Portable Medical Instruments: Design and Application

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Abstract

Now-a-days there is a tremendous increase in the use of electrical and electronic equipment in the medical field. As a gift of science, digital Sphygmomanometer (for measuring blood pressure) and Glucose meter are now in the hands of common people. Although the digital Blood Pressure Meter (BPM) is a non-invasive device and the Glucose meter is an invasive device, both of them are microcontroller-based devices with the same basic structure. In this review paper we focus on the basic principle of measurement and the building blocks (not the discrete components) of mentioned measuring devices.

Keywords: Digital Electronics, Digital Sphygmomanometer, Glucose meter.

1. Introduction:

We are the people of 21st century, accustom with our hurried life style. As a result, after a certain age most of us suffer from different kinds of diseases. High blood pressure and diabetes are two of them which cannot be cured completely but can be controlled carefully. For the patients who genuinely suffer from high blood pressure, regular monitoring of blood pressure reduces the risk of cardiovascular events [2]. Diabetes mellitus is a worldwide common health problem. According to the statistics available from the World Health Organization, the global prevalence of diabetes mellitus is approximately 155 million, which is expected to increase to 300 million by the year 2025 [1]. There is no cure for diabetes; however, the risk of organ failure can be minimized by keeping the blood sugar (glucose) level under check. So it is necessary to measure the glucose level of a diabetic patient at regular intervals. For our comfort and convenience digital Sphygmomanometer and Glucose meter are now in our hands, thanks to the advancement of electronic science. These devices are portable, cheap and easy to handle. Here we shall discuss the designs of a typical digital Sphygmomanometer and a Glucose meter.

2. DIGITAL SPHYGMOMANOMETER

2.1 Basic Principle of measurement:

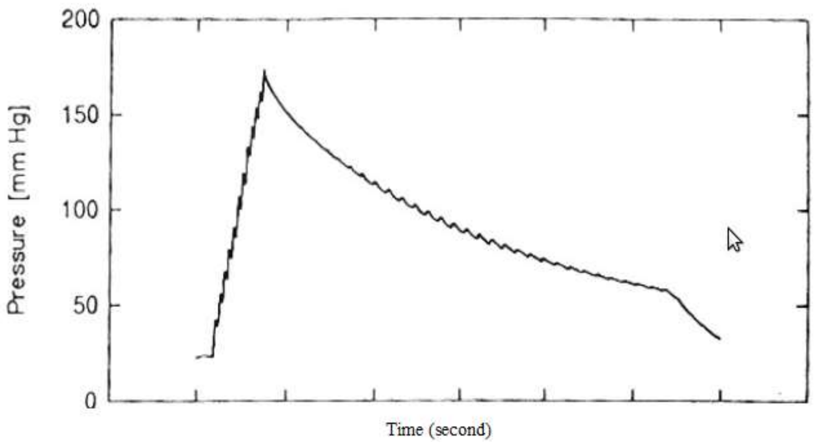

Figure 1: A recording of cuff pressure. The pressure is initially raised rapidly and then lowered slowly [4].

In 1885 the French physiologist Marey observed that, when the arm is placed in a pressure chamber, the air pressure in the chamber fluctuates with the pulse and the amplitude of the fluctuation varies with the ambient pressure in the chamber. It is now known that the amplitude of the fluctuation is controlled by the occluding (choking) effect of ambient pressure on the artery [4]. Marey's observation paved the way for indirect measurement of blood pressure. The indirect measurement, also known as non-invasive measurement, is of two types: (1) Auscultatory method; (2) Oscillometric method. In both the methods, the cuff (an inflatable band) is placed around the arm, rapidly inflated to a high pressure (well above the systolic blood pressure) and then deflated gradually. In the Auscultatory method the first appearance of pulsation is picked-up with a stethoscope placed on the brachial artery; the corresponding air pressure in the cuff is the systolic blood pressure. When the sound disappears we have the diastolic pressure. In Oscillometric method when the cuff is deflated gradually a pressure sensor detects the 'Oscillometric' signal which is then processed to display the systolic and the diastolic blood pressure [2].

