Addition to the Experimental Solution Development for the Stochastic Measurement of EOG signals

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***Abstract*—Our main goal is to design and realize the computer based instrument, with additional microcontroller hardware for analogue signal processing, for modified digital stochastic measurement (MDSM) of biomedical signals. In order to achieve this goal, and design the computer based instrument correctly, an experimental hardware solution for MDSM of non-stationary biomedical signals has been developed. The MDSM method is based on stochastic analog-to-digital (A/D) conversion, with a low-resolution A/D converters, digital multipliers and accumulation. An electrooculography (EOG) signal is taken as an example. Tests were carried out for set of 100 measurements. Various number of Fourier coefficients per set were measured: first 15 Fourier coefficients were measured, and after that only 7. The results were compared. Comparison was also made with results obtained with classical digital measurement. The obtained results are presented, analyzed and discussed.**

***Index Terms*—Modified digital stochastic measurement, electrooculography (EOG), signal processing, experimental hardware solution, computer based instrument.**

I. Introduction

DIGITAL stochastic measurement method (DSMM) has been developed and described earlier in the literature [1-6], and several prototypes and small-series of commercial instruments have been developed. These instruments were named digital stochastic instruments.

Implementation of the DSM method in the case of measurement of nonstationary signals, such as biomedical signals, has been discussed and presented in [7, 8], where electroencephalography (EEG) signal has been taken as an example of nonstationary signal.

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Further implementation of DSM method for nonstationary signals measurement has been presented in [9, 10], where electrooculography (EOG) signal was taken as an example.

Improvement of obtained measurement results and reduction of the Gibbs phenomenon have been realized with modified digital stochastic measurement method (MDSMM), that is described in [11]. An experimental hardware solution, which has been designed and realized in order to verify the simulation model presented in [11] is presented and described in detail in [12].

II. Review of Modified Digital Stochastic Measurement Method

As it is described in [11], when all tests are done and results were obtained, the significant deviations of the reproduced signal relative to the input signal occurred. These deviations arise at the beginning and at the end of each measurement interval and they are the consequence of occurrence of the Gibbs phenomenon. This phenomenon significantly increases the total measurement error.

In order to eliminate Gibbs phenomenon and decrease measurement errors, the overlapping of two adjacent measuring intervals, T_k and T'_k $(k = 1,2,...)$, has been performed and described in detail in [11]. An identical measuring channel, that measures the same EOG signal, is implemented (see Fig. 1). In the second measuring channel the measurement begins with a defined delay dT. In Fig. 1, gray parts of intervals represent areas where the Gibbs phenomenon occurs, and white parts represent areas where the Gibbs phenomenon does not exist. The resulting signal, that represents the final result, is obtained by taking only white parts of adjacent intervals (see Fig. 2). This method was named modified stochastic digital measurement method (MDSMM).

An input signal of MDSM block is 10 s of signal that are extracted from a real measurement session of the EOG signal, which was measured during a deep sleep, so called Rapid-Eye-Movement (REM) phase of sleep. These values of signal are amplified and adjusted to a range [-2.5 V, 2.5 V]. Therefore, the conditioned EOG signal is the input of the MDSM block.

Set of 100 simulations was run. For obtaining correct simulation results, each simulation included measuring the same EOG signal. Because repeatability of the input signal could not be achieved with a human subject and "live"

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measurement for each experiment, the source of input signal is not a humane subject. Input signal is generated from records previously measured by standard EOG measurement instrument [13, 14]. The simulation model has been realized using the software package Matlab [15]. The MDSM block was configured according to the data presented in Table 1.

