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Practical Realizations of Optimized Adaptive Digital Signal Processing Solutions Implemented in Preset Time Count Rate Meters

Dedicated to Professor Milić Stojić on the occasion of his 65th birthday

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Abstract: Two optimized adaptive digital signal processors were implemented to the preset time count rate meters. Three mean count rate meters, based on the developed adaptive digital signal processors, were realized and were used for experimental validation of proposed adaptive digital signal processors. The experimental results, conducted without and with radioisotope for the specified errors of 10% and 5%, showed to agree well with theoretical predictions.

Keywords: Preset time count rate meter, adaptive signal processing, Low-pass filter, FIR filter, mean count rate.

1 Introduction

Signal fluctuations at the outputs of radiation detectors are caused by random variations of time intervals between successive input pulses, even in the stationary state [1]. This holds true for both preset count and preset time mean count rate meters. The original preset count algorithm for suppression of the fluctuations is given in [2], and its practical applications in [3, 4].

Although some algorithms for digital mean count rate meters are already known [5], adaptive digital signal processing was used mainly in the fields of optimum filtering of signals from radiation detectors in the measurement of energy spectra [6]. The analysis and design of digital mean count rate meters based on the preset time

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principle using some specific methods of adaptive digital signal processing were reported in [7, 8]. The purpose of this paper is to present three practical realizations of the adaptive digital signal processors described in [8], using optimized digital filters [9] and specially devised adaptive digital signal processing circuits [10]. The theoretical background of the presented realizations has already been given in [8], but is repeated here, with additional explanations, for reader's convenience.

2 Description of the Methods

A possible way to quantitatively determine a radiation level is to measure the mean of the pulse rate from counting radiation detectors. Two methods were proposed to improve the performance of existing preset time algorithms. The reason for introducing the proposed two new methods were: to shorten preset time for higher stationary pulse rates, enable specified and controllable error when the mean count rate stays within certain predefined limits from its true value, and provide fast response to rapid changes of the mean count rate beyond the defined limits. The two adaptive digital signal processors realizable in hardware or in software are modern, powerful and flexible solutions.

The first method starts with a longer preset time of 10s assuming stationary pulse rates corresponding to background radiation levels and then uses an adaptation algorithm to adjust the duration of the preset time interval if the mean count rate is changed. The second method starts with a shorter preset time of 1s, being immediately ready to react to sudden changes of the mean count rate, but switches to a longer preset time interval of 10s if stationary pulse rates corresponding to background radiation levels are maintained.

Both methods use: an optimized detection algorithm to sense the change of mean count rate, variable-length low-pass filter to implement mean count rate error control by controllable suppression of fluctuations of the mean count rate, and an optimized algorithm of adaptation of preset time interval based on the current value of the mean count rate. Relative standard deviation defined as the ratio of the standard deviation of the mean count rate and the mean count rate is used as the performance criterion for the selection of the optimum parameter values. Optimum values are those that minimize the relative standard deviation. The methods differ in the strategy of execution of the algorithm for adaptation of the preset time interval. In the first method, the preset time interval adaptation algorithm is executed after the low-pass filters. This allows obtaining shorter time constant intervals for higher stationary pulse rates. The second method executes the adaptation algorithm before the low-pass filters, which enables sensing of the rapid changes of the mean count rate before the fluctuations suppression is carried out.

Both methods were investigated using self designed software package. The practical applications of the methods were: the second method was implemented in two versions of newly developed pocket digital gamma rate meter and the first and second methods were implemented in a newly developed modified version of the digital portable beta and gamma rate meter. The second method was also implemented in the stationary gamma monitoring system installed at the gates of the Institute of Nuclear Sciences VINČA.

3 Practical Realizations of the Proposed Methods

The presentation of three practical realizations as experimental validation of the proposed methods is given in this section.

3.1 Monitoring system at the gates of the VINČA Institute

The first realization was the monitoring system installed at the gates of the Institute VINČA. Its main purpose is to notify security personnel at the gates of the Institute of an authorized and especially unauthorized transfer of radioactive material from or into the Institute. Its duty is to give visual and audible alarm if it detects levels of gamma radiation in excess of some predetermined alarm level. Since it is an alarm monitoring system, it has to react fast to sudden changes in the gamma radiation level. Therefore, it was realized using the second method.

