Model Development for Digital Stochastic Measurement of Noised EOG Signals

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Abstract –**The paper presents simulation model development for an example of digital stochastic measurement method (DSMM) for measurement of nonstationary signals. This method is based on stochastic analog-to-digital (A/D) conversion, with a low-resolution analog-to-digital converters (ADCs), and accumulation. The simulation has been realised using the Matlab program, and electrooculography (EOG) signal is used as an example of a real low nonstationary signal. Tests are done with adding a noise-varying signal-to-noise ratio (SNR) from 10 to −10 dB.**

Keywords –**Digital stochastic measurement, electro-oculography (EOG), signal processing, simulation model, measurement errors.**

I. Introduction

The method for digital stochastic measurement (DSM) of stationary signals has been developed and described in [1-6]. Few prototypes of instruments based on these methods has been developed. This instruments were named digital stochastic instruments.

Then, a question appears - whether it is possible to apply the stochastic digital measurement methods for measurement of nonstationary signals, such as biomedical signals, audio and video signals, etc. The DSM of electroencephalography (EEG) signals has been discussed in [7, 8], where EEG signal has been taken as an example of nonstationary signals.

This paper discuses further application of DSM for nonstationary signals. An electrooculography (EOG) signal is used as an example of biomedical nonstationary signal for DSM model developed simulation tests.

Electrooculography is the standard method by which eye movements are recorded in the clinical eye movement laboratory [9]. The resulting signal is called the electrooculogram.

EOG signal presents the corresponding record in the function of time for each kind of eyeballs movements, such as up, down, left, right, and eye blinking. Obtained signals can be used for external devices control, such as virtual keyboards, electric wheelchairs, artificial arms and robots. Also, in ophthalmology the recording of eye movements is necessary for a detailed description and analysis of the eye motoric functioning. Various changes in the eye can be detected by analyzing EOG signals. In that way, the condition of the eye can be determined.

II. Stochastic Digital Measurement Method

Digital stochastic measurement (DSM) method is based on measurement over an interval [1]. Measurements are carried out by low-resolution ADCs. In order to eliminate the influence of the quantization error, which is significant here, an uniform random noise with average value equal to 0 is added to the input signal in the range of quant of the applied ADC.

If needed to measure the RMS value of the signal, than measurement block is extended by another ADC, another uniform random noise generator and multiplier-accumulator. If the uniform noises on the inputs of both ADCs are not in correlation and the same signal at the input of both channels, the mean value of the accumulator contents is then equal to the square of the effective value on interval.

If the input of the second channel multiplier-accumulator is a basis function from the orthonormal function set, such as Fourier, then the mean value of the accumulator is equal to the value of the corresponding signal coefficient in the orthonormal set. In this way, the coefficients can be measured very accurately.

The problem appears because the correct presentation of the signal over an interval, in the case of Fourier, requires a huge number of coefficients (defined by the sampling theorem). In that case, the measurement hardware would be very complicated and impractical.

Since the function of the second channel is known, as well as noise, it is possible to generate basis function values over the interval, and stores them in memory. The memory output is the second input of multiplier-accumulator. This structure is shown in Fig. 1.

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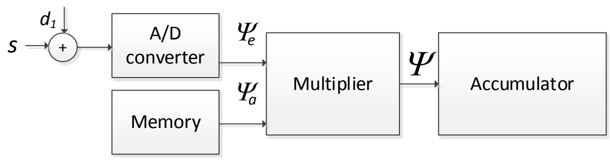


Fig. 1. Block diagram of digital stochastic measurement of one Fourier coefficient of conditioned input signal

III. Simulation and Results

The DSM system consists of three blocks: a signal conditioning block (amplification, linearization, filtering, scrolling levels, noise suppression, electrical isolation), a DSM block, and a block for data processing, recording, and presenting. The signal at the input of the DSM block is the conditioned signal. The system has been realized using software package Matlab.

A. Input Signal

As the input signal of DSM block is taken conditioned EOG signal. Typical EOG signals have amplitudes in the millivolts range with frequencies of DC - 100 Hz [10]. EOG signal is one of the standard biopotentials measured during a deep sleep, so called REM (Rapid-Eye-Movement) phase of sleep. REM involves very quick and random eye movements. In a normal night sleep, REM occurs every 90 minutes and lasts for approximately 5 to 30 minutes at a time.

An input signal of DSM block is 10 s of signal extracted from a real measure-ment session of the EOG signal. These values of signal are amplified and adapted to a range [-0.5 V, 0.5 V]. therefore, the conditioned signal is the input of the DSM block.

In the real measurement, which was a typical digital measurement procedure, the EOG signal was stored with 250 samples per second (S/s). For obtaining a smooth input for simulation, these 250 S/s records were transformed into 5000 S/s data. This was achieved by using the Matlab function *'interp'*, for resampling input signal by integer factor, with a given value of 20. Each sample of conditioned signals is stored as a value in a simulation lookup table.