2.2 Basic idea of the oscillometric method

This method is employed by the majority of automated non-invasive devices. The principle of the oscillometric method involves the measurement of the amplitude of pressure fluctuation in the cuff as the cuff is deflated from above the systolic pressure. Figure-1 shows that the pressure is initially raised and then gradually reduced in an occluding cuff. Close examination of the curve shows, in the falling edge, the synchronous oscillations present in the cuff. One may suspect that oscillations will appear at the systolic pressure and disappear at the diastolic pressure. But the fact is that the oscillation starts well above the systolic pressure and does not vanish even well below the diastolic pressure. It is seen that the amplitude of oscillation is maximum (A_m) at the pressure P_m (Mean arterial pressure or MAP). Empirical and theoretical work has shown that the systolic and diastolic pressures, P_s (SBP) and P_d (DBP) respectively, occur when the amplitudes of oscillation, A_s and A_d respectively, are certain fractions of A_m:

P_s is the pressure above P_m at which $A_s/A_m = 0.55$

P_d is the pressure below P_m at which $A_d/A_m = 0.85$

Using this method, it is therefore possible to design a device for measuring Blood Pressure.

Note: Typical systolic and diastolic pressures, for a healthy middle-aged person, are 130 and 70 mm of mercury (Hg), respectively, above the normal atmospheric pressure (760 mm of mercury).

2.3 Instrument's block diagram and description:

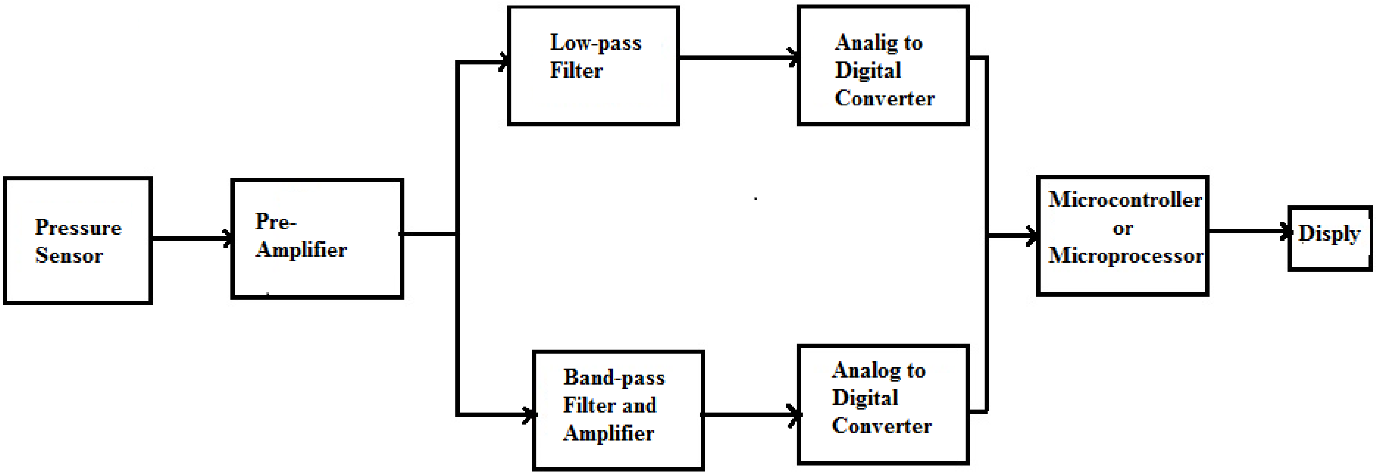

Figure 2: Block diagram of the device [2].

2.3(a) Pressure Sensor:

It is used to convert the pressure to an electrical signal with high accuracy. It must have temperature compensation and offset calibration. A diaphragm and a network of resistors are integrated in a micro-silicon chip to form a pressure sensor. An application of pressure to the diaphragm causes a change of resistance of the network which creates a differential voltage output proportional to the applied pressure [2].

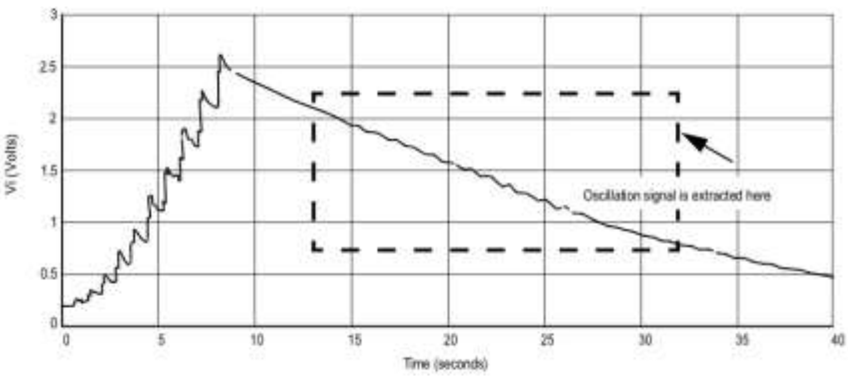

Figure 3: Cuff pressure signal at the output of the pressure sensor [3]

