REVIEW OF DIFFERENT TECHNIQUES FOR MEASUREMENT OF BODY TEMPERATURE IN BIOMEDICAL INSTRUMENT

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ABSTRACT

*The introduction of new technologies in developing of temperature sensor requires detail study with various aspect. The researchers have been discussed the new technologies for sensing of temperature. The review of this information can put some new idea to develop body temperature sensor in biomedical instrumen***t.**

Keywords: sensors, biomedical instruments

1. INTRODUCTION

A detailed survey has been performed for the sensors previously and currently being used in the biomedical instruments. The newly added technology for the sensing of physiological parameters has been studied from the papers currently published in sensor and biomedical engineering journals. In medical science the structure of the body is known as anatomy and its functioning is known as physiology. The human body contains various types of systems such as electrical, mechanical, hydraulic, pneumatic, chemical and thermal. These systems communicate with each other internally and external environment. Galvani demonstrated that most of the physiological processes are performed with electrical changes. Bioelectrical potentials are generated at the cellular level. The source of these potentials is ionic in nature, surrounding the cell of the body fluids, which are ionic and provide conducting biomedical signal for electrical potential. Electrical potential generated in the cell depends on polarized and depolarized condition. Biomedical signal characteristics like frequency range and amplitude has to be continuously monitored by biomedical instruments to investigate the behavior of the body during abnormal condition. The various sources of the signals generated from the body were studied carefully for studying the anatomy of the body. The range, amplitude and frequency range of the signal analysis were selected properly. The biomedical signal condition during normal operation of the body is known and specified as standard signal conditioning. The recorded data such as body temperature, rate of heart beat rate, pulse rate (standard specification) etc. are compared with the data recorded by the developed sensor (i.e. QRS) for investigation. It has been observed that the various sensors/transducers used in the biomedical instruments have employed electronic components, some electrodes having capacitive or resistive operations. Presently, various sensors having new technology have been developed for biomedical instruments. What is the role of sensors in biomedical instruments? Is it possible to improve the performance of biomedical instruments by replacing existing sensors with other sensors available or sensors specially designed for this purpose?

2. NEED FOR DEVELOPMENT OF SENSORS

Various stages have been observed in the operation of biomedical instruments. The first stage has been observed as measurand. The measurand has been considered as physiological parameters, which generated by the activity of the body. These physiological parameters have been measured during the treatment of a patient. In medical instrumentation system, physiological parameters are sensed by a device known as sensor/transducer. The usefulness of the biomedical instrument depends on the process of how accurately the sensor/transducer converts physiological parameters into measurable form. In the development of biomedical instruments, the sensors/transducers play on important role in sensing the physiological parameters. Standardized data have been collected from the tremendous research that has occurred in the field of medical science.

3. REVIEW OF SOME CONCEPT FOR MEASUREMENT OF TEMPERATURE:

In 1965, J.B. Cronwell suggested the development of matching and linearising thermistor probe for biomedical instruments. He proposed the sensor 'The matching and linearising of thermistor probe' for body temperature measurement. He developed Linistor's method to improve the linearity characteristics of thermistor, but this method was not very effective in temperature measuring instrument. The characteristics of sensor shows non-linearity in the range of body temperature measurement.

In 1969, G.A. Griffiths and D.W. Hill proposed the method for measurement of body temperature. They discussed the method of body temperature measurement and worked for some applications of microelectronics. Silicon diode sensor was used in the circuit for measurement of body temperature. The circuit (sensor/transducer) was designed to monitor body temperature in the range of 34°-40°C with accuracy 2.5%. The temperature sensing element, silicon diode was connected to non-inverting input of operational amplifier circuit. The disadvantages of this method was that diode as a temperature sensor required stable calibration source. It cannot measure the exact body temperature because its characteristic was suffered from surrounding temperature.

In 1974, J. Stockret and B.R. Nave suggested operational amplifier circuit for linearize temperature measured by thermistor. They observed the linear relationship output voltage and temperature from 10°C to 50°C using non-linear characteristic of thermistor as a temperature transducer. This paper discussed the method for calculation and manipulation during the measurement of temperature. The method was not used much due to power requirement the circuit.

In 1974, J.W. Heal suggested the telemetry system of temperature measurement. He observed the relation between temperature in term of mark/space ratio. He has worked on 'A physiological ratio telemetry system using mark/space ratio modulation of a square wave subcarrier. The demonstrator discussed the temperature converted into a.c. signal by oscillator circuit and modulated by square wave subcarrier for transmission. The output information was conveyed as a modulation of the mark/space ratio. The system was used to measure the temperature of a patient's body from a great distance. This telemetry temperature measurement system cannot display the direct read out of temperature at such a distance.

In 1977, T. Krelner suggested PTC thermistor for measurement of temperature instead of NTC. He described the operation of PTC thermistor in the paper titled 'Heat switches the PTC thermistor. He observed that the PTC noted constant resistance at the temperature below the switching temperature, but a rapid increase in the resistance temperatures above the switching temperature. The fact that PTC the thermistor was not suited for temperature measurement in medical instruments because of its temperature switching characteristics, was observed as most non-linear in the range of body temperature measurement .

In 1977, D.A. Christensen developed a new perturbing temperature probe used in medical instrument for sensing the temperature. The title of paper his was 'A new perturbing temperature probe using semiconductor bond edge shift'. The investigator developed a sensor based on the principle of light emitted by LED (light emitting diode) from crystal and transmitted through optical fiber. It was measured by photodetector. No metal part was used in the temperature probe design and this resulted in transparency of the probe to electromagnetic field. It was a single sensor probe with an outer diameter of 0.6 mm and four point temperature sensor probe of 1.2 mm diameter based technique. The temperature sensor has been named as LED used optical fiber the principle of which was based upon the temperature dependence of the band edge absorption of infrared light in (GaAs) Gallinum Arsenide crystal. The variation of band-gap energy with temperature (thermal wavelength shift) has provided a variation in the transmission energy efficiency of infrared light through crystal. The goal of sensor was easy to fabricate, low cost and was used in medical instruments. The size of the semiconductor material was small and it had the capability to convert temperature variation into band gap energy. It was quite new idea but measure the band gap energy of the material in practice cannot be directly possible.