For obtaining correct simulation results, each simulation included measuring the same EOG signal. Repeatability of EOG signals could not be achieved with a humane subject and "live" measurement for each experiment. Therefore, the source of the EOG signal in simulation measurements was not a humane subject, but an data source of conditioned signals was made.

B. System Properties and Results

The DSM block in simulation was configured according to the data presented in Table I. Three sets of simulations were run, with adding white noise to the input signal. The noise has a uniform probability density function, and the signal-to-noise ratio (SNR) was 10, 0, and −10 dB. There is no antialiasing filter before the DSM block, which would limit noise bandwidth.

At the output of each set of simulation is obtained the reproduced signal. As a result of simulation, errors in frequency and time domain are obtained, as well as corresponding graphics of the input and the reproduced signal. The results of one measurement series, i.e. measurement errors in the time domain, are shown in Table II.

TABLE I
DSM BLOCK PROPERTIES IN SIMULATION SETS

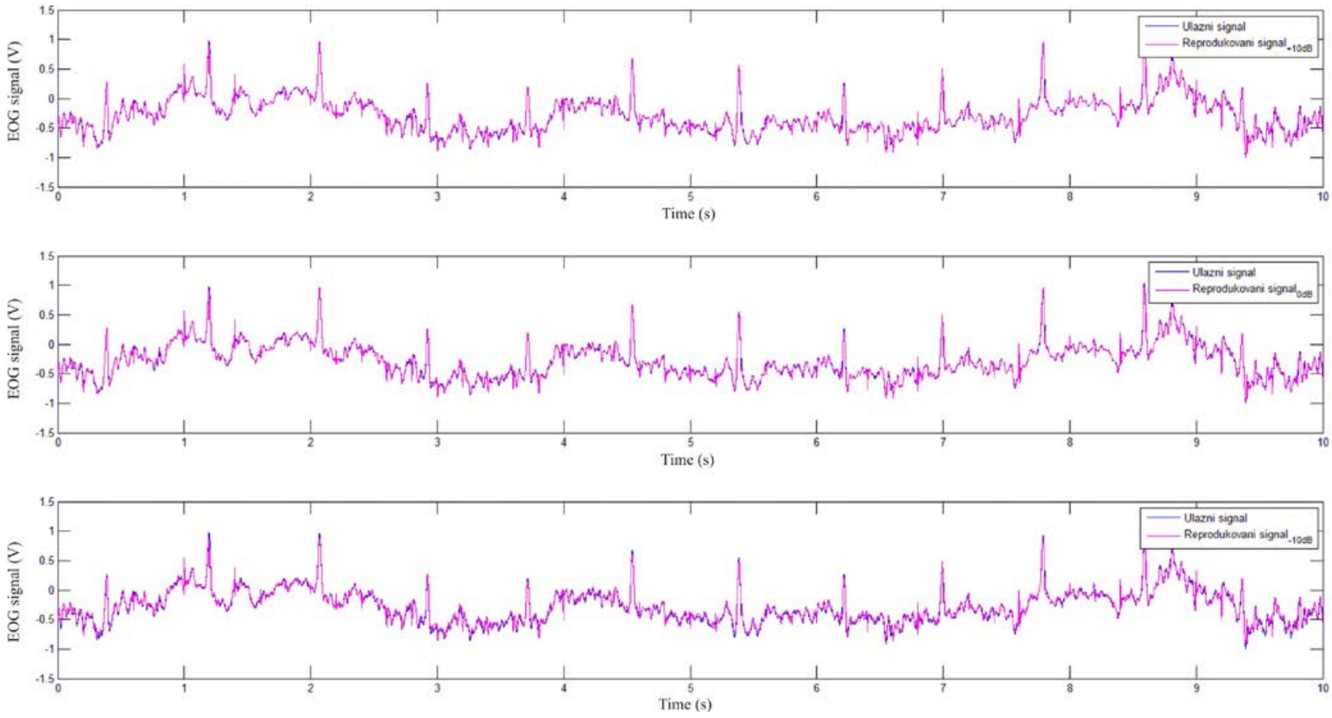
Number of simulations	3 x100 (for each SNR level)
SNR level	10 dB, 0 dB, -10 dB
A/D converter	Resolution: m_1 = 6 bits Input range: ±R and R = 2.5 V Sampling frequency: f_{ADC} = 250 kHz
Measurement Interval	[0,T] and T = 0.2 s
Fundamental frequency	f_0 = 5 Hz
Number of samples per measurement interval	$N = f_{ADC} \cdot T$ = 50 000
Digital dithered base functions	Stored in memory simulating an A/D converter with following properties: Resolution: m_2 = 8 bits Range: ±R and R=2.5V Sampling frequency: f_{ADC} = 250 kHz
Number of measured Fourier coefficients	DC component + 15 sine coefficients + 15 cosine coefficients