TABLE I
MDSM BLOCK PROPERTIES

Number of measurements	100
ADC	Resolution: m1 = 6 bits Input range: ±R and R = 2.5 V Sampling frequency: f_{ADC} = 1 kHz
Measurement interval	[0,T] and T = 0.5 s, dT = 0.25 s
Fundamental frequency	$f_0 = 1/T$ = 2 Hz
Number of samples per measurement interval	$N = f_{ADC} \cdot T = 500$
Digital dithered base functions stored in memory	Simulating an ADC with properties: Resolution: m_2 = 8 bits Range: ±R and R=2.5V Sampling frequency: f_{ADC} = 1 kHz
Number of calculated Fourier coefficients	DC component + 7 (15) sine coefficients + 7 (15) cosine coefficients

III. EXPERIMENTAL HARDWARE SOLUTION

The experimental hardware solution [12] is based on a personal computer (PC) with additional microcontroller hardware for analogue signal processing, designed as PCB. The functional block-scheme of the experimental PCB, which is connected with PC through the serial port RS-232, is presented on Fig. 3. It is valid that the signal *s(t)* is input signal (conditioned EOG signal), *d(t)* is ditter and *m(t)* is the resulting signal. All these signals are 8-bit digital words with frequency of 1 kHz. The signal $s_a(t)$, $d_a(t)$ and $m_a(t)$ are analogue signals, where is valid that $m_a(t) = s_a(t) + d_a(t)$.

The PC sends, through the serial port RS-232, a samples sequence of pre-prepared pairs of {signal, dither} to the PCB at a rate that is approximately equal to the rate of 1 kHz. Received pairs are stored into the input buffer. Driven by the real-time clock running at 1 kHz, a sample pair from the input buffer is transferred to the DAC inputs and D/A conversion of both 8-bit data {signal (t), dither (t)} is started. Analogue outputs of DAC are connected to the inputs of the analogue adder. At the adder output is the ADC that converts the analogue values into the digital, and transfers them to the PC immediately via output buffer.

Designed PCB carries out the conversion in a real-time, which means that data from input buffer are transferred to DAC at a rate of 1000 samples per second.

The digital data, achieved from the PCB through the serial port RS-232, are transferred to the digital multiplier. These digital data are multiplied with the digitized dithered basis functions, obtained from the memory, and transferred to accumulator. The outputs of the accumulator are the Fourier coefficients. Each Fourier coefficient is a function of all analog samples from the input over the measurement interval. These Fourier coefficients are the input for calculating digital values of signals in the time domain.

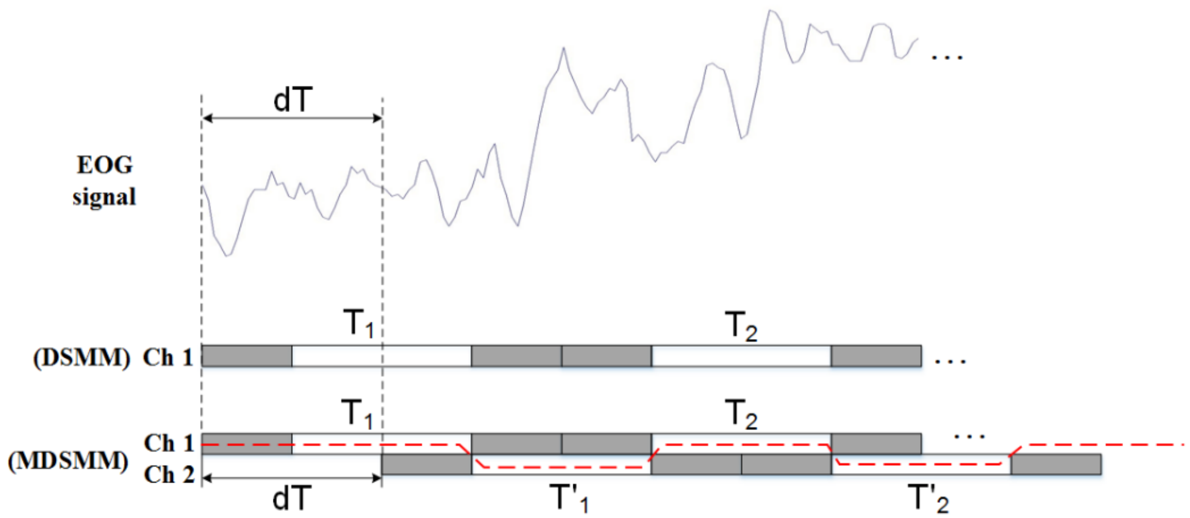

Fig. 1. Graphical presentation of measurement intervals overlapping.