2.3(b) Filter and amplifier:

The output of the pressure sensor consists of two signals - one is the underlying pressure to which cuff has been deflated and the second is the fluctuation present in the cuff pressure. The underlying signal is a low frequency signal (≤ 0.04 Hz) and can be extracted by bypassing the signal through a low-pass filter and the oscillatory signal or the fluctuation (≈ 1 Hz) can be extracted using a band-pass filter [3]. It is inappropriate to drive the two filters directly from the sensor as the signal strength is small and contains some noise. So the sensor output is fed to a preamplifier stage which drives the two filters. These two signals are then amplified by two differential amplifiers.

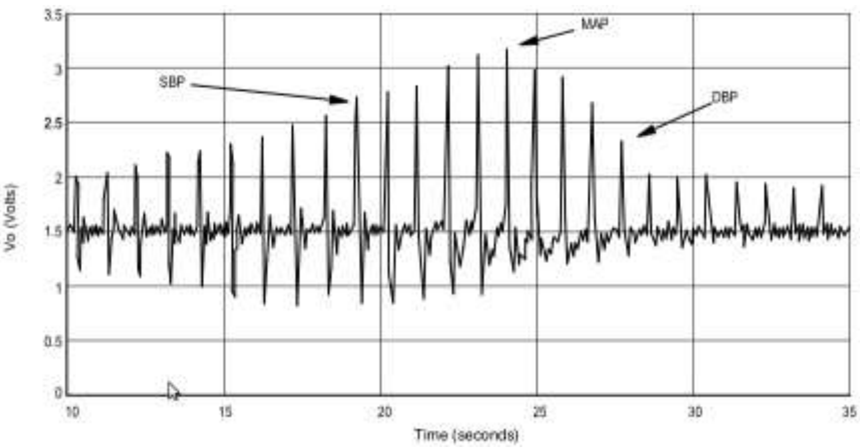

Figure 4: Extracted oscillation signal at the output of the amplifier [3].

2.3 (c) Analog to digital converters:

Now these signals should be digitised for farther processing with sufficient accuracy. An 8 bit A/D converter is used that can produce 256 possible values of the output voltage. As the underlying pressure changes from 0 mm Hg to 375 mm Hg (above the atmospheric pressure) the pressure sensor provides a signal output of approximately 0.2 V dc to 4.7 V dc whereas the amplifier provides a signal from 0.005V to 3.5V [3]. In order to maximize the resolution, separate voltage references should be provided for A/D instead of using the 5V supply. Although it compresses the range of the A/D converter (0V at 0 mm Hg to 3.8V at 300 mm Hg) it maximizes the resolution. On the other hand the 8 bit A/D converter provides 256 levels (~ 0.5% accuracy) to convert fluctuations [4].

2.3 (d) Microprocessor/microcontroller and Display unit:

The final stage is a microprocessor which runs a program to determine the systolic pressure and the diastolic pressure. The fluctuation signal is analysed to determine the maximum amplitude of fluctuations at some point of time. The maximum fluctuation occurs at the time when the underlying pressure is at Mean Arterial Pressure (MAP) value. By reviewing the data the underlying pressure (above MAP) is selected which corresponds to fluctuation amplitude of 0.55 times the fluctuation amplitude at MAP. This underlying pressure is the Systolic Pressure. In the same way the diastolic pressure is measured by finding the underlying cuff pressure (below MAP) when the amplitude of oscillation is 0.85 times the fluctuation amplitude at MAP [4].

The liquid crystal display (LCD) is directly driven from the I/O port on the microcontroller. The programming is done in such a way that when the measurement is successful, a high frequency pulsation tone is heard.