In 1982, M. Sapoff suggested a technique to improve the linearity in characteristics of thermistor used in biomedical instruments. He stated the idea of linearity improvement in the paper titled as 'Thermistor Optimum Linearity Technique'. The material of the thermistors has non-linear characteristics with respect to temperature. For linearising the characteristics of thermistor over a limited range, he employed two approaches :

i] The thermistor is supplied with constant current and voltage across the thermistor used to indicate temperature. Linearization can be obtained by shunting the thermistor with the resistor R_p selected for this purpose.

ii] The current passing through thermistor for a fixed applied potential difference is used to indicate the temperature. The series arrangement is employed with thermistors.

By using this technique the maximum deviation from linearity observed is 0.03°C for every 10°C. The linearity improvement achieved the result in the effective temperature coefficient combination. The temperature coefficient is 3.3%°C for a thermistor when optimally linearized with series resistance. The disadvantages of this technique is that more complex circuit arrangements are needed to achieve better linearization over a wide temperature range.

In 1984, A.M. Scheggi and M. Brenci suggested the technique of optical fiber for medical use. He described the concept of temperature measurement by optical fiber as sensor in the paper titled 'Optical Fiber Thermometer for Medical Use.' Investigators have developed a sensor named Miniature Temperature Probe based on variation of refractive index with temperature. The temperature sensor consists of an optical fiber in which at one end of the layer is liquid crystal. Temperature sensor uses silica -core silicon clad fiber with an unclad terminal potion immersed in liquid, which replaces the clad. A temperature rise causes a reduction in refractive index of the liquid-clad fiber section. Light traveling from the silicon-clad fiber to the liquid-clad fiber undergoes an attenuation which decreases by increasing temperature. The light having wavelength 860 nanometer of light emitting diode (LED) is coupled with the fiber. Light reflected backwards, is sent along the same fiber and the light amplitude modulation induced by the thermo-sensitive cladding applied on distant end of the fiber is detected and processed. This miniature temperature probe sensor used for medical purpose has 0.8 mm external diameter and 0.5 mm internal diameter. Sensitivity achieved was ±0.1°C in the temperature interval 20-50°C.

The application of sensors to control hyperthermia (elevated temperature in the range of 42-45°C) or higher for cancer treatment by electromagnetic energy either in radio frequency or microwave frequency, poses a difficult temperature measurement. Traditional temperature sensor such as thermistors, thermocouples etc have metallic components and connecting wire which perturb the incident electromagnetic (FM) field and may even localize the heating spot and therefore the temperature reading may be erratic due to interference. Investigators have suggested temperature sensors based on fiber optics in which change in the transmission characteristics of the optical fiber changes with temperature. The sensor has typical advantages as flexibility, small dimensions and immunity for electromagnetic interference. The sensor has objectives like non-metallic contact, light source use for temperature sensing. The temperature is converted into light energy and electromagnetic field does not affect the temperature measurement. Hence this technique is more effective in measuring temperature as compared to the temperatures measurement performed by thermistor, thermocouple or semiconductor material .

In 1991, Roger A. Wolthuis, Gordon L. Mitchell and Martin A. Afromowitz developed medical pressure and temperature sensor based on optical spectrum modulation tested by Fabry-Perot interferometer. Fiber optic Fabry-Perot sensors have been developed to measure optical reflectance which varies with optical cavity depth for pressure measurements or change in the refractive index of the material for temperature measurements. Sensors developed using LED, which are designed to operate within single reflectance cycle. Their reflected light is analyzed by a dichoric ratio technique. The sensors use slip index glass fiber and are relatively insensitive to absolute light level and fiber bending. They have linear operating range and can be built for low cost disposable applications. Sensor performance meets or exceeds established medical requirement.

The specific goals achieved by investigators are,

(a) small sensor size, ideally less than 0.1 mm^3,

(b) a single 100/140 mm optical fiber per sensor,

(c) easy of sensor fabrication/manufacture,

(d) low sensor cost,

(e) sensor performance equal to or better than existing American Association of Medical Instrumentation (AAMI) specifications.

4. FEATURES FOR DEVELOPMENT OF SENSORS

In the development of sensors, some general features have been studied and the characteristics of the sensors have been plotted.

- Sensors sense physiological parameters most efficiently and convert physiological parameters into measurable form.
- The size is selected as small as possible due to its utility in medical application.
- The sensor accuracy has to be more for correct measurement. It finds the difference between measured value and the actual (theoretical) value. It has been corresponds to the percentage of full scale output.
- Precision has been observed as the most important feature in the development of sensors. It indicates the degree of repeatability of the measurement.
- Resolution feature indicates the smallest measurable quantity in the scale of sensor.
- Sensitivity is a very important feature of the sensor. It indicates transfer ratio of output to input.
- Drift indicates the change of baseline or sensitivity with time and temperature, humidity or other parameters.
- Linearity has also been considered as an important feature. It shows closeness of a transducer's calibration curve to specified straight line within a given percentage of full scale output.
- Threshold feature indicates the smallest change in measurement that has resulted in a measurable change in the sensor / transducer output.
- Noise has observed as the important feature, which indicates unwanted signals at output due to internal or external source interference with output.

