MEDICAL APPLICATION OF EMBEDDED SYSTEMS

Malcheva R.V., Saulenko A.A., Sultan
Donetsk National Technical University, Ukraine

The principle of pulse oximetry is based on the red and infrared light absorption characteristics of oxygenated and deoxygenated haemoglobin. Oxygenated haemoglobin absorbs more infrared light and allows more red light to pass through. Deoxygenated (or reduced) haemoglobin absorbs more red light and allows more infrared light to pass through. Red light is in the 600-750 nm wavelength light band. Infrared light is in the 850-1000 nm wavelength light band.

Keywords: *Pulse Oximetry, LED Driver Circuit and Multiplexer Circuit , Microcontroller*

Introduction

Pulse oximetry is a particularly convenient non-invasive measurement method. Typically it utilises a pair of small light-emitting diodes (LEDs) facing a photodiode through a translucent part of the patient's body, usually a fingertip or an earlobe. One LED is red, with wavelength of 660 nm, and the other is infrared, 905, 910, or 940 nm. Absorption at these wavelengths differs significantly between oxyhaemoglobin and its deoxygenated form; therefore, the oxy/deoxyhaemoglobin ratio can be calculated from the ratio of the absorption of the red and infrared light. The absorbance of oxyhaemoglobin and deoxyhaemoglobin is the same (isosbestic point) for the wavelengths of 590 and 805 nm; earlier equipment used these wavelengths for correction for haemoglobin concentration [1].

1. Pulse Oximeter Principles

A pulse oximeter shines light of two wavelengths through a tissue bed such as the finger or earlobe and measures the transmitted light signal. The device operates on the following principles:

1) The light absorbance of oxygenated haemoglobin and deoxygenated haemoglobin at the two wavelengths is different. To be more precise, the set of associated extinction coefficients for the absorption of light for these wavelengths is linearly independent with great enough variation for adequate sensitivity but not so large that the blood appears opaque to either of the light sources. This model assumes that only oxygenated and deoxygenated haemoglobin are present in the blood.
2) The pulsatile nature of arterial blood results in a waveform in the transmitted signal that allows the absorbance effects of arterial blood to be identified from those of nonpulsatile venous blood and other body tissue. By using a quotient of the two effects at different wavelengths it is possible to obtain a measure requiring no absolute calibration with respect to overall tissue absorbance. This is a clear advantage of pulse oximeters over previous types of oximeters.

3) With adequate light, scattering in blood and tissue will illuminate sufficient arterial blood, allowing reliable detection of the pulsatile signal. The scattering effect necessitates empirical calibration of the pulse oximeter. On the other hand, this effect allows a transmittance path around bone in the finger.

2. Main Components of a Embedded Pulse Oximeter

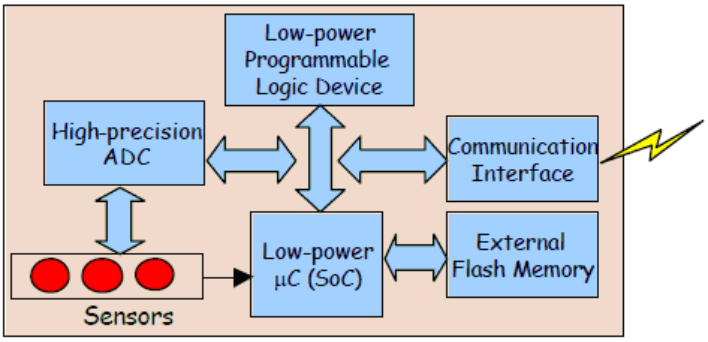

Figure 1. Reconfigurable Medical Sensor Platform

LED Driver Circuit and Multiplexer Circuit:

The pulse oximeter needs two different wavelengths to perform measurements. These wavelengths are generated using two Light Emitter Diodes (LEDs), a Red LED (660 nm,) and an Infra Red LED (940 nm).

Samples cannot be taken at the same time because there is only one photo detector for two signals, therefore signals must be multiplexed. MED-SPO2 includes an analog multiplexor that allows selecting the wavelength to be sampled. LED intensity is controlled using a PWM (Pulse Width Modulation) signal.

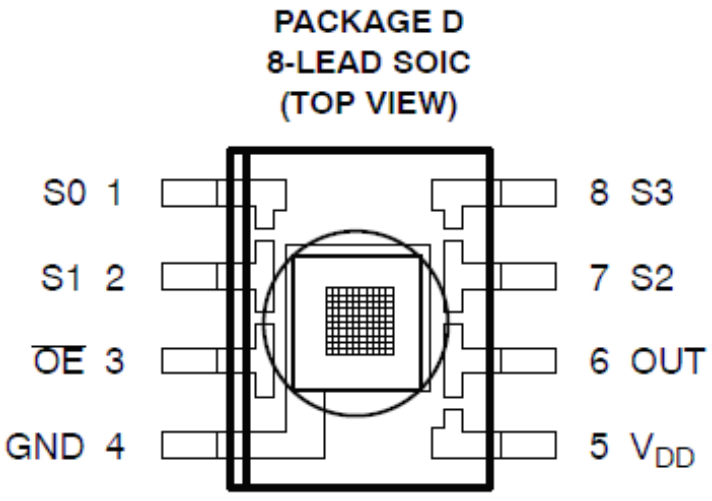

Figure 2. A Light to Frequency Converter

The TSL230RD, TSL230ARD, and TSL230BRD programmable light-to-frequency converters combine a configurable silicon photodiode and a current-to-frequency converter on single monolithic CMOS integrated circuit. The output can be either a pulse train or a square wave (50% duty cycle) with frequency directly proportional to light intensity. Device sensitivity is selectable in three ranges, providing two decades of adjustment. The full-scale