3. GLUCOSE METER

3.1 Basic Principle of measurement:

The glucose meter determines the concentration of glucose in blood. Most of them are based on electrochemical technology where electrochemical test strips are used to perform the measurement. A small drop of blood to be tested is placed on a disposable test strip that the glucometer uses for the glucose measurement [5]. In general there are two invasive methods based on electrochemical technology to measure the amount of glucose in blood- the Amperometric method and the Colorimetric method [6]. Another method is the Spectroscopic method which is a non-invasive method based on optical detection or optical scanning [8]. In the Colorimetric method colour reflectance principle is used. The test trip contains some chemicals or enzymes. As the glucose in the blood sample undergoes a chemical reaction the photo-sensor senses the intensity of a colour in the reaction layer of the test strip. This sensor is followed by a Trans-impedance Amplifier (TIA). But in the Amperometric method the numbers of electrons produced in the chemical reaction are measured. In self-measurement blood-glucose-meters the Amperometric method is mainly used [5].

3.2 The Amperometric method:

In this method, which utilises an electrochemical test strip, a capillary tube that is used to draw in the solution is placed at one end of the test strip. The test strip also contains an enzyme electrode containing a reagent such as Glucose Oxidase. Glucose undergoes a chemical reaction to produce electrons. The number of these electrons is measured and the number is found to be proportional to the concentration of glucose in the blood sample. An ambient temperature measurement is also made in order to compensate for the effect of temperature on the rate of reaction [5]. These electrons then are transferred to an electrode to produce an electrical signal which is then processed, amplified and digitised for a display device by microcontroller.

3.3 Instrument's block diagram and description:

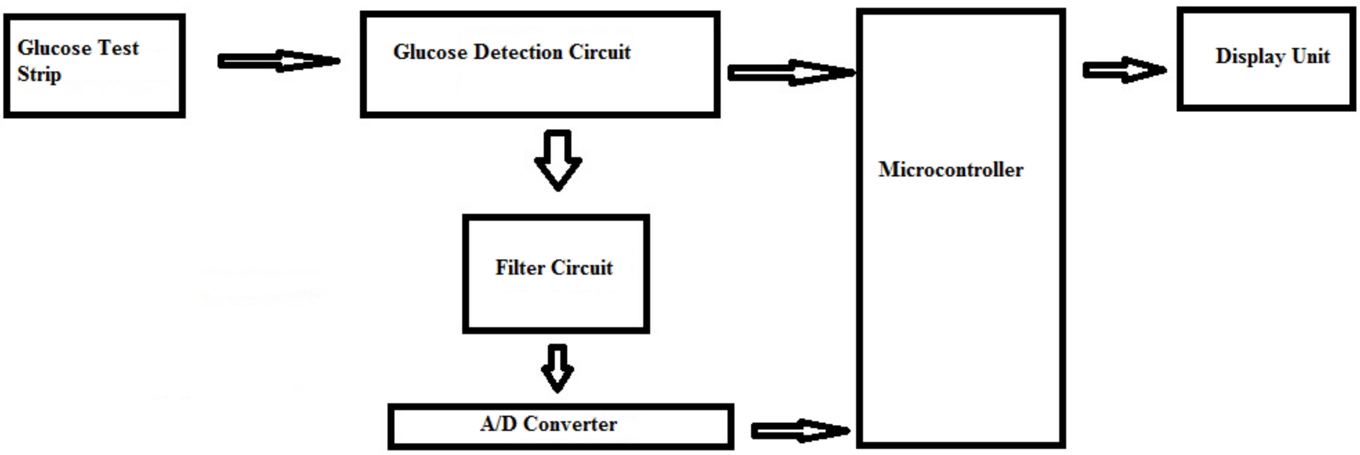

Figure 5: Block diagram of Glucose meter [6].

3.3(a) Glucose Test strip:

The test strip contains the main biosensor or biochemical sensor where the sample solution is applied. A biosensor is a sensor which senses biological or organic material. In the test strip hydrogen peroxide is produced as a result of the oxidation of glucose in the presence of glucose oxidase catalyst. The strips used in this design have three electrodes [7].

The Working Electrode: Electrons are produced here during a chemical reaction. It is directly connected to a current to voltage converter.

The Reference Electrode: It is held at a constant voltage with respect to the Working Electrode to push the desired chemical reactions.

The Counter Electrode: It supplies current to the working electrode [5].

$$\text{Glucose} + O_2 \xrightarrow{\text{Glucose Oxidase}} \text{Gluconic acid} + H_2O_2$$

The Working Electrode senses the number of electrons transferred due to the subsequent conversion of hydrogen peroxide → oxygen + water. This electron flow is proportional to the number of glucose molecules present in the blood sample [6].

