Biological Digital Signal Processing

Interpretation and Combination

Ionescu Marius
"Politehnica" University of Bucharest
Faculty of Electronics, Telecommunications and Information Technology
Bucharest, Romania
Email: yonescumarius@gmail.com

Abstract— **In this work, we discuss methods, filters and algorithms for processing of biological signals, as well as the interpretation and display of the results. Biological signals can help us diagnose certain diseases, and their combination and interpretation can provide us with relevant information about our health. The discussed problem is related to how biological signals can be processed, combined, interpreted and displayed in order to make accurate diagnoses. The article illustrates a new prototype based on spectroscopic methods which uses near infrared sensors to monitor blood glucose levels. The prototype combines spectroscopic methods with other methods, such as Electrocardiography or Electromyography. The work focuses on light absorbance in matter and on non-invasive blood glucose detection using near infrared technology by colorimetric interpretation of the values transmitted.**

Keywords- Digital signal processing; Haar filter; Butterworth filter; signals combination; signals interpretation; spectroscopic signals.

I. INTRODUCTION

In this paper, we discuss methods and algorithms for processing of biological signals, as well as the interpretation and display of the results using development platforms that enable digital acquisition and processing of biological signals. Digital signal processing is a bio-medical method that can help us make a faster diagnosis and provides more reliable treatment options for patients. Combining medical digital signals from Electrocardiography, Electroencephalography, Electromyography, or spectroscopic near infrared, can help us in monitoring diseases. Biological signals can come from different types of sources: audio, video, electrical, magnetic, etc. The challenge is to understand how these signals have been converted into electrical signals through methods of capturing and using transducers, such as sensors that measure physical and chemical values [1].

The challenge mentioned above is related to the interpretation of signals for the calculation and prognosis of diseases, such as diabetes, cancer or stroke. The prototype proposed in this article is an assembly between an Arduino board and two near infrared sensors for absorption and colorimetry. The signals acquired by Electrocardiography, Electromyography or light absorption sensors through biological tissues are processed and combined by a piece of software. Signal processing is based on the processing of the biological electrical properties of the body, which occur in tissues. Biological signals can be correlated with the mechanical, magnetic or spectroscopic signals, and used in biological analysis and signal processing [3].

Regarding the technique of acquiring biological signals, nowadays, Biological Signal Import Module (BSIM) is often used for acquiring biological signals [23]. It supports the acquisition of analog biological signals (2.5 V) from sensors like a pH electrode or an UV detector. BSIM uses multiple acquisition channels to acquire and interpret data using appropriate software for each channel. Thus, a module that receives signals from more than one electrode may be able to generate data for the analysis of Electrocardiography and Electromyography signals, as well as spectroscopic signals. This analysis is important because it helps with the detection of diseases that a patient may suffer from by processing biological signals.

According to the studies of Lapique Nicolas [1], professor in the Department of Biosystems Science and Engineering, Zurich, Germany, a biological signal processing circuit is based on a biological sensor that controls the activity of individual components using an internal timer. This prevents a sensor circuit from being active when the system is not in use and there is no need for processing biological data transmission. When the system is active, it transmits data via a control signal [1]. However, it is a challenge to combine different biological components to form a complex bio-signal in order to convey as much biological information as possible to the computer software for analysis and processing [21]. Lapique Nicolas [1] explains that biological signals travel differently through an electronic wire, and that, in biology, there is a variety of different signals from proteins to micro ribonucleic acid molecules [2]. A special feature in processing biological signals consists not only in transforming a signal into another, but also in transforming multiple input signals into multiple output signals.

The rest of the paper is structured as follows. In Section II, we talk about processing, interpretation and display of signals, Electrocardiography, Electromyography and near infrared spectroscopy signals. In Sections III and IV, we

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present the filters that can be applied over these signals, such as Butterworth and Haar filters, for a more accurate interpretation and acquisition of channel settings. In Section V, we discuss the near infrared signals for glucose and blood analysis. We conclude the paper in Section VI.

II. ELECTROCARDIOGRAPHY AND ELECTROMIOGRAPHY SIGNAL PROCESSING, COMBINING AND DISPLAYING

Electrocardiography signals can be combined with other signals, or information can be extracted from signals coming from different sources, such as Electromyography or near infrared, spectroscopic signals [4].