- Hysteresis characteristics are related with change of output with same value of input but output has been observed somewhat different nature of output with respect to input.
- The operating range of sensor has been taken into consideration during development.
- The proper response of sensor has been studied by obtaining the relation between input parameter and output parameter with its graph having positive or negative slopes.
- Saturation level has to be avoided in the development of sensor.
- The conformance indicates the response close to specific characteristics in the measurement.
- The sensor has to be inexpensive and easy to handle for the user in medical instruments.

Temperature Sensor:-

A silicon diaphragm acts as an optical reflectance cavity. The designing of an LED - micro shift temperature sensor based on silicon was pursued. As the temperature changes the refractive index of silicon changes. This index change is substantial when observed with light near the band gap of silicon e.g. in an LED source with 850 nm, the refractive index change with temperature is several times larger than other changes occurring within silicon. As the refractive index of silicon changes, the spectral reflectance of each LED wavelength also changes. These reflectance changes occur within a sensor reflectance cycle and are of the same order of magnitude as seen for the pressure sensor. A single crystal having a thickness of 0.8 mm provides a more than adequate linear range for medical temperature measurement. In pressure and temperature sensor, the pressure or the temperature is changed to diachoric ratio.

$$\text{Diachoric ratio} = \frac{1}{2} + \frac{2}{\pi}\left(\frac{(1-k)\sin\Delta'}{2k-(1-k)\cos\Delta'}\right)$$

where $\Delta' = \pi(\lambda c - \lambda c')/2W$ and $W = W_L = W_S$

The sensor performance goal have been largely met or exceed by the data presentation.

In 2003, Francesco Chiadnmi, Alfredo Paolillo and Antonio Scaglione developed the reflect metric optical fiber sensor used for temperature measurement in medical instruments and it has been characterized. The sensing probe is obtained by replacing the cladding with temperature sensitive liquid on a short length of fiber. Its reduced dimension is suited for monitoring application where a high spatial resolution is required. A sensor is based on a ray tracing technique. The response of the sensor is very good in terms of accuracy, above all and response time.

The sensing element was realized on a TESC hard clad 600 mm optical fiber (silicon core n_{co} = 1.457 and plastic cladding n_{cl} = 1.368) by locally modifying its cladding. A short section of the fiber cladding was removed and replaced by a liquid with suitable refractive index n_{mcl} (modified cladding). A temperature variation in the liquid acts as a localized change of the cladding refractive index and thus is modified along the fiber. The large diameter of optical fiber core (600 mm) is used to study the sensor as ray optic model. A ray propagating through the sensing element suffers power loss when partial reflection occurs at the modified cladding/core interface. The amount of reflection depends on the refractive index of the modified cladding n_{mcl} and consequently on the temperature. Hence power transmitted by the sensing element depends on the length of the element and on the temperature of the modified cladding.

Reflectometric temperature has a relationship between temperature and power coming out from the field. The sensor is excited by replacing the fiber input end in front of the glass window of a 5 mW laser diode (LD) operating at visible wavelength (l = 635 mm). The equilibrium is achieved at input section of sensing element. A strong mode scrambling is introduced by wrapping the sensor fiber several times around a 2 cm diameter cylindrical post. The normalized intensity distribution is measured along a diameter of the output fiber end (near the field) and along the diameter of the cross section of the beam coming out from the fiber at 0.75 cm from the fiber tip respectively.

The system is based on INTEL™ MCS96 microcontroller which has following features. The measurement software is composed of data acquisition interrupt service routine, external command interrupt service routine, and main program.

The experimental

characterization showed that the resolution obtained is 0.1°C and sensor static characteristics is similar to transmission sensor. The new sensing element is characterized by small dimensions of the reference tank. Noticeable improvements in both dynamic performance (4.5-5 times constant) and spatial resolution (0.03 m) were obtained. A comparison with data reported that the resolution of the sensor exhibited by the proposed sensor on the investigated temperature range is comparable to most popular alternatives. The spatial resolution and the time constant appear to be suitable for applications requiring large volume monitoring.

In 2003, Shr-Lungchen, Chien-Hung Kuo, Shen-Iuanlia developed the CMOS magnetic field to frequency converter with high resolution. It composed of two voltage-controlled ring oscillators whose output frequency differences linearly vary with the magnetic field perpendicular to the chip surface.

The prototype circuit has been fabricated in a 0.5 gm CMOS process and operated at 5V supply voltage. The measured sensitivity is 24 KHz/mT and power consumption is 5.1 mW. The small equivalent resolution of at least 20 GT can be achieved. The frequency offset is 42 Jz when no magnetic field applied. Its non-linearity within ±120 MT is smaller than 0.56%.

Magnetic sensor is a transducer, which can convert a magnetic field into a corresponding electrical signal. Investigators have investigated highly sensitive magnetic field sensor with frequency output using magnetic MOSFET (MAGFET). They integrate the magneto operational amplifier (MOP) with two voltage-controlled ring oscillators to realize the magnetic field sensor. MOP is a conventional folded-cascade amplifier except that the NMOS current sources are replaced by MAGFET arrays as a sensing element and aspect ratio of each MAGFET device is chosen to be W/L = 80 mm and d = 2. The bias current of the MAGFET is 700 mA and power consumption of the chip depends on MOP. When two magnetic fields are applied, the output of drain currents of MAGFET are equal which means the voltage between two differential outputs of MOP is zero. This condition decides MOP work as operational amplifier. When a perpendicular magnetic field is applied, there is current imbalance between two drains. The voltage difference between differential outputs Vout+ and Vout- will be general. A magnetic field induced voltage is added to the input of the MOP.

Output voltage of MOP can be expressed as -

$$V_{out+} - V_{out-} = A \cdot (V_{in+} - V_{in-} + V_m)$$

A is the finite dc gain and Vm is induced voltage.

