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Proposal of Architecture for the Monitoring of Vital Signs based on Embedded Systems

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Abstract. In this paper, we propose an embedded system architecture, using programmable devices and standard sensors, to continuously monitor the vital signs of hospitalized patients. The vital signs to monitor are body temperature and heart rate. Body temperature is measured by the 16-bit MAX30205infrared temperature IIC sensor. The heart rate is measured using an analog photoplethysmograph model SEN11574, which signal will be digitized using the 12-bit ADC MCP3201 with SPI interface. An embedded system based on the Xilinx MicroBlaze processor, which is a soft-core processor, implemented on a FPGA of Spartan 6 family is used. The processor local bus is used for the interface with the peripherals, an IIC core for the temperature sensor configuration and an SPI core for the ADC interface. Different algorithms for calculating the heart rate signal frequency are analyzed.

Keywords: embedded system, FPGA, sensors, signal processing, vital signs.

1 Introduction

In hospitals in Mexico, control of information on the health status of patients is of paramount importance for physicians and nurses to perform their care tasks efficiently. Usually, the control of information is carried out through a clinical file which, according to Official Mexican Standard NOM-168-SSA1-1998, is the "set of written, graphic and imaging documents or of any other kind, in which the health personnel, must make the records, annotations and certifications corresponding to their intervention, according to the sanitary dispositions" [1]. As part of the documents that make up this file, we find nursing sheets that, among other data, contain personal information of the patient and results of a physical examination or measurement of vital signs [2].

Nowadays, medical personnel must physically go to check the health status of each patient. The periodicity of the revision of the vital signs is given by the normativity of each institution and by the medical orders for each patient. Nursing records are made manually from a standardized printed format; they are stored in the patient's clinical record or, if the hospital handles an electronic medical record, the data in this record must be captured in the system.

The time required for the review of each patient may be prolonged because each of the vital signs must be verified in a separate way. The time required for the transcription of data in nursing sheets should also be considered, as well as the possibility of making mistakes in filling the sheets of nursing.

1.1 Vital Signs

The four vital signs represent a simple assessment of the physiological and physical state of an individual. They are used by physicians as a quick and general evaluation of their patients and are often measured by a medical assistant prior to the medical office visit. The vital signs of hospitalized patients are also regularly measured for periodic evaluation of their condition. The four basic signs are: body temperature, heart rate, respiratory rate and blood pressure (see Table 1) [3].

Table 1. Definition and characteristics of vital signs.

Vital sign	Definition	Method of measurement	Stability range (people between 19 and 26 years)
Body temperature	Measurement of the kinetic energy of the atoms or molecules of a substance or object [4]	Contact thermometer (mercury or electronic)	Between 36.5°C and 37.2°C
Blood pressure	The force exerted by the blood against the walls of the arteries [5]	Tensiometer and a stethoscope	Systolic < 120 mm Hg Diastolic < 80 mm Hg
Heart rate	The number of times the heart beats per minute [6]	Pressing firmly on the arteries / Electrocardiogram	Between 60 and 100 beats per minute
Breathing frequency	The amount of breaths a person does per minute [7]	Count the breath for one minute	Between 12 and 16 breaths per minute

2 Proposed System Architecture

2.1 Methodology

In this research, a study from the general to the particular is realized, in other words, the deductive method is used [8]. It is from the investigation of monitoring systems and vital signs to the investigation of the characteristics and principle of operation of the sensors for their measurement, as well as the processing of the signals obtained.

The choice of vital signs to monitor is performed qualitatively while the choice of sensors and devices for their processing is performed quantitatively, considering the sensitivity, working range and processing speed of these devices, among other characteristics.

2.2 V-Model for Embedded Systems

The chosen model for the development of this embedded system is the V-model since the design stages can be related to the test stages. This is convenient for the type of systems involving hardware and software. For this, it is necessary to consider all the steps shown in Fig. 1 [9].