3.1.1 Description of the detector

The gamma alarm monitoring system at the gates uses a pan-cake GM counter SI-8B, with mica window thickness of 4 mg/cm^2 and surface of 33 cm^2. Its measuring range is 4000 c/s, or expressed in dose rate from 87 nSv/h to approximately 350 μSv/h. GM counter SI-8B is used as soft beta and gamma radiation detector.

The monitoring system uses a suitable arrangement of 4 GM counters SI-8B in order to increase detection sensitivity compared with a single detector system, while preserving fast response to sudden changes in gamma radiation level that is an inherent feature of the counting radiation detectors. Since it is primarily an alarm monitoring system, there is no need for the system to measure energy spectrum, and, therefore, more sophisticated counting detections systems (proportional GM counters, scintillation detectors) are not needed. The information on the type of radioisotope detected by the alarm monitoring is provided, if required, by portable gamma spectrometry devices.

3.1.2 Measurement results

The experiments were conducted in order to validate the implementation of the second method for the alarm monitoring system at the gates of the Institute VINČA. The experimental set-up is shown in Fig. 1. The four GM counters, forming a square, are placed in a PTFE holder which is fastened to an iron pillar by four screws. The pillar is welded to an iron footer. The center of the square formed by detectors is 1.2 m above ground according to the standards.

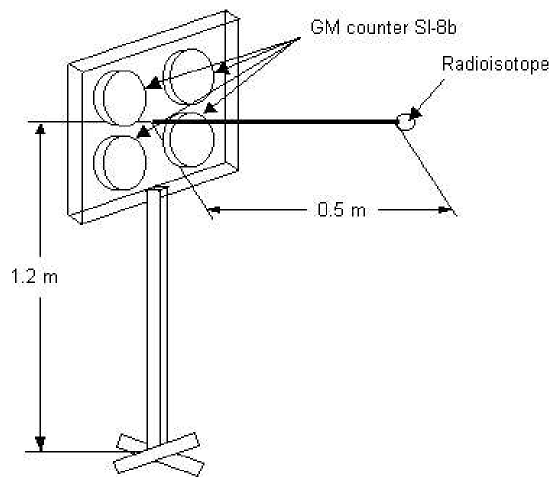

Fig. 1. Measurement set-up for experimental validation of the second method at the Institute VINČA.

The measurement results are given in Table 1. A set of 20 measurements was carried out. The duration of data acquisition for each measurement was 20 min. The specified mean count rate error was held fixed at 10% since tighter error limits were not necessary for alarm monitoring. The number of low-pass FIR1 filter used in stationary state was held fixed at 10 coefficients [8].

Three quantities were derived from the measurement results: mean count rate, averaged over time interval of 20 min and over a set of 20 measurement runs, mean relative standard deviation averaged over time interval of 20 min and over a set of 20 measurement runs, and standard deviation of the set of relative standard deviation values obtained from each of the 20 conducted measurements. An additional measurement of 20 min was carried out for background radiation when only one GM counter. This measurement was conducted in order to compare the measured a calibrated measurement device with the same detector. The results for background radiation matched very closely: 1.3 c/s for the calibrated device and 1.35 c/s for the device under test. After the inspection of the measurement results one may notice that:

Table 1. Measurements results for the second method at the gates of the Institute VINČA

	Background radiation		Measurement with radioisotope	
Stationary characteristics	Mean count rate (20 measurements)	5.42 c/s	Mean count rate (20 measurement)	10.2 c/s
	Mean value of r.s.d. (20 measurements)	2.9%	Mean value of r.s.d. (20 measurements)	11.11%
	Standard deviation of r.s.d. (20 measurements)	0.6%	Standard deviation of r.s.d. (20 measurements)	3.26%
Dynamic characteristics	Measurement with radioisotope			
	Sudden bringing **IN** of the radioisotope		Sudden bringing **OUT** of the radioisotope	
	Mean response time (20 measurements)	2.3 s	Mean response time (20 measurements)	3.6 s
	Standard deviation of response time (20 measurements)	31%	Standard deviation of response time (20 measurements)	47%

1. The mean relative standard deviation for the measurements with the radiation source is larger than that for background radiation. This is because in the second method the preset time for the mean count rates less than the threshold of 6 c/s is 10s and 1s for the mean count rates above the threshold. Since the mean count rate is 5.4 c/s for background radiation and 10.2 c/s with the radiation source, the number of pulses for the background radiation is larger than with the radiation source on the average.