The oscillating frequency of the sensor is,

$$f_{osc} = 1/N \times T_D$$

where, T_D is delay time and N = 3 for compromise among power, speed and chip area.

The experimental result shows that a measured output frequency difference is obtained by averaging five measurements. The coarse measurement results in the range of ±120 mT and magnitude incremental is 10 mT. A linear response owing to the magnetic field can be obtained. The calculated sensitivity is 24 KHz/mT. The linearity is also maintained in the range of ±0.2 mT with 20 mT increment. The real resolution should be much smaller. The accuracy of instrument is restricted, as the change of magnetic field smaller than 20 mT could not be generated. Only for the dc magnetic field, cut off frequency for the magnetic signal is low. The minimum detectable magnetic field of the circuit under dc excitation is limited by l/f noise and not thermal noise. Output frequency with no magnetic field corresponds to center frequency 42 KHz. The sensor has shown improvement in sensitivity over previous report, using MAGFET. A highly sensitive magnetic field sensor sensitivity of 24 KHz/mT is presented. This sensor can detect the magnetic field smaller than 20 mT. Sensor has merit and fine resolution. The frequency output is further processed by digital signal processing circuit such as micro-controller to achieve the high resolution.

In 2003, Rachel A Yotler and D.M. Wilson have reported the photo-detector for sensing light emitting reporters in biological systems. They used photo-detector devices for optical detection in biological applications. Investigators have studied the characteristics such as biological stimulus, optical pathway.

Photo-detectors operate on the transition of an electron having a lower energy state to higher energy state because of the absorption of a photon. The energy transition has classified into the following categories.

a. ***Photo-conductive or photo-volatic :-*** The electron undergoes a transition from valence band to conduction band. In photo- conductive devices, the photons generated charge carriers that lower resistance of the device.
b. ***Photoelectric (Photo-emissive) :-*** The electron undergoes a transition from the conduction band to a vacuum. One electron is released into the vacuum per photon of sufficient energy.
c. ***Polarization :-*** The electron undergo a transition to virtual energy state. (as in the changes of refractive index and other polarization effect.)
d. ***Phonon generation :-*** The electron undergoes a transition to midgap states and back to an initial relaxed level. This is equivalent to heat generation.
e. ***Other :-*** The energy is converted into other forms such as excitation.

Direct photo-detectors convert incident photon into electrical signal without any intermediate transduction stages. These detectors include photo-emissive, bulk photoconductive, junction- based. Direct photo-detectors operate using three basic processes such as carrier generation by incident light, carrier separation, transport and multiplication and collection of current by external circuit. Indirect optical sensors have at least two transduction stages, which do not provide the sensitivity in visible light range to be applicable in bio-sensing application.

Avalanche photodiode (APD) is the most sensitive solid state device available of being miniaturized for micro -scale devices, The disadvantages of this device include high operating voltage a need for complex circuitry, continuous photon requirement for operation APD devices and implementation of a mode of operation similar to that of used for PMT.

APD are also P-type-Intrinsic-N-type (p-i-n) diode structures, which are required at reverse bias voltage. In this device, photogenerated carriers required for signal multiplication are obtained from the electric field. The secondary carriers are also operated by the electric field and they generate other electron-hole pairs. APD p-i-n photodiode operated at large reverse voltage and ionization coefficient of electrons and holes $a_n(E)$ and $a_p(E)$ in cm^{-1} respectively. The ionization coefficients are constant throughout the depletion region and the Avalanche multiplication factor is,

$$M = \frac{[1 - \frac{\alpha_p}{\alpha_n}] \ \exp [\alpha_n W (1 - \frac{\alpha_p}{n})]}{1 - (\frac{\alpha_p}{\alpha_n}) \exp \ [\alpha_n W (1 - \frac{\alpha_p}{\alpha_n})]}$$

W is width of the depletion region.

The avalanche multiplication processes also introduce avalanche noise called excess noise. The noise is result of the random nature of the avalanche multiplication process of electron-hole pair generated at random location; the depletion region does not experience the same multiplication.

The excess noise factor F is given by,

$$F = M(\frac{\alpha_p}{\alpha_n}) + (2 - \frac{1}{M}) \ (1 - \frac{\alpha_p}{\alpha_n})$$

when $a_p = a_n$,the noise factor is maximized and equal to M. On the other hand, if one of the ionization coefficients is zero i.e. $a_p = 0$, then noise factor is equal to 2. Complicated APD structures have been developed in order to reduce one of the ionization coefficients and thus reduce noise factor. APDs are expensive to manufacture and they require complex temperature compensation and supply voltage stabilization circuitry. Quantum efficiency in APDs can be greater than 90% at the peak wavelength response. Hence the primary photocurrent generation mechanism is highly efficient. Avalanche gain is accompanied by noise, which is worse than that of a photomultiplier.

Photodiodes appear to be the choice for use in biological applications because they are inexpensive, easily miniaturized and can be implemented in array. They are not as sensitive as APD or PMT. Many biological sensing applications produce enough light to be easily detected by photodiodes. In photovoltaic operations more light intensity is required to generate a change in voltage large enough for detection. It is therefore unsuitable for low level light intensity.

Photoconductive mode is more sensitive for low level light intensity and can be applicable for biological applications. In photoconductive mode, a reverse biased voltage is placed across junction and reverse current increases when photons are absorbed within depletion region. Although electron pair generation occurs with the absorption of photon in or near the depletion region, which contribute, to the signal current, an electron-hole pairs generated close to depletion region may diffuse into depletion region and be collected. The charge separation results in a potential difference across junction decrease the built-in potential barrier (forward bias junction).