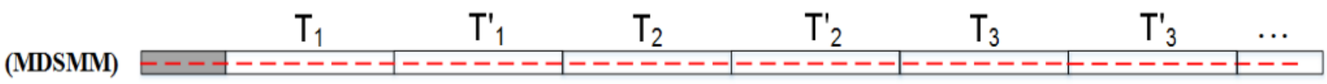

Fig. 2. Resulting signal.

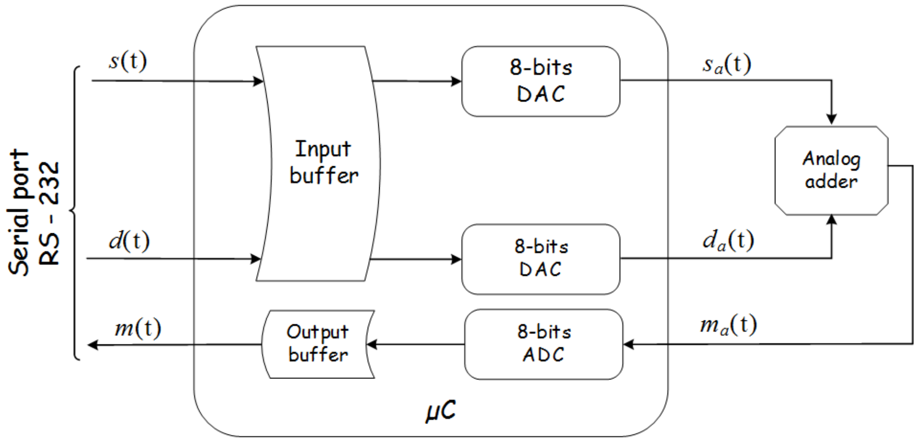

Fig. 3. The functional block-scheme of the experimental PCB which is connected with PC through the serial port RS-232, where *s*(t) is input signal, *d*(t) is ditter and *m*(t) is the resulting signal.

The PC application for the DSM of non-stationary signals provides the graphical user interface (GUI) for preparing and carrying out the experiments, as well as the analysis of obtained results.

IV. Results and Discussion

When all running tests are done, the results of the concrete experiment are generated and presented in textual and graphic format. As a result of measurements, the errors in the time domain are obtained. Various number of Fourier coefficients per set were measured: first, 15 Fourier coefficients were measured, and after that only 7.

Comparative view of measurement results obtained by classical digital measurement, as well as by experiments with various number of Fourier coefficients, i.e. all measurement errors in the time domain, is presented in Table 2. Classical digital measurements were carried out with 6-bits ADC and sampling frequency of 1 kHz in order to achieve the same conditions as in simulation and experiment.

TABLE II
Comparative view of measurement errors

		Experiment	
Time domain errors	Classical dig. measurement	Fourier coef: 7	Fourier coef: 15
Max absolute (mV)	0.0297	0.0192	0.0241
Max relative (%)	3.8249	2.4733	3.0954
Average absolute (mV)	0.0149	0.0030	0.0031
Average relative (%)	1.9104	0.3841	0.4012

From Table 2, it can be seen that the experimental errors, in both cases, are less than measurement errors obtained by classical digital measurement. Also, it can be seen that the results obtained by seven Fourier coefficients are slightly better than results obtained by fifteen Fourier coefficients.

V. Conclusion

The paper presents a comparison of experimental results obtained with various number of Fourier coefficients that are measured. An experimental hardware solution for modified digital stochastic measurement of EOG signals in the time domain is based on a personal computer (PC) with additional microcontroller hardware for analogue signal processing, designed as PCB. The realization of MDSM block is carried out by 6-bits ADCs. Experimental results are also compared with results obtained by classical digital measurement. The mean relative errors obtained by experiments are decreased related to the mean relative error obtained by classical digital measurement. After analyzing all results, it can be concluded that the best results are obtained for measurement of 7 harmonics. It is good to emphasize that experiments with lower number of Fourier coefficients need less time to be finished.

Considering all presented, the proposed experimental hardware solution with 7 harmonics can be used for realisation of a hardware simplicity instrument with sufficient accuracy for precisely digital measurement of biomedical signals.

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