output frequency can be scaled by one of four preset values. All inputs and the output are TTL compatible, allowing direct two-way communication with a microcontroller for programming and output interface. The output enable (OE) places the output in the high-impedance state for multiple-unit sharing of a microcontroller input line.

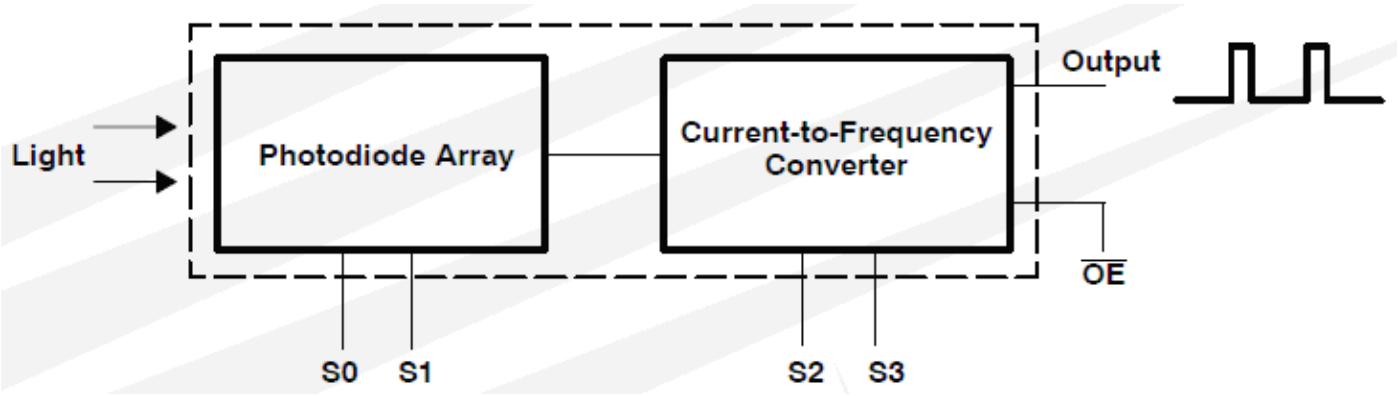

Figure 3. Functional Block Diagram

A Microcontroller:

An implemented pulse oximeter in a single printed circuit board, as represented in fig. 4.

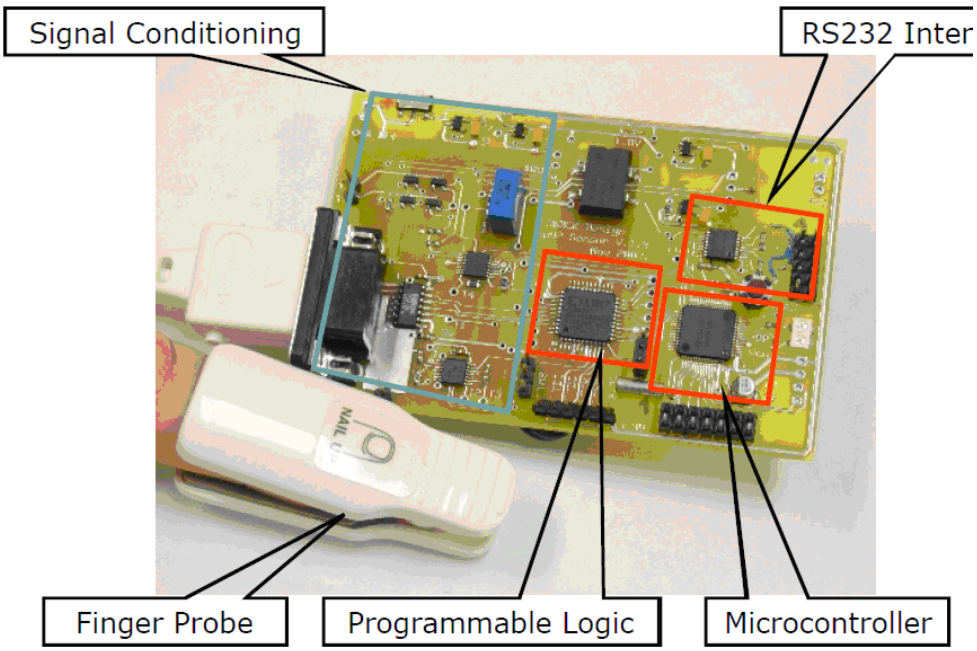

Figure 4. A Pulse Oximeter

The sensor consists of three functional units:

– *Signal conditioning circuit* drives red and infrared diode in a probe, amplifies, and conditions signal generated on photodiode.
– *Programmable logic device* generates control signals for the signal conditioning circuit and synchronization signals for the microcontroller.
– *Microcontroller* with integrated AD converter performs AD conversion, filtering, processing, and communication with the monitoring station.

