction), acquisition of ((X – У) / 3 + 1) measurements with $f_{max\ n}/K_d$ frequency	$\Delta_{\mathrm{max\,n}}$ = У, …, 3 bits, issue of 1 packet with ((X – У) / 2 + 1) measurements with 2x $f_{max\ n}/K_d$ frequency, transition to action 1 $\Delta_{\mathrm{max\,n}}$= 2 bits, issue of 1 packet with ((X – У) / 3 + 1) measurements with $f_{max\ n}/K_d$ frequency, transition to action 1 $\Delta_{\mathrm{max\,n}}$ < 2 bits, transition to action (У + 3m – 1)
		У + 3m – 1	Accumulation of ((X – У) / 2 + 1) x K_d measurements with $f_{max\ n}$ frequency, decimation by a factor of K_d (equivalent of sampling frequency reduction), acquisition of ((X – У) / 3 + 1) measurements with $f_{max\ n}/K_d$ frequency	$\Delta_{\mathrm{max\,n}}$ = У, …, 2 bits, issue of 1 packet with ((X – У) / 3 + 1) measurements with f_{max}/K_d frequency, transition to action 1 $\Delta_{\mathrm{max\,n}}$ = 1 bit, transition to action У + 3m
…				

Table 2. Generalized ADAD algorithm

Sampling frequency, Hz	Frequency decimation stage	Step No. (action)	Action for measurement collection buffer	Analysis of $\Delta_{\max n}$ – maximum amount of bits required for representing the measurement value differences in binary form
f_{max}/K_{d_max}	$m_{\max} = \log_2 K_{d\_max}$	$У + 3m_{\max} - 3$	Accumulation of $((X - У) / 4 + 1) \times K_{d\_max}$ measurements with f_{max} frequency, decimation by a factor of K_{d_max} (equivalent of sampling frequency reduction), acquisition of $((X - У) / 4 + 1)$ measurements with f_{max}/K_{d_max} frequency	$\Delta_{\max n} = У, \ldots, 3$ bits, issue of 1 packet with $((X - У) / 2 + 1)$ measurements with $2\mathrm{x} f_{max}/K_{d\_max}$ frequency, transition to action 1 $\Delta_{\max n} < 3$ bits, transition to action $(У + 3m_{\max} - 2)$
		$У + 3m_{\max} - 2$	Accumulation of $((X - У) / 3 + 1) \times K_{d\_max}$ measurements with f_{max} frequency, decimation by a factor of K_{d_max} (equivalent of sampling frequency reduction), acquisition of $((X - У) / 3 + 1)$ measurements with f_{max}/K_{d_max} frequency	$\Delta_{\max n} = У, \ldots, 3$ bits, issue of 1 packet with $((X - У) / 2 + 1)$ measurements with $2\mathrm{x} f_{max}/K_{d\_max}$ frequency, transition to action 1 $\Delta_{\max n} = 2$ bits, issue of 1 packet with $((X - У) / 3 + 1)$ measurements with f_{max}/K_{d_max} frequency, transition to action 1 $\Delta_{\max n} < 2$ bits, transition to action $(У + 3m_{\max} - 1)$
		$У + 3m_{\max} - 1$	Accumulation of $((X - У) / 2 + 1) \times K_{d\_max}$ measurements with f_{max} frequency, decimation by a factor of K_{d_max} (equivalent of sampling frequency reduction), acquisition of $((X - У) / 2 + 1)$ measurements with f_{max}/K_{d_max} frequency	$\Delta_{\max n} = У, \ldots, 2$ bits, issue of 1 packet with $((X - У) / 2 + 1)$ measurements with f_{max}/K_{d_max} frequency, transition to action 1 $\Delta_{\max n} = 1$ bit, transition to action 1

N0 – input number of measurements; N – number of measurements issued in packet;
n – step number of the adaptive difference algorithm with decimation, $1 \le n \le У + 3m_{\max} - 1$;
X – packet data portion size, bit; У – ADC capacity, uncompressed measurement size;
$\Delta_{max\,n}$ – number of bits necessary for displaying the differences of two adjacent measurements in step n; f_{max} – maximum sampling frequency, Hz
f_{min} – minimum sampling frequency, Hz; K_d – decimation factor, multiple of 2, $1 \le K_d \le K_{d\_max}$;
K_{d_max} – maximum decimation factor ($f_{min} = f_{max} / K_{d\_max}$); m – frequency decimation stage, m = 0, 1, 2, …, $m_{\max}$
$m_{\max}$ – final stage of frequency decimation, corresponds to the maximum decimation factor K_{d_max}