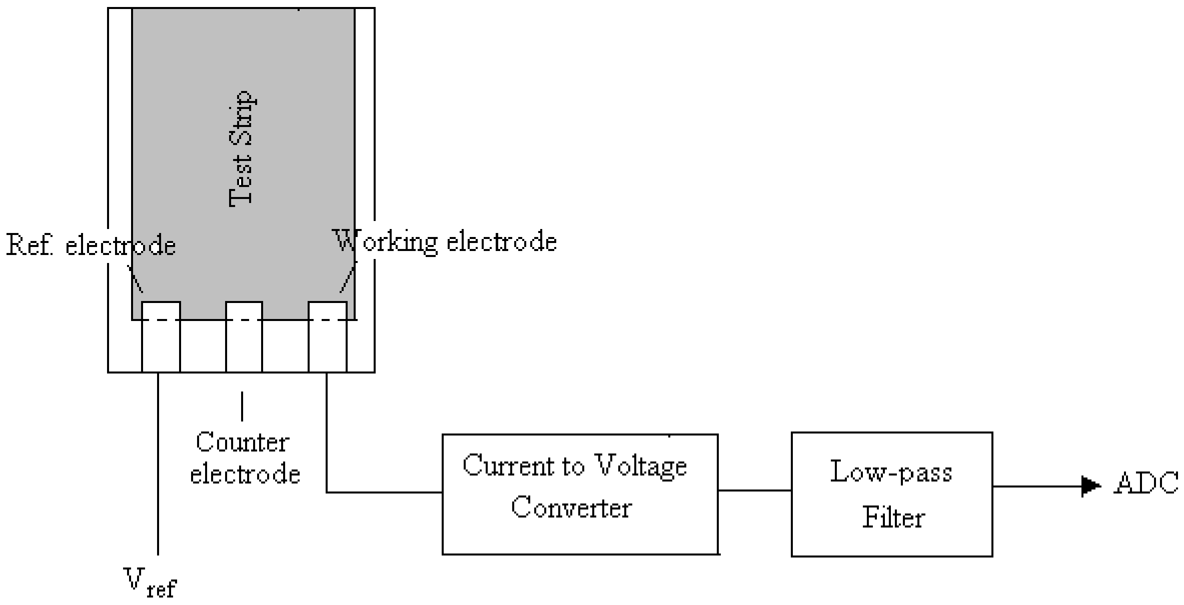

Figure 6: A schematic diagram of the glucose test strip and glucose detection unit meter [5]

3.3(b) Glucose detection unit:

When the test strip is inserted in the glucose meter, the microcontroller senses the presence of the strip. The small current output from the glucose test strip is then converted to a voltage by a current-to-voltage converter. (A current-to-voltage converter is nothing but an OPAMP with a feedback resistor). The OPAMP is used as a high impedance device that forces all of the current to flow through the resistor. The average current I produced by the glucose test strip is in the µA range [6].

3.3(c) Filter Circuit and A/D converter:

The output of the OPAMP is then given to the filter circuit. It can be a Sallen-Key-type low-pass Butterworth filter (with cut off frequency ~100 Hz). This analog signal is then converted to a digital one by a 12 bit ADC module for further processing by the microcontroller [5].

3.3(d) Microprocessor/microcontroller and Display unit:

When a sample is applied to the test strip the voltage jumps to a peak value and then begins to decay linearly between 1 and 5 seconds. The voltage reading is taken 2 seconds after the sample is applied.

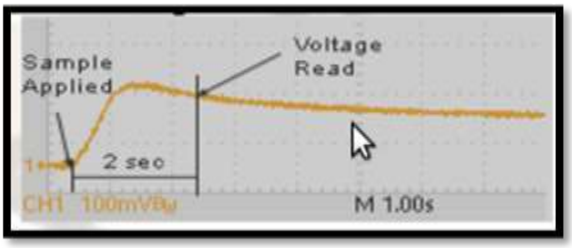

Figure 7: Glucose voltage curve [6]

The voltage level is then converted to a glucose concentration using an equation (the nature of the equation depends upon the sensor) by the microcontroller and displayed in the LCD in units of mg/dl. The microcontroller uses a 5 MHz clock. LCD display is used as it can display any alpha-numeric character and symbol and also consumes less power.

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