The acquisition of Electrocardiography signals uses the latest generation of microprocessors. Before being forwarded, the signals are extensively processed. At the moment, the acquisition of Electrocardiography signals is investigated with silver/silver chloride electrodes. The Ag (silver)/AgCl (silver chloride) electrode is used in common Electrocardiography systems and has a maximum offset voltage of ± 300 mV. A ± 0.5 mV desired signal is superimposed on the electrode offset. In addition, the system also takes the noise 50/60 Hz power lines forming common mode signal. The amplitude of power line noise could be very large and must be filtered [5].

Signal processing is a big challenge as the real value of the signal will be in an environment of 0.5 mV offset by 300 mV. Other factors, such as Alternating Current (AC) power interference, Radio-Frequency (RF) interference from surgery equipment, and implanted devices, or rhythm changes and physiological monitoring system, can also have an impact. The main sources of noise in Electrocardiography are:

- Low frequency noise (drift);
- Power line interference (50 Hz or 60);
- Muscular noise (this noise is very difficult to remove because it is in the same region as the real signal. It is usually corrected by software);
- Other interferences (ie., radio frequency noise from other equipment).

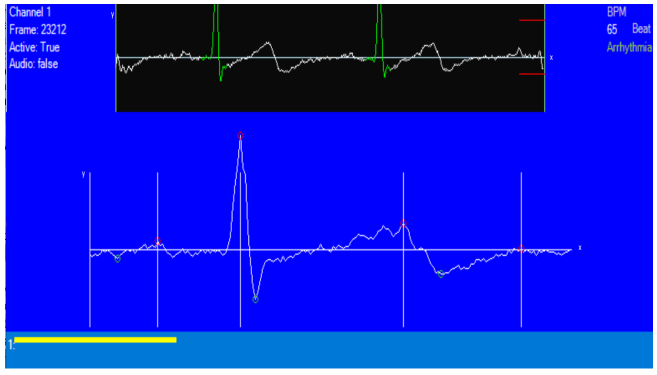

Figure 1. Combined graphical display of a raw ECG and an EMG chart.

This article aims to discuss the acquisition, takeover and processing of Electrocardiography and Electromyography signals, combining and displaying them using software. The goal is to extract as much information as possible from the data that is captured by using a developed board, which uses an advanced microcontroller receiving advanced processing signals from transducers. The signals which came in through the serial computer software are processed and displayed using advanced graphics.

The goal is to extract as much information as possible from the received data and display it in a more comprehensive way in order to be understood by bioengineers, doctors or trained personnel, based on which they can diagnose and predict certain diseases or information about the health of a patient or a pathological case (Figure 1).

III. SIGNALS - HAAR AND BUTTERWORTH FILTERS

For processing and filtering graphics, we used two filters. The Haar filter, which is part of a wavelet family, is used in mathematics for waves. Wavelet analysis is similar to Fourier analysis because it allows a target function to be represented as an orthonormal basis. Using the wavelets for Electrocardiograph representation is quite useful if the sampled signal is continuous and has sudden transitions (Figure 1).

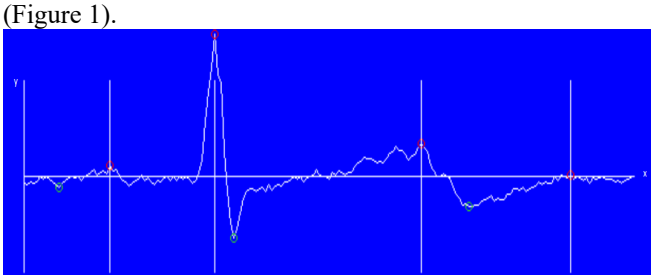

Figure 2. Electrocardiography signal capture.

