Physical Sensors for Biomedical Applications

(*Invited review*)

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***Abstract*—Use of sensors is increasing day-by-day in the real world to improve the quality of life by providing information on medical diagnostics for healthcare. Among numerous emerging sensing technologies, physical sensors "electronic devices" have been successfully demonstrated in the field of biomedical applications because of their excellent operation capability. Physical sensing is a unique sensing platform, where sensing devices are responsive towards physical properties (e.g., radiation, light, flow, heat, pressure, magnetic field, and parameters related to mass or energy) and convert them into signals for quantification. This review paper describes the different physical sensors and their biomedical applications, current main challenges, and future developments.**

Keywords—physical sensors; electronic devices; healthcare; biomedical applications.

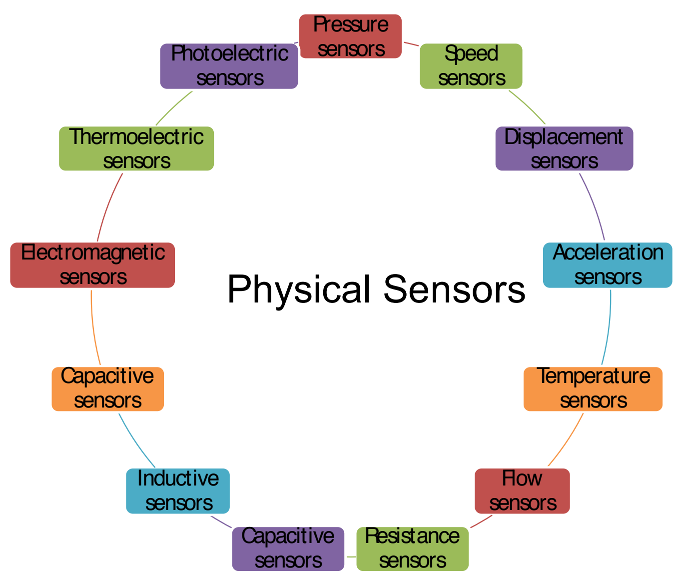
I. Introduction

In the physical sensing platforms, the physical variables (such as thermal, mechanical, electrical, magnetic, and atomic/nuclear) associated with the biomedical systems are detected and monitored [1, 2]. The natural physical properties such as shear, torsion, pressure, temperature, and humidity are the fundamentals for physical sensors that are converted into the signals for measuring the physical quantities using an observer or instrument. The use of physical sensors is not limited to the real-time healthcare monitoring but are also utilized in other advanced applications, such as soft robotics, wearable consumer electronics, electronic skins, and smart medical prosthetics [3]. However, mainly in the biomedical field, there is an increasing demand for developing the effective and implementable sensors.

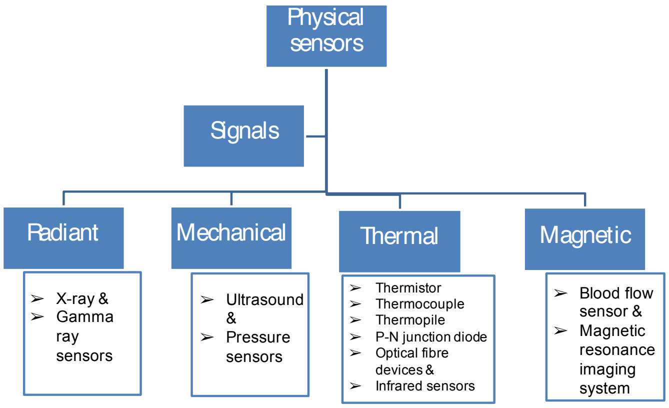
There has been an increasing attempt to design physical sensing devices with long-term stability, excellent optical transparency, and increased sensitivity, mainly with optimized for particular sensing platform [4-6]. The utilization of materials such as superconductors or nanophase materials, optical fibers and semiconductors micro fabrication technology have guaranteed the high precision, possibility of multifunction, and integration of physical sensors. Sensors developed with different flexible materials and substrate have been designed and implemented for biomedical applications that provide an excellent surface for various topologies and geometries. Notably, flexible physical sensors are attractive because of superior deformability, optical transparency, stretchability, and compliancy.

Physical sensors operate based on relative output signal variations in their electrical parameters. A classification of physical sensors is presented in Fig. 1. These sensors detect and quantify the different physical nature or phenomenon or physical system. Physical sensing devices have been most widely used and made a remarkable contribution to our daily life including agriculture, aerospace, military, and industry development. Recently, nanomaterials such as semiconductors, metals, and polymers have been extensively utilized as active sensing elements to enhance the sensing performance of physical sensors. Such nanomaterials (e.g., carbon nanotubes, metal and metal oxide nanowires, polymers nanofibers, and metal nanoparticles) based physical sensors have been developed for healthcare and medical applications.

This paper provides a review of current research developments on the physical sensors that are mainly utilized in the biomedical applications. This review briefly introduces the physical sensors and discusses the potential biomedical applications followed by conclusions.