2. The mean relative standard deviation for the measurements with the radiation source is 11.11% which is somewhat larger than the specified error of 10%. The theoretical predictions for the first method [8] suggest that the expected mean relative standard deviation for the similar conditions should be between 5% and 6%. However, these results were obtained for the preset time interval of 4 s, while in the second method, used here, it is only 1 s. Theoretically, the 4 times decrease in the preset time interval doubles the error, which explains the relatively larger value of the mean relative standard deviation obtained here.

3. The dynamic characteristics given in Table 1, for the case when the radiation source was suddenly brought into the specified location of the detectors closely match the theoretical expectations of response time = 2 s [8]. However, for the case when the radiation source was brought out of the specified location, the response time increased to 3.6s, on the average, which was

somewhat larger than 2 s predicted [8], but still acceptable for the given purpose. The response time could be somewhat reduced if the lower decision threshold of the algorithm for the detection of the change of the mean count rate is increased from 90% to 95% at the expense of the slight increase in the mean count rate error as shown [8].

3.2 Modified version of the digital portable beta and gamma count rate meter

The second realization was the Modified version of the digital portable count rate meter RMK-10P. The Digital portable count rate meter is used for measurements of surface beta contamination and gamma radiation. It uses one GM counter SI-8B already described in section 3.1.1. It is a microcontroller-based, portable device with menu-oriented user-friendly interface, in which both proposed methods were implemented in the software. The first method is used for the measurements of surface beta contamination which is more convenient for essentially stationary environments. The second, faster method, is used for the measurements of gamma radiation. The mean count rate error can be selected from the set of two discrete values, i.e. 5% or 10% for both methods.

3.2.1 Measurement results

The experiments were carried out in order to validate the implementation of the first and second method for the Modified digital portable beta and gamma count rate meter. The experimental set-up is shown in Fig. 2. Radiosotope, when used for the measurements, is placed along the main axis perpendicular to the surface of the pan-cake style detector at the point of the center of the circle, at a distance of 0.2m from the center of the circle.

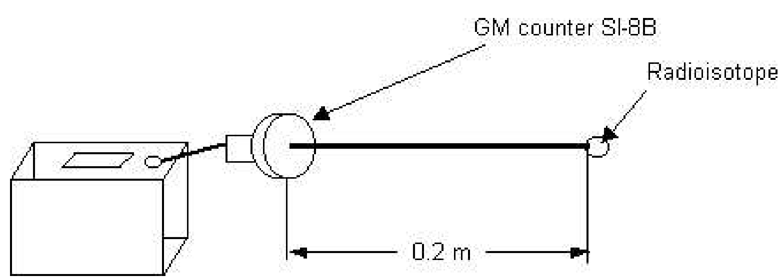

Fig. 2. Measurement set-up for experimental validation of the first and second Modified digital portable beta and gamma count rate meter.

The measurement results are given in Tables 2 and 3. A set of 20 measurements was carried out for both error values and both methods without and with the radioisotope. The duration of data acquisition for each measurement was 20 min. The specified mean count rate error was first set to 10% and then to 5% for both methods. The number of low-pass FIR1 filter coefficients used for the error of 10% was 10 and for the error of 5% was 20 [8].

Table 2. Measurements results for the first method for the Modified digital portable beta and gamma count rate meter.

<table>
<tr><td rowspan="12">Stationary characteristics</td><td colspan="4">The specified error= 10%</td></tr>
<tr><td colspan="2">Background radiation</td><td colspan="2">Measurement with radioisotope</td></tr>
<tr><td>Mean count rate (20 measurements)</td><td>1.35 c/s</td><td>Mean count rate (20 measurement)</td><td>32.3 c/s</td></tr>
<tr><td>Mean value of r.s.d. (20 measurements)</td><td>6.73%</td><td>Mean value of r.s.d. (20 measurements)</td><td>7.23%</td></tr>
<tr><td>Standard deviation of r.s.d. (20 measurements)</td><td>0.4%</td><td>Standard deviation of r.s.d. (20 measurements)</td><td>0.98%</td></tr>
<tr><td colspan="4">The specified error= 5%</td></tr>
<tr><td colspan="2">Background radiation</td><td colspan="2">Measurement with radioisotope</td></tr>
<tr><td>Mean count rate (20 measurements)</td><td>1.35 c/s</td><td>Mean count rate (20 measurement)</td><td>32.3 c/s</td></tr>
<tr><td>Mean value of r.s.d. (20 measurements)</td><td>3.67%</td><td>Mean value of r.s.d. (20 measurements)</td><td>4.84%</td></tr>
<tr><td>Standard deviation of r.s.d. (20 measurements)</td><td>0.29%</td><td>Standard deviation of r.s.d. (20 measurements)</td><td>0.66%</td></tr>
</table>