The electric I-V characteristics of photodiode describe as

$$I = I_s [\exp (qv/kT) - 1] - i_{ph}$$

where, I_s - saturation current, i_{ph} - current resulting from photon generation, V - applied voltage bias, k - Boltzmann's constant, T - absolute temperature, q - electron charge.

The I-V characteristics shift of p-n junction is lowered and therefore, results in increased reverse current.

A p-i-n photodiode is a photodiode with a highly doped region at the p-n junction. The architectural efficiency increases the depletion width, which results in a higher collection efficiency. Therefore, the incoming photons are more likely to generate electron-hole pairs. It also lowers the junction capacitance and increases transit time. Less junction capacitance reduces the RC time constant of the degree; longer transit time limit the overall time response of the device. Investigators observed that photodiode speed is mainly determined by three factors; diffusion time of carriers generated outside the depletion region which are close enough to diffuse into it, drift time in diffusion region and junction capacitance.

In short, the designing of a high-speed microscale biological system, the samples flow through multiple parallel micro-channel. This architecture is integrated with photodiode array. The arrays are fabricated in a silicon substrate. Integration with signal processing circuit becomes trivial. The development of micro-channel arrays integrated with photodiodes in silicon and these devices have the potential for achieving high throughout processing of biological sample CCD (cold charge device) become popular choice in biological applications.

6. Existing temperature measuring / monitoring system for human body

a. The body temperature is measured by expansion of mercury (Hg) in a glass capillary. Calibration and conversion was required for measurement of temperature, which is a difficult task.

b. Thermocouple is a junction of two different material wires, which is formed by two or more junctions. One junction is cold or reference junction (kept at 0°C) and other junction is hot or measuring junction. Thermoelectromotive force (emf) generated across wire is developed current in the circuit. The emf generation range is in millivolt with respect to temperature Copper-constant. A combination of thermocouples is preferred for medical application. In this construction, a one junction is kept at 0°C while other is kept at 37°C. An ice bath is used to maintain constant temperature, which is a major drawback in measuring system.

c. The temperature dependence of resistance of certain metals (platinum or nickel) makes it convenient to construct temperature transducer for biomedical instruments. Most of the metal resistance depends on temperature. Thermometer constructed from coil of the metals is used for skin, rectal and oesophageal temperature measurement. The coefficient of resistivity of platinum is 0.004 W/°C. Practically the measurement of resistance with respect to temperature is quite difficult because circuit resistance and electrochemical changes affect the resistance of metal during measurement. The temperature coefficient is very small.

d. Thermistors :- Thermistors are the oxides of certain metals like manganese, cobalt, nickel which have large negative temperature coefficient (NTC) of resistance. The sensitivity is about 4% change in resistance per degree. This device is a better solution for the measurement of temperature in medical applications. However a major disadvantage observed here is that, the resistance of thermistor is exponentially changes with respect to temperature. In a temperature-measuring instrument, resistance should change linearly with respect to temperature. The thermistor is a better solution for sensing of temperature, but its characteristic has to linearized by some technique.

The researcher has proposed the technique for linearization of characteristic of thermistor. For this purpose, the review is made for various techniques used for linearization the characteristic of thermistors.

e. Other temperature sensors :- Other sensor characteristics have also been studied for sensing the temperature. These sensors are like semiconductor material devices, photoconductors, photoemitters, optical fibers the characteristics of which depend on temperature. In the body temperature measurement technique, it is observed from a review of sensors/transducers skin surface temperature measurement is more effective.

7. Clinical temperature measurement technique

Clinical temperature measurement is performed using two concepts, one is skin surface temperature measure and other is core temperature measure. The tympanic membrane connected to outer ear and middle ear is an ideal location for temperature measure. Conventional methods of measuring temperature are on the surface or inside the tissue. Sensors like thermocouple and thermistor are employed from measurement of body temperature. C.P. Cain and A.J. Welch suggested some rules for measure of body temperature.

a. The bead and leads should be as small as possible within required strength limitation. They developed a micro thermocouple thin film deposited quartz filament. Recently Chato suggested a glass or quartz encased thermocouple junction that can measure the temperature for biomedical instrument with a of size range of size 10 to 50 cm.

b. The wire leads should be placed along the isotherm going through measuring junction for as long a distance as practicable.

c. For surface temperature measurements, the surrounding air should be kept at or near the same temperature, as the surface of skin and surface should be dry.

8. Surface temperature measurement

Radiation from the skin surface is the main mechanism of the body heat loss from the body. In 1996 Guyton and Hall discussed about the body heat loss under normal conditions. He stated that the body heat loss is 60%. The relationship between the energy emitted from the skin surface and skin temperature forms the basis of surface temperature measurement. The surface temperature is determined by skin blood supply and condition of subcutaneous tissues and it is good indicator for bone fractures and inflammation. Abdominal placement of a thermal sensor (thermistor) for skin temperature measurement is important in neonatal monitoring against cold stress. Medical thermography is a technique to scan the skin surface and map its thermal distribution. Physicians have used this technique to diagnose tumors or breast cancers.

9.Core temperature measurement :-

Core temperature measure is a routine method in hospitals or clinics or even at home. It can detect fever caused by pathogen released from virus, bacteria or by degradation of the old tissues. Body temperature rise from 41°C is caused the brain damage or other internal organs, which are vital to human life. Therefore, core temperature measurement should be accurate and quick. Temperature measurement varies from site to site. In 1995, While Bair and Davies reported that temperature measurement at the pulmonary artery reflects the best core temperature in critically patient monitoring. Rectal or tympanic temperature measurement is quite reliable and is less dangerous, low cost and more accessible.

10. Temperature monitoring system

Temperature monitoring system uses thermistor or thermocouple probes for body temperature sensing which may be esophageal, rectal, cetaceous, subcutaneous, intramuscular measurement and in cardiac caters.