1. Physical sensors.



2. Types of physical sensors in biomedical applications based on their signals.

II. TYPES OF PHYSICAL SENSORS AND BIOMEDICAL APPLICATIONS

The biomedical physical sensors are divided into four classes based on their signals (Fig. 2). In the class 1, radiation sensors address the X-ray and gamma ray-based sensors. In the class 2, mechanical sensors include ultrasound and pressure sensors. In the class 3, thermal sensors include a range of sensors such as thermocouple, thermistor, thermopile, optical fibre devices, P-N junction diode, and infrared sensors. Among these thermal sensors, the optical fibre devices are the most promising and offer enormous expectations [7]. In the class 4, magnetic sensors include the important blood flow monitoring sensors and magnetic resonance imaging systems. Brief descriptions of these classes are presented bellow.

A. Radiation Sensors

Radiation sensors utilize radiations (X-rays or gamma rays) for imaging and treatment in a variety of biomedical applications. In particular, radiation sensors are mostly employed for medical imaging while using ionising radiation. However, there are effects of ionising radiation on health. To overcome danger of ionising radiation, a clear understanding of the benefits and risks associated with radiation and radioactivity are needed. Currently, medical imaging are categorized into three categories based on the ionising radiation.

(i) Medical imaging using X-rays as an external beam source

(ii) Medical imaging using a radiation source (radio-isotope) internal to the body

(iii) Medical imaging without using ionising radiation

For better and precise imaging, combinations of two categories are preferred. For example, combination of images from positron emission tomography (PET) and single photon emission computed tomography (SPECT) measured using radio-pharmaceutical tracers (e.g., computed tomography (CT) or magnetic resonance imaging (MRI)) for position accuracy; combination of CT and PET but it requires radiation dose before measurements; and combination of PET and MRI has been recently developed. There are still attempts to design sensor systems to lower the cost.

B. Mechanical Sensors

Mechanical sensors include ultrasound and pressure sensors for biomedical applications. These sensors target a large number of physical variations (e.g., force, mass, strain, pressure, velocity, weight, and acceleration). A detailed physical variables are listed in Table 1. The ultrasound waves emitted by transducer pass into the tissues and are detected using sensors to monitor health conditions without involving any invasive procedures [8, 9]. The mechanical sensors rely on the mechanical vibrations, piezoresistive effect, capacitance, triboelectricity, and resistance. Additionally, these sensing components are driven by mechanical deformations (pressing, bending, stretching, and twisting) of devices.

On the other hand, pressure sensors utilize force applied on the piezoelectric material that produce the electric potential. These sensors are required in many fields, such as industrial process controls, biomedical systems, and environmental monitoring. To detect external pressure in human beings, a new capacitive pressure sensor is utilized as non-invasive blood pressure measurements, which had extremely high sensitivity of 2.24 μF/kPa [10]. Also, pressure sensors are used to monitor internal pressure [11].

TABLE 1. PHYSICAL VARIABLES DETECTING SENSORS.

Physical Quantity	Sensor	Variable detected
Geometric	Linear variable differential transformer	Displacement
	Ultrasonic transit time	Displacement
	Strain gauge	Strain
Force-torque	Load cell	Applied force/ torque
Kinematic	Accelerometer	Acceleration
	Velocimeter	Velocity
Thermal	Thermometer	Temperature
	Thermal flux sensor	Heat flux
Fluidic	Flow meter	Flow
	Pressure transducer	Pressure

C. Thermal Sensors

Thermal sensors are utilized to measure the on-body temperature measurements, which is a vital indicator of person's health [12-14]. A vide variety of sensor devices are available that record oral, skin, tympanic, and rectal mucosa temperatures. These clinical thermometers are based on the variety of transducers (e.g., thermistors, thermocouples, thermopile, semiconductor temperature sensors, P-N junction diode, Resistance Temperature Detectors (RTDs), optical fibre devices, infrared radiation sensors, and liquid crystal temperature sensors).

D. Magnetic Sensors

Magnetic sensors are mainly based on the magnetic moment of magnetic material that change the magnetic field or temperature, or cause mechanical stress [15]. These variations are measured using sensors. In biomedical applications, magnetic sensors are utilized to hyperthermia treatments or for drug delivery. These applications may include blood, cerebrospinal fluid, culture medium, and organic tissues. Some of the biomedical applications are listed bellow.

(i) Cell culture measurement in in situ

(ii) Test of blood coagulation and blood flow

(iii) Early detection of heart valve bio prostheses failure

(iv) Cancer cell (hyperthermia HeLa cell) treatment with silica coated manganese oxide (MnO_2) nanoparticles

(v) Endoluminal artificial urinary sphincter

III. Conclusion

This paper discussed the different physical sensors used in biomedical applications. Several types of physical sensors are used in biomedical applications, such as blood pressure, muscle displacement, blood flow, core/external body temperature, bone growth, and cerebrospinal fluid pressure measurements. Among most of the physical sensors, optical sensors are mostly used in the biomedical applications. Physical sensors are frequently used in the electronic instruments, such as X-ray tomography, PET, ultrasonography, MRI, and measurement of blood flow/pressure, and body temperature. However, researchers are working to develop more sensitive, reliable, stabile and low-cost sensors. Miniaturization of the sensors is a hot topic, which is currently done using semiconductor fabrication methods of microelectronics. The main advantage of fabricating microelectronics is their small size that allows the combining of several sensors on a single chip. In addition, there is progress towards fabrication of better physical sensors with advanced sensing materials and conventional electronics devices.

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