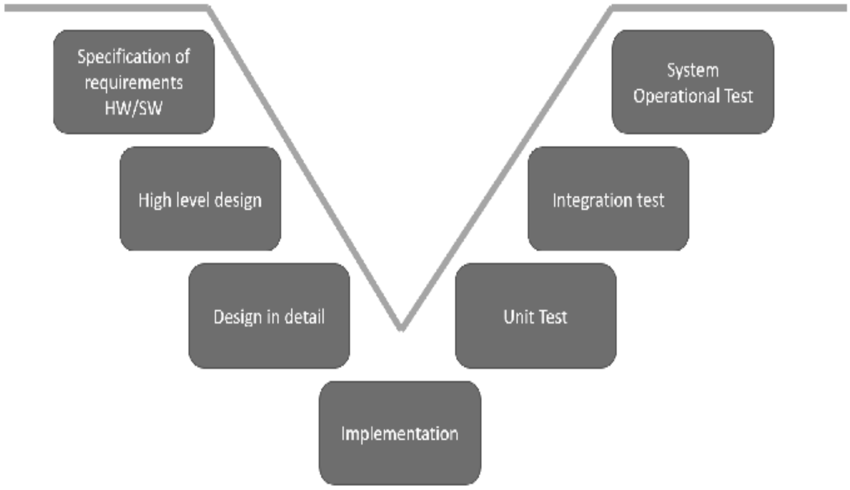

Fig. 1. V-model for the development of embedded systems.

2.3 System Analysis

The temperature sensor used is the MAX30205, which is powered with a voltage between 2.7 V and 3.3 V and with an average consumption of 600 μA. The working range of this sensor is between 0 ° C and 50 ° C, with an accuracy of 0.1 ° C. The output signal is digital with a 16-bit resolution. This sensor has an IIC interface, which is used for communication with the programmable device that processes the signal. The resolution of the output signal is sufficient to comply with the medical standard of the National Center for Technological Excellence in Health (CENETEC) which requires a minimum of 12-bit resolution [10].

The pulse sensor used to obtain the heart rate is the photoplethysmograph SEN-11574, due to the integration of a circuit containing a protection diode in the supply voltage, in addition to a filter and an amplifier to increase the amplitude of the pulse wave and normalize the signal around a reference point. The schematic diagram of this sensor is shown in Fig. 2.

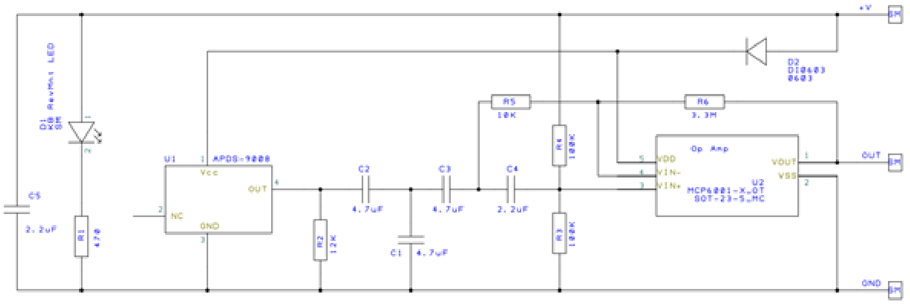

Fig. 2. Schematic sensor SEN-11574.

To condition the signal obtained from this sensor, the Microchip MCP3201 analog-to-digital converter (ADC) is used. This ADC has a sampling frequency of 50 kHz and a 12-bit resolution, sufficient to comply with the CENETEC standard, which indicates a minimum sampling frequency of 500 Hz and a minimum of 12-bit resolution for a basic electrocardiograph [10]. In addition, it has SPI (Serial Peripheral Interface) interface; in this way the digitized signal will be sent to the programmable device for processing.

High speed and sensitive response of system are necessary in measuring vital signs parameter. Measures can change drastically in a very short time, depending on the health status of patient. Well-known as high-speed IC processor, FPGA can work for specific purpose with high speed requirement [11,12]. Because of its flexibility and advantages, FPGA is perfectly suitable in medical instrumentation environment. The programmable device that will process the signals is a FPGA XC6LX16CS324 of the Spartan 6 family, implemented in a Xilinx Nexys 3 development circuit.

2.4 System Design

The purpose of the proposed system is to help physicians better monitor their patients. Considering that the system only contemplates the level of prototype, laboratory tests are carried out, placing sensors of the vital signs in students and professors of the Superior School of Computer Sciences (ESCOM). The overall process of the proposed architecture is shown in Fig. 3.

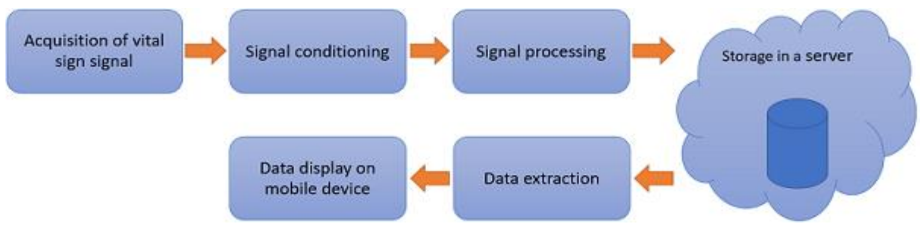

Fig. 3. Block diagram of the overall process.