Temperature monitoring system comprises of the following:

- Sensor or transducer to sense the body temperature.
- Temperature is converted into measurable form by manipulation of circuit or signal conditioner.
- It must always be kept into mind that the biomedical temperature range for body temperature measurement is 30-42°C
- The circuit of manipulation i.e. amplifier should be isolated from the patient body.
- The display part is in the form of calibrated scale, digital read out.
- For continuous monitoring a microprocessor or microcontroller employed in temperature monitoring system.

The temperature monitoring system becomes accurate and sensitive only when the temperature is sensed by the sensor with true value and sensitively. Therefore, there is need to study and review the various techniques used to sense the body temperature.

11. Characteristic of thermal resistance materials:

Variation in resistance of material with temperature is used in constructions of resistance thermometer. It is observed. The resistance of most of the metals varies with temperature. that the Platinum material R-T characteristic is linear, but its sensitivity is quite low in the measurement of temperature. The R-T characteristics of various metals are shown in Fig. 4.8.

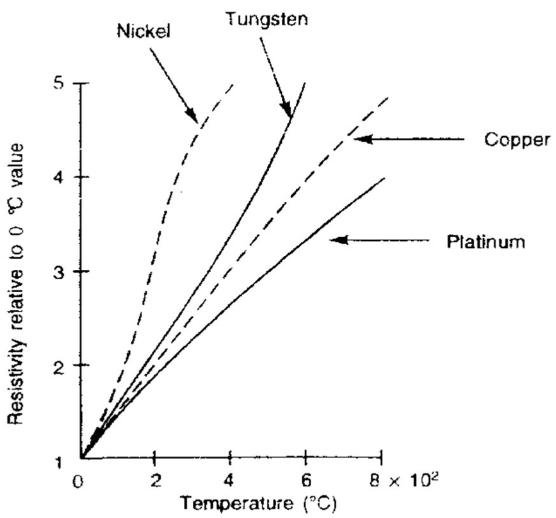

Fig. 4.8: R-T characteristics of metals.

12. Characteristics of Thermocouple:

The characteristic of thermocouples is studied for emf as an output versus temperature as input in degree. The two important facts considered from this graph (i) sensitivity (slope) of each curve for the materials of thermocouples are different (ii) none of the curves are perfectly linear at the rate of change of emf output per degree. Thermocouple characteristics of various thermocouple materials are shown in Fig. 4.9.

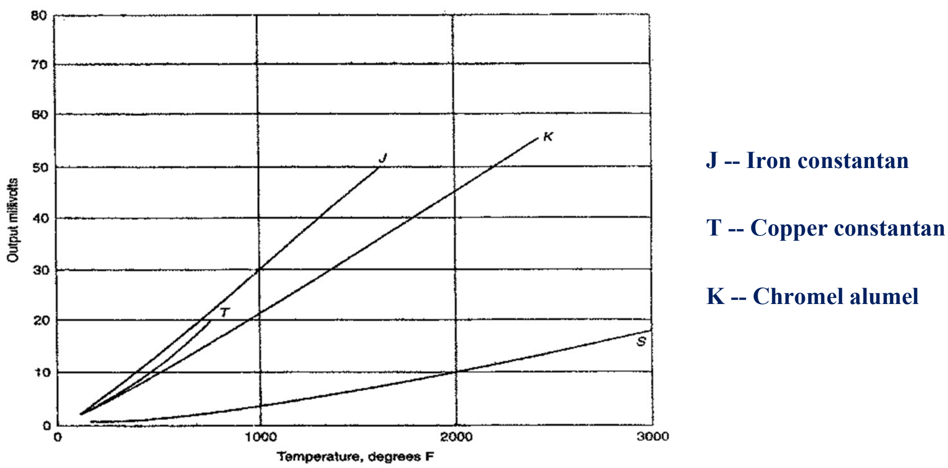

Fig. 4.9 : Characteristics of thermocouple materials.

13. Thermistor characteristics with NTC property:

Some thermistor materials (oxide of metals) have negative temperature coefficient (NTC) property. Thermistor resistance changes with temperature in degrees, is observed to be highly non-linear. The R-T characteristic of metal oxide material of a thermistor used in temperature measurement required linearization as shown in Fig. 4.10.

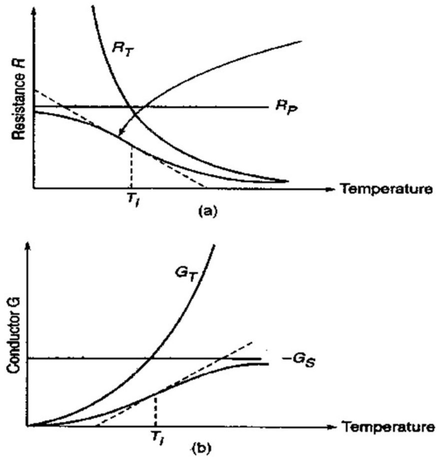

Fig. 4.10 : Linearization of thermistor characteristics with NTC property.

14. Thermistor characteristics with PTC property :

PTC thermistor exhibits a remarkable high variation in resistance with increasing temperature. Important considerations are observed from the graph shown in Fig. 4.11.

i) Resistance change is almost constant before the switching temperature.

ii) Resistance change is rapid above the switching temperature.