One advantage of using a Haar filter for Electrocardiography signals graphical representation that it helps us represent any sample time as a continuous function, uniformly, approximated by linear combinations. Thus, this algorithm is extended to those areas where any function of this type can be uniformly approximated by continuous functions [14]. Samples are types of discontinuous functions that can distort the signal according to the formula below, where $\delta_{n,k}$ represent Kronecker delta and $\psi_{n,k}$ represent the real line R [25].

$$\int_{-\infty}^{\infty} 2^{\frac{(n+n_1)}{2}} \Psi\left(2^n t - k\right)\Psi\left(2^n t - k_1\right)dt = \delta_{n,n_1}\delta_{k,k_1} \quad (1)$$

Input sequences, which, in our case, are sampled Electrocardiography signals, are passed through a matrix type Haar by applying the wavelet transform discrete type, a 4x4 matrix:

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & -1 \end{bmatrix} \quad (2)$$

Butterworth had a reputation for solving "impossible" mathematical problems. At the time, this filter design required a considerable amount of designer experience because of the limitations of the theory in use. The filter has not been used for more than 30 years after its publication [24]. Butterworth has shown that close successive approximations were obtained by increasing the number of screening the correct values. At the time, filter waves generated substantial low-pass filter. Butterworth has shown that a low-pass filter can be designed with a cutoff frequency normalized to 1 radian per second and whose frequency response is:

$$G(\omega) = \frac{1}{\sqrt{1 + \omega^{2n}}} \quad (3)$$

where ω is the angular frequency in radians per second, and n is the number of poles in the filter equal to the number of reactive elements in a passive filter. If $\omega = 1$, the magnitude of this type of filter passband is $1 / \sqrt{2} \approx 0.707$, which is half power or -3 dB. Butterworth filters work only with an even number of poles in his work. He can ignore that these filters can be designed with an odd number of poles. He built his higher order filters, the filters with two poles separated by vacuum tube amplifiers. The frequency response plot of 2, 4, 6, 8 and 10 pole filters is shown as A, B, C, D and E in his original chart.

Butterworth solved the equations of two or four-pole filters, that show how the latter could be in waterfall when they are separated by vacuum tube amplifiers, allowing the construction of higher order filters despite the losses. In 1930, Butterworth used forms of coil with diameter of 1.25 cm and 3 cm long, with plug-in terminals, capacitors and associated resistors contained inside a coil. Coil resistance forms part of the load plate. Two poles were used for each vacuum tube and RC coupling was used for the electric grid of the next tube [7].

The Butterworth filtering algorithm can be transformed with the Haar filter used for Electrocardiography graphics. That can help to sample the Butterworth signal processing, where the algorithm has a defined number of low and high pass Butterworth filters with three poles, and which works on a certain frequency threshold [17]. A band-pass filter can be implemented by applying sequential algorithms to filter high-pass and low-pass [15].

In this sense, we applied algorithms corresponding to impulse response filters, which were designed by applying the bilinear transformation to the transfer functions of the corresponding analog filters [9], resulting in a recursive digital filter with seven real coefficients. So, in this application, we will have Butterworth type filters with the following settings (Figure 3):

- Butterworth_FreqHP - frequency high-pass which has the default 3 dB;
- Butterworth_FreqLP - low-pass frequency is 170 dB default value;
- Butterworth_Level - up crossing that has the default 1;
- Butterworth_PowerHP - high-pass power that has the default 57;

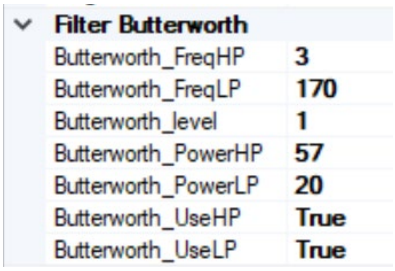

Figure 3. Settings the seven real coefficients for Butterworth filter

- Butterworth_PowerLP - low-pass power that has the default 20;
- Butterworth_UseHP - to enable high-pass, default is true;
- Butterworth_UseLP - to enable low-pass, default is true;

The expressions for filtering coefficients depending on the separation frequency and the sampling period are derived. The transfer function shows a plateau over the passband and a gradual attenuation more apparent at the frequencies above and below the cutoff frequency, with a slope of 60 dB / decade [8].

There is an attenuation of 3 dB frequency cutting and a gradual increase in phase shift frequency at every 10 steps. Low-pass filters show a maximum of 8 % overshoot and high-pass filters down show a maximum overshoot of about 35%. The algorithm to calculate filter coefficients for an arbitrary limit frequency of Electroencephalography may be useful in modern laboratories and for software designers for electrophysiological applications [19].