N0 – input number of measurements;
N – number of measurements issued in packet;
n – step number of the adaptive difference algorithm with decimation, $1 \leq n \leq \text{У} + 3m_{max} - 1$;
X – packet data portion size, bit;
У – ADC capacity, uncompressed measurement size;
$\Delta_{max\ n}$ – number of bits necessary for displaying the differences of two adjacent measurements in step n;
f_{max} – maximum sampling frequency, Hz
f_{min} – minimum sampling frequency, Hz;
K_d – decimation factor, multiple of 2, $1 \leq K_d \leq K_{d\_max}$;
K_{d_max} – maximum decimation factor ($f_{min} = f_{max}/K_{d\_max}$);
m – frequency decimation stage, m = 0, 1, 2, …, m_{max}
m_{max} – final stage of frequency decimation, corresponds to the maximum decimation factor K_{d_max}

Figure. Adaptive difference algorithm block diagram.

Eighty-two measurements are accumulated in step nine with a frequency of 200 Hz and they are decimated by a factor of two. The 41 measurements that are thus obtained are processed by analogy with step six. At first, the condition for transitioning from the previous step $\Delta_{max\ n} < 3$ is checked. If the condition is not fulfilled, the packet formed in step seven (61 measurements with a frequency of 200 Hz packed in 16 bytes) is issued and the algorithm returns to step one. If the condition is met ($\Delta_{max\ n} < 3$ bits), a specifying condition is checked: $\Delta_{max\ n} = 2$ bits. In the case of its fulfillment, a packet with 41 measurements received with a frequency of 100 Hz and packed in 16 bytes is issued. If the specifying condition ($\Delta_{max\ n} = 2$ bits) is not met, then $\Delta_{max\ n} = 1$ bit and the measurements are continued to be accumulated. After this, the transition to the tenth step of the ADAD algorithm is performed.

During the tenth step 122 measurements are accumulated with a frequency of 200 Hz and are decimated by two-fold. The 61 measurements that are obtained with a frequency of 100 Hz are processed in an analogous manner to step seven. At first, the condition for transitioning from the previous step $\Delta_{\max n} < 2$ bits is checked. If the condition is met, a packet generated in step nine (i.e., 41 measurements with a frequency of 100 Hz and packed in 16 bytes) is issued and the algorithm returns to the first step. Upon the fulfillment of the condition, measurement accumulation continues and the ADAD algorithm transitions to step eleven.

The results of ADAD algorithm operation are given in Table 1. According to Table 1, all of the subsequent steps are subdivided into repeating groups of three steps that differ from one another only in the sampling frequencies of output data packets.

The actions in steps eleven, twelve and thirteen are analogous to those of steps eight, nine, and ten with the only difference that the equivalent sampling frequency of the measurements being packed into packets is, once again, lowered by a factor of two. These iterating groups can symbolically be called *steps of an adaptive algorithm with decimation (AAD) operating with ADA, or with decimation stages*.

In the final step of the ADAD algorithm instead of a transition to the following step of decimation, a packet is issued, consisting of 61 measurements (with a frequency of 12.5 Hz) packed in 16 bytes of the data portion of the packet. After that, the ADAD cycle repeats itself from the beginning.

In generalized form the ADAD algorithm is given in Table 2.

A block diagram of the generalized ADAD is given in the Figure.

Conclusion

Therefore, not only does the ADAD algorithm that has been developed allow for a decrease in redundancy, owing to a reduced number of transmitted bits – as is done by the ADA, but it also is able to compensate the redundantly assigned sampling frequency. The ADAD cumulative maximum redundancy reduction factor is formed by multiplying the ADA compression ratio and the maximum factor of decimation. The ADA compression ratio depends on the size of the packet data portion and the ADC capacity. In the example provided, the ADA compression ratio is equal to 3.8125 and the decimation factor is equal to 16. If the sensor signal changes insignificantly and in such a manner that processing by means of ADAD reaches the final step, then instead of 976 accumulated measurements with a frequency of 200 Hz , a packet containing only 61 measurements with a frequency of 12.5 Hz is issued. Due to the fact that the data portion of the packet is chosen to contain 16 measurements without decimation, then the redundancy reduction factor is equal to $976/16=3.8125\times16=61$.

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