The general architecture of mobile computing is shown in Fig. 4, which shows the way to communicate the sensor node with the server via WiFi. The mobile device connects to the server also via WiFi.

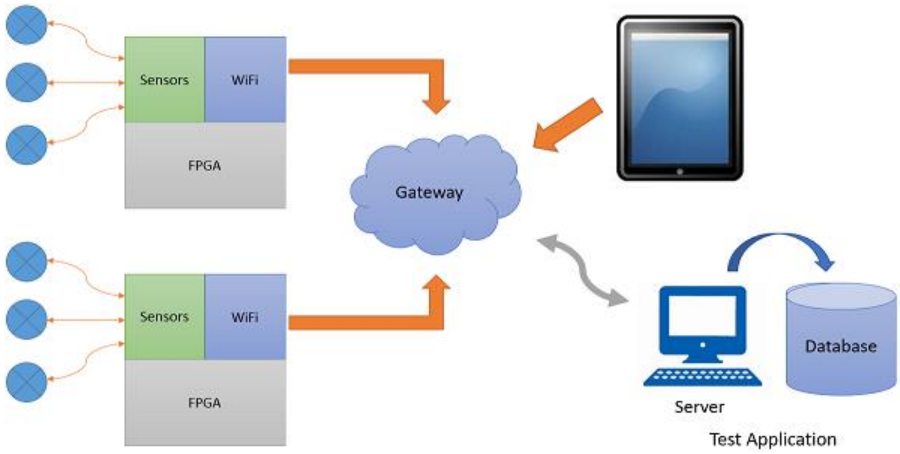

Fig. 4. General architecture mobile computing.

Fig. 5 illustrates the sensor node architecture in detail, it shows the master (FPGA) – slave (ADC) configuration via the SPI modules connected to the processor local bus (PLB). In addition, the IIC core to communicate with the temperature sensor is observed. The data obtained from the vital signs sensors are processed by the soft-core MicroBlaze. At the end of processing, the UART communication module connected to the PLB is used to send the results via WiFi to the server, using the WiFi ESP click module.

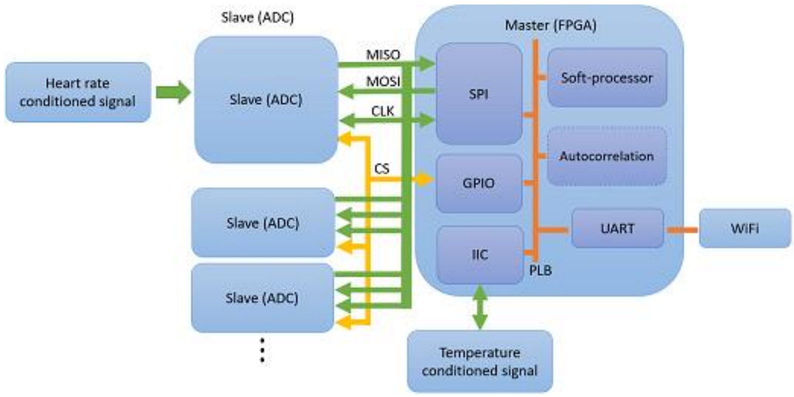

Fig. 5. Sensor node architecture.

2.5 Tests Performed

Initially, tests were performed on a sample obtained with a photoplethysmograph. The signal was digitized with a sampling frequency of 500 Hz and an 8-bit resolution. It was processed with different mathematical methods to obtain the fundamental frequency, such as: autocorrelation [13], fast Fourier transform and Goertzel algorithm [14].

Choice of mathematical method: The functions mentioned above can be implemented in software, running a program on a common computer or using a microprocessor or microcontroller based system. In this case, its performance depends on the computing power of the processor used and the processing speed which is usually medium in size, making it impossible to perform a real-time processing of high frequency signals. Another method is its implementation on FPGAs, which, due to their flexibility, possibility of parallel implementation and high integration capacity, have become the ideal hardware for those designs that are robust and require high speed [15]. After performing the calculations shown by MATLAB software, to choose the most convenient method, the graphs obtained are shown in Fig. 6.