IV. SETTINGS AND USING CHANNELS FOR ARRHYTHMIA

Current applications for processing biological signals can set and use multiple channels simultaneously, which can receive different signals. Each channel has its settings. For example, the heart rate settings can be used as follows:

- Beat Level High;
- Beat Level High Limit;
- Beat Level Low;
- Beat Level Low Limit;
- Filter Haar;
- Filter Butterworth;

Each channel can sample its own independent set of signals and may apply a set of specified filters. In our case,

the Electrocardiography signal can analyze, filter and display muscle activities in real time from the main sample data transmitted by a transducer.

The application allows diagnosis mode that draws the PQST axis based on filters used at some point. The goal is to save the PQST state at certain time intervals [12].

The signals based on flows and electric excitations of the body, detected and transmitted by electrodes, can display, process and set various diagnoses, prognoses and can interpolate the obtained information, so that the area of diagnostics includes batch jobs related to other regions or functions of the biological body, such as Electrocardiography or Electromyography (Figure 4).

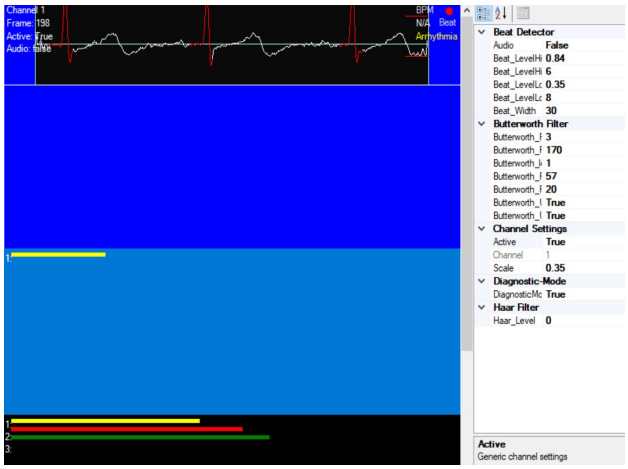

Figure 4. Settings channels of application processing signals

Arrhythmia (Figure 5) is a problem with the rate or rhythm of the heartbeat. During an arrhythmia, the heart can beat too fast, too slowly, or with an irregular rhythm. If the heartbeat is below 60 beats per minute, the condition is called bradycardia and if it is over 100 beats per minute, the condition is called tachycardia.

The arrhythmia algorithm calculation is based on data from the sampling difference every 6 beats. If a heartbeat is detected at each 6 beats, an anomaly is detected and the software will send alerts (Figure 6).

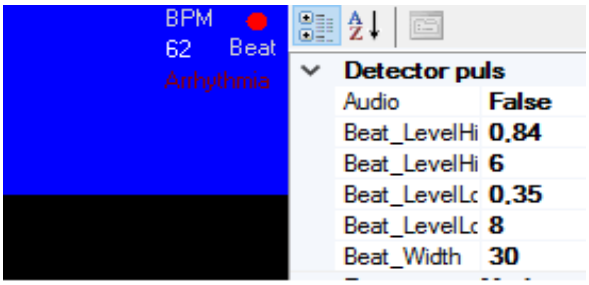

Figure 5. Arrhythmia detector

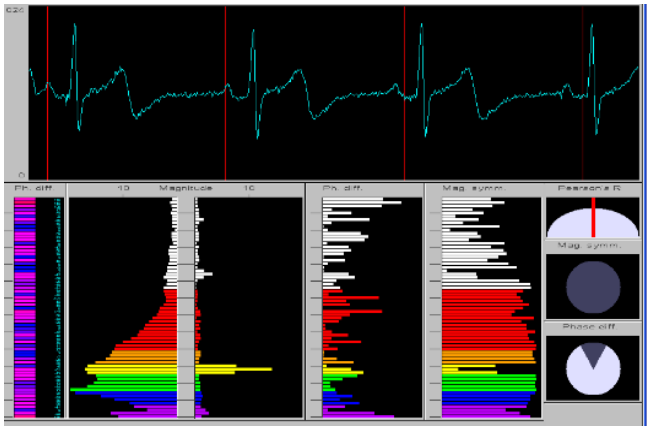

Figure 6. Acquisition data Electrocardiography and Electromyography

The proposed prototype starts with Electrocardiography signals, which can be interpreted and displayed by the software. To this prototype were attached sensors, such as near infrared spectroscopic sensors, which measure the absorption of light through biological tissue. In this sense, an algorithm has been developed to calculate light absorption through the three layers of the skin [10], light absorption through blood, plasma and formed elements (erythrocytes, leukocytes and thrombocytes, as well as nutrients). In this article, we focus only on the absorption of light through glucose, as a biological signal correlated with Electrocardiography signals.