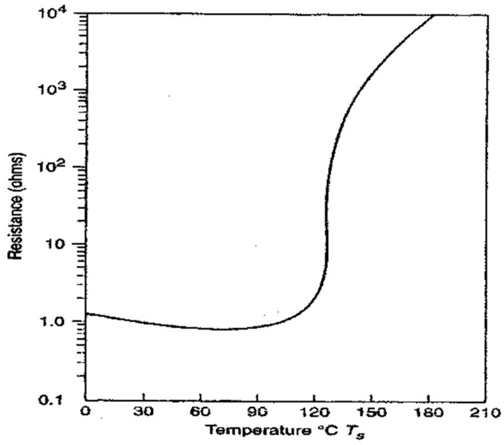

Fig. 4.11 : Characteristic of thermistor with PTC

15. LED characteristics for temperature measurement :

The variations in output power over the temperature range 0-40°C for a ridge wave guide device providing latter current confinement is shown in Fig. 4.12. The non-linear nature of output characteristic is observed at 0 - 40°C. This limitation is not useful in selecting LED as a temperature sensor/transducer.

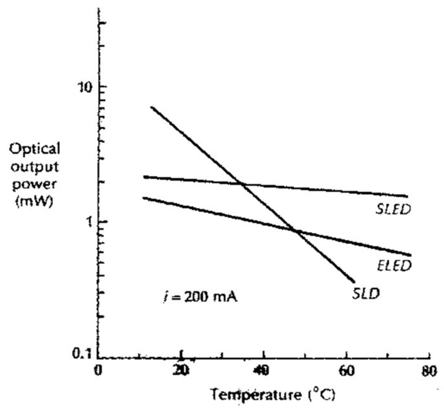

Fig. 4.12 : Temperature LED characteristics.

16. Temperature response of LM Series National Semiconductor Temperature Sensor :

LM 35 series are integrated circuits, which are designed to measure temperature for medical instruments. The output voltage is linear and proportional to temperature in degrees. In this sensor the quiescent current is measured with variations of temperature as shown in Fig. 4.13.

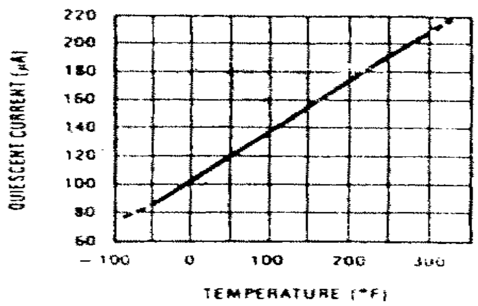

Fig. 4.13 : Temperature characteristic of LM 35 sensor.

17. Characteristic of Photodiode :

The magnitude of photocurrent depends upon the number of charge carriers generated on illumination diode element. This current is also affected by the frequency of light falling on the junction. The photocurrent varies with the illumination of light is as shown in Fig. 4.14. Dark current is minimum and it is reverse leakage current. Germanium has higher dark current than silicon. Photodiodes are used as light detectors.

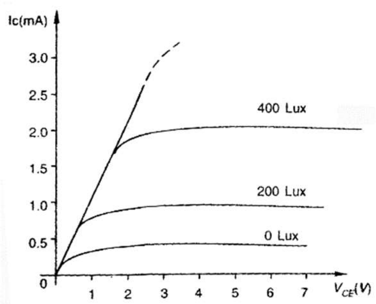

Fig. 4.14 : Characteristics of photodiode.

18. Characteristics of Phototransistor :

The current in the phototransistor depends mainly on intensity of light entering the lens and it is less affected by the applied voltage to the external circuit. A graph of collector current Ic, is a function of collector-emitter voltage and illuminations of light in lux. Characteristics are shown in Fig. 4.15.

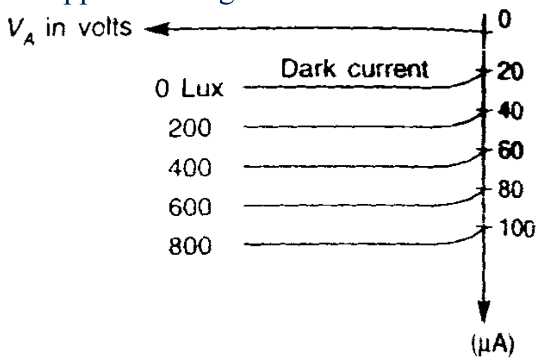

Fig. 4.15 : Characteristics of phototransistor.

Phototransistor current response finds extensive high speed as compared to current response photodiode and LDR. It is used in high-speed applications.

19. Spectral characteristics of semiconductor material :

The spectral response of silicon, germanium and selenium is shown in Fig. 4.16. The spectral response of silicon and germanium is well in infrared region and its efficiency is quite high. But selenium has two advantages (i) its spectral response is almost similar to that of human eye. (ii) It has the ability to withstand damaging radiation environments lasting up to 10,000 times longer than silicon. Therefore, selenium material is best photoconductive material with respect to silicon and germanium.

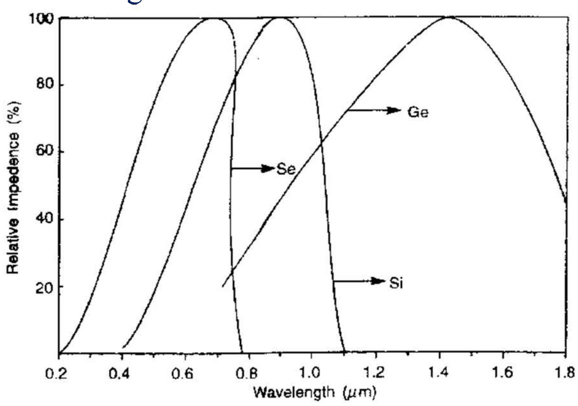

Fig. 4.16 : Spectral characteristic of semiconductor material.