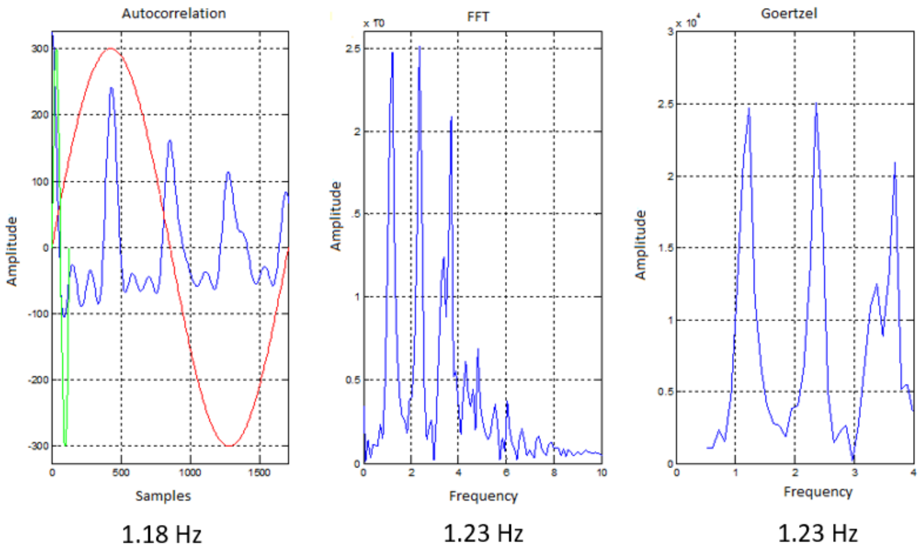

Fig. 6. Comparison of mathematical methods for obtaining fundamental frequency.

The calculation of the fundamental frequency with the autocorrelation method is 1.18 Hz. This value is like that obtained with the Fast Fourier Transform (FFT) and the Goertzel algorithm, which is 1.23 Hz. Observing that the values obtained are similar, it can be considered acceptable any of the three methods. When implementing the algorithms on the FPGA, the computational cost would be higher using the Fast Fourier Transform, since the signal must be converted from time to frequency, and then find the maximum that indicates the heart rate. This process can be simplified by using the Goertzel algorithm, which is a frequency filter and does not perform the complete signal conversion in time, only uses a specific frequency range. With autocorrelation, the computational cost is reduced, since it is not necessary to transform the signal in time to frequency because the calculation of the fundamental frequency is obtained from the maximum value of the signal in a specific range of the samples.

The signal obtained with the photoplethysmograph was autocorrelated to obtain its fundamental frequency, obtaining the value of 1.18 Hz. After that, a Hamming window was applied to the original signal to avoid the Gibbs effect in frequency. When the windowed signal was autocorrelated, smaller values were obtained in the amplitude, but the value of the fundamental frequency is the same. The graph of the windowed signal and its autocorrelation are shown in Fig. 7.

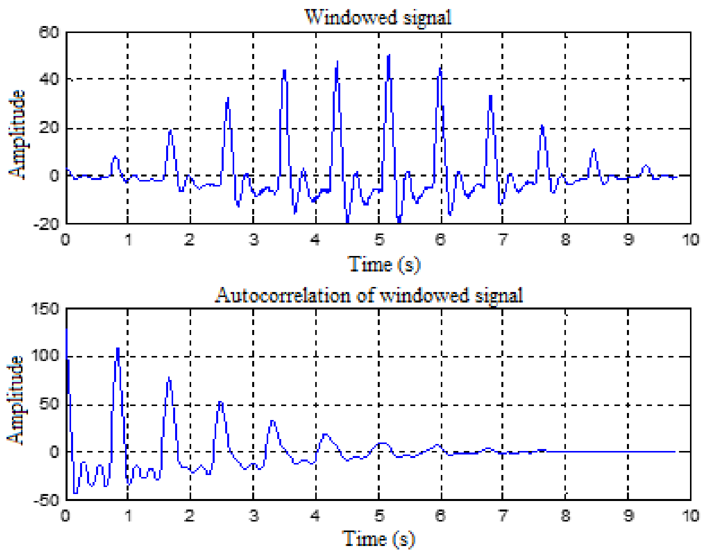

Fig. 7. Photoplethysmograph windowed signal with autocorrelation.

Table 2. Relative error percentage

Time (s)		1	2	3	4	5	6	7	8	9	10	
Number of samples		512	1024	1536	2048	2560	3072	3584	4096	4608	5120	
Frequency (Hz)	1.00	300.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Error (%)
	1.17	9.71	1.12	0.26	0.42	0.20	0.26	0.03	0.03	0.26	0.03	
	1.33	4.35	1.05	0.26	0.26	0.00	0.26	0.00	0.00	0.26	0.00	
	1.50	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	
	1.67	3.09	0.39	0.26	0.07	0.07	0.26	0.26	0.26	0.26	0.26	

Calculation of necessary samples by measurement: After testing with the signals obtained and validating the autocorrelation method for calculating the fundamental frequency, a script is performed to check how many seconds are necessary to have for a sample. Assuming ADC at 512 Hz sampling rate is used, we obtaine the Table 2, which represents the percentage relative error in each case. Different signals are digitally generated using frequencies within the range of heart rate stability (between 60 and 100 beats per minute). It can be seen that among fewer samples are used, the error, compared to the real frequency value, is higher; from 7 or 8 seconds (3584 or

4096 samples) the error does not decrease significantly. Therefore, 4096 samples will be measured using the ADC at 512 Hz sampling rate.