V. NEAR INFRARED SPECTROSCOPY SIGNAL IN MEASURING GLUCOSE

A. Introduction

One of the modern methods proposed in this paper at the development phase and research is non-invasive glucose detection in correlation with Electrocardiography signals. The prototype has two hardware modules that are interconnected through different interfaces. Electrocardiography helps spectroscopic measurement (in this case, glucose) by providing the moment of maximum blood flow through the body.

The invasive colorimetric method produces a chemical reaction activated by an enzyme, not oxidizing glucose. The process itself consists of placing a drop of blood on a test strip. The blood glucose will react with a chemical reagent (bromine or chlorine) that changes color. This modification of blood color is measured and interpreted as a blood glucose level. In this regard, the proposed prototype in this paper brings two general problems in detecting the glucose level in the blood [22]:

- Non-invasive blood glucose detection using near infrared technology by colorimetric interpretation of the values transmitted by a sensor;
- Absorption of light in matter;

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The research proposes an interface that analyzes and calculates the colorimetric values transmitted by a development board through two near infrared sensors: one for light absorption and one for colorimetry. The blood glucose measurement algorithm is based on the absorption of the amount of monochromatic light that passes through the tissues to the capillaries that contain blood [10]. The blood glucose concentration is measured based on the amount of monochromatic light absorption through tissues [14]. The error rate can go up to 20% due to the light that has to pass through to the capillary veins. Also, the spectral bandwidth may have large errors in this sense. The paper proposes an interpretation algorithm based on the RGB interpretation of the data coming from the near infrared sensor, and only an interpretation of the monochromatic absorption. RGB data is interpreted based on tint and saturation to obtain the average blood glucose level [22].

Classical blood glucose measurement devices are based on colorimetry and measure the amount of light absorbed by matter [20].This way, the glucose concentration is measured by the detection of the luminous intensity passing through a blood sample, which contains the serum and chemical reagent products [6].

The measurement procedure is similar to urine analysis, where a urine sample passes through the yellow light and absorbs the blue and green lights [21].

B. Prototype

The proposed prototype uses light that passes through matter, for example, through our finger, so that the light can reach the capillaries. Tests were performed on a physiological serum that was mixed with 100g of glucose [18]. The near infrared sensor passes through the sample, being helped by the auxiliary light, and returns the RGB values in order to determine the amount of glucose in the sample. To analyze and measure blood glucose, some standard measures should be taken (Table I).

TABLE I. STANDARD ABSORBANCE

1.	Wavelength (400 ~ 800 nm)
2.	The standard amount of glucose used in the test
3.	Incubation time
4.	Standard sample quantity
5.	Volume of the reagent
6.	Limit of Absorbance
7.	RGB color standard

The principle of measurement is based on the uniform dispersion of light through matter to capillary. This is facilitated by the auxiliary light that allows the near infrared sensor to collect better values of the RGB in the blood. To measure the density of blood glucose, the data of a polynomial mathematical function is utilized [21].

Maximum glucose absorption is detected between 260 nm and 270 nm and the one of xyloses is from 245 nm to 255 nm. At 270 nm, absorption of xyloses is only half of the glucose. The 6 channels of the sensor detect the light absorbance at a given wavelength (R = 610nm; S = 680nm; T = 730nm; U = 760nm; V = 810nm; W = 860nm) on which blood glucose can be detected. We know that normal blood glucose is between 4.4 millimole and 6.7 millimole per liter (ie., between 0.8 and 1.2 grams per liter) taken at no more than 6.7 millimols per liter (1.2 grams per liter) two hours after having a meal [22].