TABLE II
MEASUREMENT ERRORS IN TIME DOMAIN

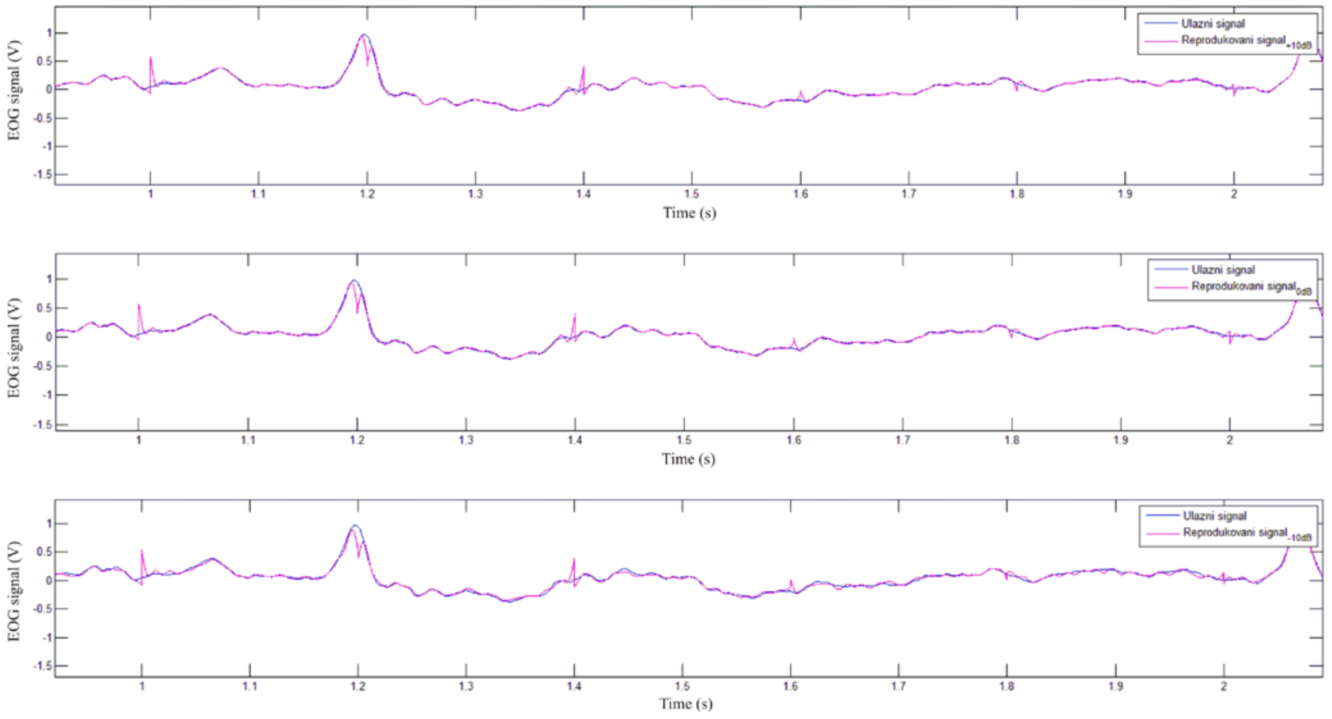
Measurement interval: 0.2 s			
Number of harmonics: 15			
ERRORS	**SNR = 10 dB**	**SNR = 0 dB**	**SNR = -10 dB**
Max apsolute	0.551834	0.557231	0.539366
Max relative (%)	27.2716	27.5384	26.6555
Average apsolute	0.015895	0.017386	0.030128
Average relative (%)	0.7856	0.8592	1.4889

In Fig. 2a is a graph showing the input and of reproduced signals.

In Fig. 2b can be observed significant deviations of reproduced signal from the input signal.



a)



b)

Fig. 1. Measurement results for Digital Stochastic Measurement of noised EOG signals, for measurement interval 0.2 s: a) comparation of input signal and noised signals for the series of 100 measurements, b) zoomed panel a)

These deviation occur at the beginning and at the end of each measurement interval, i.e. every 0.2s, and they are the consequence of occurrence of Gibb's phenomenon. This phenomenon significantly increases the total measurement error, so that the maximum relative error of measurement (for SNR 0dB) reaches 27.5384%.

IV. Conclusion

This paper presents a model for digital stochastic measurement of EOG signals where the realization of DSM block is carried out by 6-bit and 8-bit ADCs. The entire system has been implemented using Matlab. Based on analysis of results, can be concluded that the greatest influence on the total measurement error is appearance of the Gibb's phenomenon at the ends of measurement interval.

The idea of further model development is to eliminate the Gibb’s phenomenon, in order to improve the model and to decrease the measurement error. It would be interesting to explore what will be the results if an identical measurement sequence had been realized, where measurement starts delayed by a certain Δt. In that way, an overlap of the measurement intervals on the places where the Gibb’s phenomenon occurs is achieved.

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