Communication photoplethysmograph - computer. Once the number of samples needed to take measurements and the mathematical method applied to the signals have been defined, tests are performed with the chosen photoplethysmograph. Through a 192 Hz sampling rate and 10-bit resolution ADC, digitized photoplethysmograph signal is obtained. It is sent to a script in MATLAB by serial communication to perform the calculation of the heart rate (see Fig. 8).

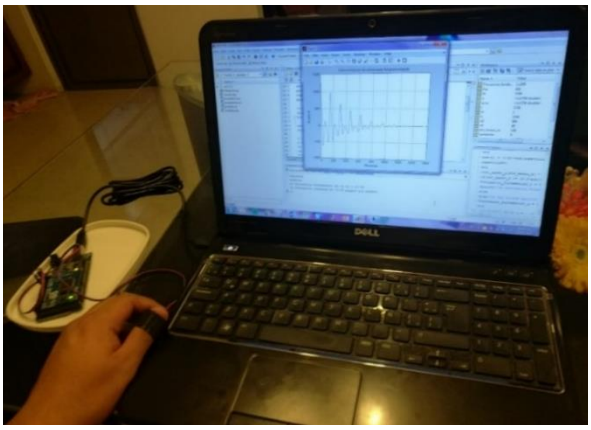

Fig. 8. Communication photoplethysmograph with MATLAB.

The procedure performed after obtaining the signal is the same as that performed with the above photoplethysmograph signal. Fig. 9 shows the graph of the autocorrelation of the windowed signal; the result of the script indicates that the fundamental frequency of the signal is 1.23 Hz, ie 73.85 beats per minute (see Fig. 10).

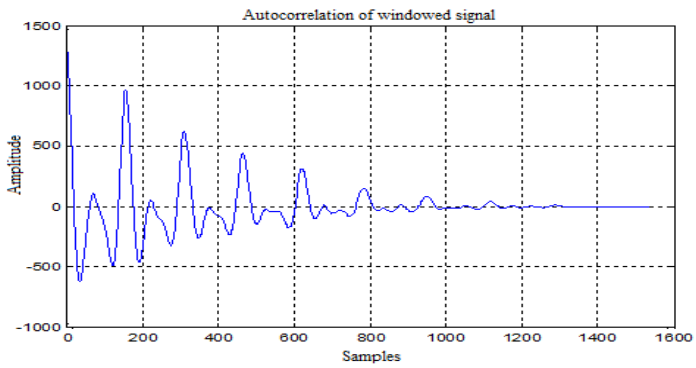

Fig. 9. Autocorrelation of the windowed signal.

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comienza
termina
La frecuencia fundamental de va es 1.23 Hz
La frecuencia cardiaca es 73.85 pulsos por minuto
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Fig. 10. Result of the script on MATLAB.

3 Conclusions

In addition to the fundamental frequency results, the signal obtained by using electrodes to detect heart beats is more susceptible to noise than when using a photoplethysmograph. Since these sensors deliver an analog signal, it must be conditioned with an ADC that complies the medical standards of the CENETEC. The ADC must also be able to communicate with the FPGA, in this case, by SPI. Some sensors like the one used for temperature measuring might have digital outputs. Anyway, an interface is needed to communicate the sensor with the programmable device; in this case, this sensor has an IIC interface.

There are several advantages using an FPGA for the processing of this type of signals; for example, the ability to implement an HDL processor that is not limited to components or ports, plus the flexibility to add or remove components by reprogramming the FPGA and its ability to work in parallel.

Autocorrelation is very useful to find repetitive patterns within a signal, the periodicity of a masked signal under the noise and to identify the fundamental frequency of a signal that does not contain this component, but numerous harmonic frequencies appear from this one. This function has not been used in systems for obtaining vital signs that have been reviewed in this research, since all use the threshold method or that of obtaining the immediate frequency. Nor have we found systems that work with faster communication such as Ethernet or WiFi, which would allow a monitoring of the chosen vital signs in real time.

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