People who do not have diabetes should have a value below 6.9 mmol / L (0.25 g / L) and those with diabetes have a value between 5.0-7.2 mmol / 0.9-1.3 g / L) before meals and less than 10 mmol / L (1.8 g / L) after meals, according to [22].

The application of near infrared spectroscopy on the human body is based on the fact that absorption of near infrared light from human body tissues contains important information about changes in hemoglobin concentration, which is very important for the detection of glucose in tissues. When a certain area of the brain is activated, it detects that the volume of blood in the area is changing rapidly [13]. Near infrared spectroscopy technology can be used as a rapid monitoring tool for cases of intracranial hemorrhage by placing the scanner on the head [11]. When it is internal bleeding from a stroke, the blood can be concentrated in a single location where the near infrared light will be more absorbed than in other locations [22].

The prototype proposed is based on optical spectroscopy that quantifies the level of glucose in human blood based on several near infrared sensors. The proposed prototype device has not yet been tested on the real human body to determine the level of blood glucose.

A module that contains more sensors stays on top and passes through the finger that sits on a device. The bottom module is equipped with an internal module to retrieve the signals transmitted by the sensors [22]. The process involves inserting the near infrared light beam into the test samples (tissues) and detecting the amount of light passing through these samples. Near infrared transmission spectroscopy is practiced on the fingertips or ear lobes, while for the forearms and cheeks, reflexive spectroscopy is not used due to the fact that the near infrared does not have the same penetration power. When near infrared light passes through a tissue, glucose is detected when the tissue absorption rate is very low. It should be noted that near infrared spectroscopy is renowned for its simple concept and its applications. This technique can be used to monitor the water content in the blood that can be avoided by selecting a specific infrared range.

The prototype (Figure 7) is an assembly between an Arduino board and two near infrared sensors of absorption and colorimetry. The signals are taken and processed by software resulting in a combination of Electrocardiography, Electromyography and light absorption through biological tissues. AS7263 is the near infrared version of the spectral sensor capable of measuring 610, 680, 730, 760, 810 and

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860 nm of light, each with a maximum detection error of 20nm. The 6 light channels have the following wavelengths: R = 610nm; S = 680nm; T = 730nm; U = 760 nm; V = 810nm; W = 860nm.

TABLE II. PROTOTYPES RESULTS ACQUISITION

Glucose/nm	R-610	S-680	T-730	U-760	V-810	W-860
200 mg Gl	235.25	84.75	27.79	16.67	20.77	15.45
400 mg Gl	135.25	78.75	20.79	18.91	22.77	17.45
600 mg Gl	94.36	30.99	15.0	9.95	10.89	8.14
800 mg Gl	78.42	67.15	62.52	57.73	58.40	48.85
1000 mg Gl	65.42	30.99	57.52	55.22	49.30	43.15

For glucose measurement in vitro, a high glucose solution (100 mMol) was used and the near infrared spectra were measured. The software application receives the results from channels and tempF signals from a module based on an Arduino device to which a near infrared sensor module has been attached. Two aqueous glucose solutions were prepared in advance for in vitro testing. An initial solution of ~ 100 mMol and one ~200 mMol were prepared. Several readings were performed for each concentration. Finally, an average of each reference set was taken (Figure 7). If the glucose concentration (mMol) increases (reading), the output voltage increases.

Figure 7. Hardware prototype

VI. CONCLUSION AND FUTURE WORK

Channels analysis receiving multiple signals can be very useful in the diagnosis and prognosis of many diseases, especially when the channels contain rich information that can be extracted from Electrocardiography, Electromyography, Electroencephalography, near infrared spectroscopy etc. In this case, the Electrocardiography signal can be processed and correlated with other signals using specially developed algorithms to analyze and display more useful information in a comprehensive way. In the future, the program will try to implement periodograms, correlograms, and other signal analysis tools to display a rich variety of information that may be useful for bioengineering and medical staff [22].

The application aims to implement in the future:

- an advanced graphical display for Electrocardiography and Electromyography that can correlate with and illustrate muscles activity;
- an advanced graphic display of Electrocardiography arrhythmia;
- real time display of possible diseases based on Electrocardiography signals;
- attaching new sensors, which makes possible the display a heartbeat correlation with muscles activity in real-time;
- saving and creating a database of transmitted and processed values in real time to create a history.

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