Three quantities were derived from the measurement results: mean count rate, averaged over time interval of 20 min and over a set of 20 measurement runs, mean relative standard deviation averaged over time interval of 20 min and over a set of 20 measurement runs, and standard deviation of the set of relative standard deviation values obtained from each of the 20 conducted measurements.

After the inspection of the measurement results one may notice that:

1. The results for the first method for both specified errors, with and without the radioisotope are in accordance with predictions [8].
2. The error values for the second method for both stationary and dynamic characteristics are in accordance with results given in [8]. The error values for the second method for stationary characteristics are slightly larger than those for the first method, which was expected for the reasons already explained, i.e. the preset time intervals for the mean count rate of around 30 c/s (the case with radioisotope) in the first method is 2 s and only 1s in the second

Table 3. Measurements results for the second method for the Modified digital portable beta and gamma count rate meter.

	The specified error= 10%			
	Background radiation		Measurement with radioisotope	
	Mean count rate (20 measurements)	1.36 c/s	Mean count rate (20 measurement)	32.6 c/s
	Mean value of r.s.d. (20 measurements)	9.54%	Mean value of r.s.d. (20 measurements)	10.57%
	Standard deviation of r.s.d. (20 measurements)	0.59%	Standard deviation of r.s.d. (20 measurements)	1.8%
	The specified error= 5%			
	Background radiation		Measurement with radioisotope	
	Mean count rate (20 measurements)	1.35 c/s	Mean count rate (20 measurement)	32.3 c/s
	Mean value of r.s.d. (20 measurements)	4.9%	Mean value of r.s.d. (20 measurements)	5.4%
Stationary characteristics	Standard deviation of r.s.d. (20 measurements)	0.9%	Standard deviation of r.s.d. (20 measurements)	1.1%
	Measurement with radioisotope			
	Sudden bringing **IN** of the radioisotope		Sudden bringing **OUT** of the radioisotope	
	Mean response time (20 measurements)	1.7 s	Mean value of r.s.d. (20 measurements)	2.6 s
Dynamic characteristics	Standard deviation of response time (20 measurements)	21%	Standard deviation of response time (20 measurements)	29%

method. In the case of background radiation the difference lies in the length of the FIR1 low-pass filter used to suppress fluctuations in the stationary state.

3.3 Pocket gamma radiation digital mean count rate meter

The third realization was the Pocket gamma radiation digital count rate meter. The Pocket gamma radiation digital count rate meter is used as a personal device for measurements and monitoring of gamma radiation. It uses one GM counter ZP1400. It is a microcontroller- based, personal device with menu-oriented user-friendly interface, in which only the second method was implemented in the software. The second, faster method, is used for the measurements of gamma radiation. The mean count rate error can be selected from the set of two discrete values, 5% or 10%.

3.3.1 Description of the detector

The Pocket digital count rate meter uses GM tube ZP1400, with chrome-iron cathode with thickness of 250 mg/cm^2, mica window whose diameter is 9mm and thickness 2.5mg/cm^2. Its measurement range is 0-30000 c/s, or expressed in dose rate from 0.02 μSv/h to approximately 10 mSv/h.

3.3.2 Measurement results

The experiments were carried out in order to validate the implementation of the second method for the Pocket gamma radiation digital count rate meter. The experimental set-up is shown in Fig. 3. The radiosotope, when used for measurements, is placed along the axis perpendicular to the main axis of the detector at the point corresponding to the center of the detector GM tube, at a distance of 0.1 m from the center of the detector.