20. Spectral response of silicon diode :

Diode arrays are assemblies of individual detector elements in linear or matrix form, which in the spectrometers can be mounted so that the complete spectrum is focused on to an array of appropriate size. The photodiode array is PMOS (p-channel metal oxide semiconductor) integrated circuit that is over 1.25 cm long. Each photosensitive diode in array is 0.05 to 0.5 mm and has a spectral response that extends well beyond the 200 to 800 nm range. It is shown in Fig.4.17 The diode arrays exhibit a leakage current less than 10 pA, but current increases exponentially with temperature and so it cannot used to measure temperature in biomedical instruments.

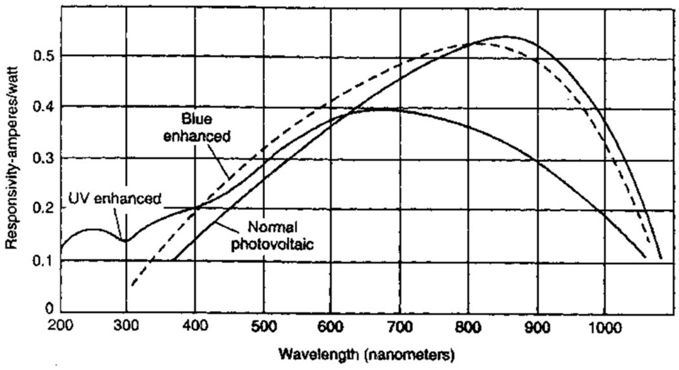

Fig. 4.17 : Spectral response of silicon diode.

21. COMPARISON OF EXISTING Temrerature SENSORS

Comparison of existing sensor for temperature measurement in biomedical instruments

Sr. .	Parameters	Thermal resistance	Thermocouple	Thermistor (NTC)	Thermistor (PTC)	Optical sensor
1.	Sensitivity	0.004 %/°C	21.4 mV/°C	4% change in resistance/°C	0.01 □/□°C	± 1°C
2.	Linearity	Good	Medium	Non-linear	Most non-linear	Fair
3.	Range for measurement	Platinum resistane-200 to 600°C	Copper constantan -150 to +350°C	10-50°C	0-120°C	20-50°C
4.	Technology of construction	IC	IC	IC	IC	Core
5.	Output	Resistance	Volt	Resistance	Resistance	Refractive index
6.	Digitalization	Conversion	Conversion	Conversion	Conversion	Conversion

22. CONCLUSION

The study of various concepts of sensors/transducers used for the measurement of body temperature in biomedical instruments is carried out during study. The detailed study of the characteristics of existing sensors/ transducers is highlighted. This Study helps the researcher to design the new sensor for measurement of body temperature in medical instruments using electronics devices such as LED,LDR,UJT The F-T (Frequency-Temperature)characteristic is observed most linear as compared to the existing sensors used in biomedical instruments to measure medical temperature. The researcher can developed the sensor/transducer to measure body temperature. The effectiveness of the developed body temperature sensor/ transducer is compared with existing sensors/transducers such as thermal resistance, thermocouples, thermistor with NTC and PTC properties, optical sensors and LM35 used in biomedical instruments. The linearity in R-T characteristics and sensitivity are observed as compared to existing sensors in temperature.

21. REFERENCES

Ackerman S.W and Weith P., (1995), Knowing you pulse oximetry monitor, Medical Electronics 3, 82.

Allen J, (1978), NTC Thermistor Microprocessor, Measurements and control, April 1978, 7.

Anbar M, (1978), Clinical thermal imaging today, IEEE, Eng Med and Bio, 19, 4- 25.

Bair while and Davis, (1995), Temperature measurement at the pulmonary artery reflects monitoring, Bio Med. Eng. 13(2), 231

Benders D, (1976), Electro Surgery Interface: Minimize its effects on ECG monitors, Hewlett Packard Application Note, 743.

Benz P D, (1999), Ambulatory cardiac event recorder, Med Electronics, Sept 1999, 38.

Bom N C T, Lances G, Van Zwieten, F E Kloster and Roelandt, (1973), Multiscan echocardiography, Technical description, circulation, 48, 1066.

Branthwaite M A and R D Bradley, (1968), Measurement of cardiac output by thermal dilution in man, Jorn Appl Physiology, 24, 434.

Brimbal M and J C Robillard, (1990), Thermal Array Recorder, Medical Electronics, April 1990, 100.

Burbank D P and Webster J G, (1978), Reducing skin abrasion, Med Bio Engg. and compute, 16, 31.

Cain C P and Welch A J, (1974), Thin film temperature sensor for biological measurement, IEEE Trans Bio Medical Eng., BME, 21, 421-423.

Carter L M, (1978), The clinical role of thermograph, Jorn Med Eng and Tech, 2, 125.

Chazal P de and Reilly R B, (2006), A patients Adapting Heart beat classifier using ECG morphology and Heart-beat Interval Features, IEEE Trans on Bio Med. Eng. 52(12) – 2532.

Chen M M, Pedersen C O and Chatto J C, (1977), On the feasibility of obtaining three dimensional information form thermographic measurement, Trans ASME Journal Bio. Mech. Eng, 99, 58-64.

Cheng E M, W.H. Ko, R J Lorig, W.D Beveridge, J S Broadkey and F E Nulsen, (1975), Intra cranial pressure and temperature telemetry system using asynchronous PFM's with RF shifting for multiplexing 28th ACEMB, Sept 20-24, 106.

Chiadini Francesco, Paolillo Alfredo and Scaglione Antonio, (2003), A Reflectometric optical Fiber temperature sensor, IEEE Sensor Journal, 3, 132.

Christensen D A, (1977), A new non perturbing temperature probe using semiconductor band edge shift, Journal Bio Eng, 1, 541.

Cohen A and N Wadsworth, (1972), A light emitting diode skin reflectance oximeter, Med and Biol Eng, 10, 385.

Conrad D P, (1990), Capacitive electrode, Medical Electronics Oct. 1990, 3, 185.