The signal conditioning circuit amplifies a signal from photodiode caused by red and

infrared diodes and ambient light. As the pulsatile component of the signal does not exceed a couple of percents of the DC value, we amplify the difference between two consecutive samples to a full AD converter range. The microcontroller is responsible for the signal reconstruction. In the current configuration we use a Texas Instruments IVC102U transimpedance amplifier to integrate the current from the photodiode in the finger probe worn by the patient. The advantage of integration is better noise immunity. However, any jitter in the timing of control signals will directly generate an undesired variation of the output values. Since the microcontroller is performing different tasks in real-time, measured jitter of control signals generated variation of the output that was not acceptable. Consequently, we had to generate a precise timing using a programmable logic device. Control signals for the integrator are generated using Xilinx's CoolRunner-II XC2C32 – an ultra low-power CPLD (Complex Programmable Logic Device). The programmable device is controlled by the microcontroller, and it generates interrupts and status bits used for digital signal processing. Due to a variety of technology advances and an innovative design technique called RealDigital, which enables a chip core solely based on CMOS technology, the CoolRunner-II delivers high performance with the industry's lowest power - a standby current is less than 100 micro amps).

Processed results and/or raw signals are output to a PC workstation using a standard RS-232 serial link. We use a custom application protocol for a specialized real-time monitoring program running on a PC. The monitoring program can represent the results of sensor processing in low power sensor mode or display/save raw data received from sensor for debugging and algorithm development. The core of our intelligent sensor is a low-power Texas Instruments microcontroller MPS430F149. The microcontroller features a 16-bit architecture, ultra-low power consumption (less than 1 mA in active mode and about ~1 μA in standby mode), 60KB on-chip flash memory, 2KB RAM, 8-channels of 12-bit A/D converter, and a dual serial communication controller. Internal microcontroller analog channels monitor battery voltage and temperature. Therefore, the sensor is capable of reporting the battery status and temperature to the monitoring program. The microcontroller can directly control JTAG interface of the programmable device -- therefore allowing reconfiguration of the programmable logic.

Conclusion

Pulse oximeters may be used in a variety of situations but are of particular value for monitoring oxygenation and pulse rates throughout anaesthesia. They are also widely used during the recovery phase. The oxygen saturation should always be above 95%. In patients with long standing respiratory disease or those with cyanotic congenital heart disease readings may be lower and reflect the severity of the underlying disease.

This paper describes the hardware implementation to detect the saturation of oxygen in the blood and the pulse rate in realtime.

The design of pulse oximeter proposes the small size, light weight, low power consumption, standardized signal processing, data processing.

Run-time reconfiguration can be achieved through software migration and programmable logic reconfiguration.

References

[1] Reconfigurable Intelligent Sensors for Health Monitoring: A Case Study of Pulse Oximeter Sensor by E. Jovanov, A. Milenkovic, S. Basham, D. Clark, D. Kelley Electrical and Computer Engineering Dept., University of Alabama in Huntsville, Huntsville, Alabama, U.S.A.

[2] http://www.nda.ox.ac.uk/wfsa/html/u05/u05_003.htm#intr

[3] E. Jovanov, A. Lords, D. Raskovic, P. Cox, R. Adhami, F. Andrasik, "Stress Monitoring Using a Distributed Wireless Intelligent Sensor System," IEEE Engineering in Medicine and Biology Magazine, Vol. 22, No. 3, May/June 2003, pp. 49-55.

[4] G. Asada, M. Dong, T.S. Lin, F. Newberg, G. Pottie, W.J. Kaiser, H.O. Marcy, "Wireless Integrated Network Sensors: Low Power Systems on a Chip," in Proceedings of the 1998 European Solid State Circuits Conference.

[5] XILINX, CPLD Products, http://www.xilinx.com/cpld.

[6] J.G. Webster (Ed.), Design of Pulse Oximeters, Institute of Physics Publishing, 1997.

[7] K. Compton, S. Hauck "Reconfigurable computing: a survey of systems and software," ACM Computing Survey, Vol. 34, No. 2 pp. 171—210, 2002.

[8] J.T. Love, S. Warren, G. R. Laguna, T. J. Miller, Personal Status Monitor, SAND97-0418, February 1997.

[9] J. Yao, S. Warren. "Design of Plug and Play Pulse Oximeter," in Proc. 2nd Joint EMBS-BMES, Houston, Texas, October 2002, pp.1752-1753.

[10] Texas Instruments/Burr-Brown, http://www.ti.com

[11] E. Jovanov, J. Price, D. Raskovic, K. Kavi, T. Martin, R. Adhami, "Wireless Personal Area Networks in Telemedical Environment", in Proc. Third IEEE EMBS Information Technology Applications in Biomedicine – Workshop of the International Telemedical Information Society ITAB ITIS 2000, Arlington, Virginia, November 2000, pp. 22-27.