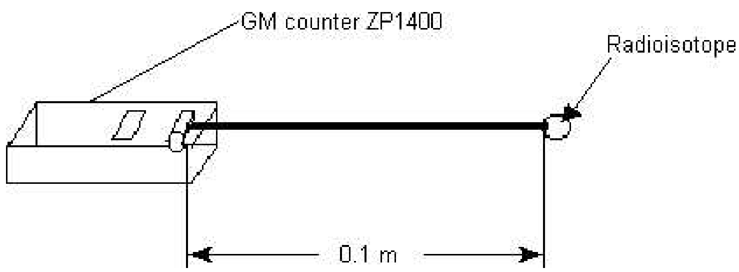

Fig. 3. Measurement set-up for experimental validation of the second method in gamma radiation digital count rate meter.

The measurement results are given in Table 4. A set of 20 measurements was carried out for both error values and the second method for background radiation and with the radioisotope. The duration of data acquisition for each measurement was 20 min. The specified mean count rate error was first set to 10% and then to 5%. The number of low-pass FIR1 filter coefficients used for the error of 10% was 10 and for the error of 5% was 20 [8].

Three quantities were derived from the measurement results: mean count rate, averaged over time interval of 20 min and over a set of 20 measurement runs, mean relative standard deviation averaged over time interval of 20 min and over a set of 20 measurement runs, and standard deviation of the set of relative standard deviation values obtained from each of the 20 conducted measurements.

Table 4. Measurements results for the second method in the Pocket gamma radiation digital count meter.

Stationary characteristics	The specified error= 10%			
	Background radiation		Measurement with radioisotope	
	Mean count rate (20 measurements)	0.42 c/s	Mean count rate (20 measurement)	7.1 c/s
	Mean value of r.s.d. (20 measurements)	12.6%	Mean value of r.s.d. (20 measurements)	13.6%
	Standard deviation of r.s.d. (20 measurements)	1.9%	Standard deviation of r.s.d. (20 measurements)	3.2%
	The specified error= 5%			
	Background radiation		Measurement with radioisotope	
	Mean count rate (20 measurements)	0.41 c/s	Mean count rate (20 measurement)	7.09 c/s
	Mean value of r.s.d. (20 measurements)	6.4%	Mean value of r.s.d. (20 measurements)	7.2%
	Standard deviation of r.s.d. (20 measurements)	1.6%	Standard deviation of r.s.d. (20 measurements)	4.4%
Dynamic characteristics	Measurement with radioisotope			
	Sudden bringing **IN** of the radioisotope		Sudden bringing **OUT** of the radioisotope	
	Mean response time (20 measurements)	3.6 s	Mean response time (20 measurements)	5.1 s
	Standard deviation of response time (20 measurements)	44%	Standard deviation of response time (20 measurements)	61%

After the inspection of the measurement results one may notice that:

1. The mean relative standard deviations for both error values, although somewhat larger than specified, are still acceptable bearing in mind that this device is meant for personal measurements and monitoring in which tight error limits are not critical. The larger error values are primarily due to GM counter ZP1400 which is much smaller than Si-8B and less sensitive, especially for the measurements with radioisotope. These measurements were conducted in a way that the radioisotope was not facing the mica window of the GM counter, but was perpendicular to the main axis of the GM counter.
2. The dynamic characteristics of the Pocket gamma radiation digital count rate meter are somewhat worse than predictions [8], which is also due to

the poorer sensitivity of ZP1400 GM counter. The size and performance of the GM counter were dictated by the available space for the detector and the measurement range which had to be over one order of magnitude larger than for the instruments using GM counter Si-8B.

4 Conclusions

Three mean count rate meters were realized using the newly developed adaptive digital signal processors (methods): the stationary gamma monitoring system at the gates of the VINČA Institute, the modified version of the digital portable beta and gamma count rate meter and the pocket gamma radiation digital count rate meter. They were used for experimental validation of the proposed adaptive digital signal processors. Only the second realization implemented the first method, while all three of them implemented the second method.

The first method was designed to improve stationary characteristics of the count rate meter by implementing the control of the error of the mean count rate when the changes of the mean count rate are due only to its stochastic nature. The second method is focused on dynamic characteristics. Its time response is made adaptive to the changes of the mean count rate which are due to increased or decreased radiation levels. The change of the mean count rate is sensed by a specially devised detection algorithm.

The experimental results, conducted without and with radioisotope for the specified errors of 10% and 5%, showed to agree well with the theoretical predictions.

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