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Review Of Mems-Based Sensing Technology And Human-Centered Applications In Health Prespective

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ABSTRACT:
As a consequence of the incredible growth in technical improvements over the last several years, there has been significant progress in biomedical engineering applications. Today's sensing technologies in medical may be part of a solution to the socioeconomic and demographic challenges that worldwide healthcare systems are experiencing. The global biomedical sensors market, especially the noninvasive kind, is expected to reach 15.01USB$ by 2022. There is a lot of interest in using microsystems in healthcare applications as a worldwide research focus, with researchers coming up with new techniques to noninvasively diagnose and monitor patients. Micro & Nano manufactured technologies like MEMS/NEMS that enable more compact, cost-effective, precise and efficient diagnostic instruments to discover earlier life-threatening ailments. This review article will concentrate on biomedical sensors utilised in the detection of tropical illnesses, as well as MEMS/NEMS based smart sensors recently developed for healthcare applications and smart application development. In addition to novel intelligent sensor solutions, each non-invasive biomedical sensor technology will be used in conjunction with specialised applications.

Keywords: Biosensors, MEMS, Sensors, actuators, Tropical diseases, Invasive, Noninvasive, smart implants, chemical sensing, micro/nano device, microfluidics, nanomaterial

1. NTRODUCTION

Tropics and subtropics ailments are now prevalent in urban climates[1]. These subtropical illnesses are common in different temperatures settings, resulting in viral infections. Tropical conditions such as malaria, dengue, tetanus, hepatitis, yellow fever, cholera, etc. may also contain such illnesses. Diagnoses of these tropical illnesses include serological testing of pathogenic indicators, through the use of proteins, antigens and antibodies X-rays, physical testing and fungi and bacteria cultivars. These procedures need the collection of body fluid samples such as blood, sputum, or urine. However, the diagnosis of tropical illnesses has numerous obstacles, featuring a lengthy turnaround time for specimen evaluation, a controlled atmosphere, trained experts, and huge blood (or) bodily fluid samples which is also the most expensive. Not only can a sick organ or joint dysfunction in a human body be studied in these tropical illnesses and cuts across the skin to open the body so that they can only establish the nature of the issue and choose the course of action. However, what can or cannot occur during surgery. For this sort of medical treatment, the phrase exploratory surgeries is used, and several complications are inherent in such approaches, and these techniques and evaluations are always invasive.

Recent research and studies have provided a variety of biomedical engineering techniques using non-invasive biomedical sensors in recent year [1] to give diagnostic methods that are simpler, more precise, cheaper, and less time consuming for detecting these tropical ailments. This innovative non-invasive sensing technology can replace the invasive techniques and give fresh insights into their physiological condition. This paper focuses on biomedical sensors that were developed so far using existing methodologies in medical engineering and prospective research topics for the detection of diseases by biosensors using Microelectromechanical systems

Table 1: Classification of Biomedical sensors in domain area of MEMS/NEMS

	Type	Application	Placement Type
Classification of Biomedical Sensors	Temperature Blood Glucose Blood Oxygen ECG Image Motion Inertial Pressure	Diagnostic Monitoring Medical therapeutics Imaging Wellness and fitness	Strip Wearable Implantable Invasive/ Non invasive Ingestible

1.1. Sensors in Medical field

In the medical field, sensors play an important role in detecting particular biological, chemical, or physical processes and subsequently communicating same data. These sensors can also be part of a system that processes clinical samples like common lab-on-a-chip devices more and more.

The worldwide medical sensors business is expected to be worth $15.01 billion by 2022, growing at an 8.5% CAGR throughout 2016 and 2022. Because of the escalating expenses of medical procedures in hospitals and medical services centres, people are increasingly turning to home healthcare services. As a result, demand for different healthcare equipment is projected to increase in the future.

1.2 Sensing Techniques:

A state-of-the-art biomedical sensor is a device consisting of a sensing element incorporated physiologically into the physical transducer that converts a measurements and output signal. As a well biomedical sensor is required to have one particular parameter or to be able to determine the accurate position or precisity, the reaction time, bio - compatibility, ageing features, size, durability, relatively cheap, without interference with the other dimensions or the ability to assess tiny improvements in the given measurement. The sensor should also be compatible with the technologies of the chemical, optical, electrical or IC enabled circuit.

Many non-invasive biological sensors and their applications have been described in this section and underlying concepts have been outlined in earlier sections.

Author, Sandra. C[4] provides valuable beginning recommendations in the construction of dependable noninvasive detection systems based on radiofrequency or millimetre waves as excitation sources for biological purposes. It emphasises the extraction of dielectric characteristics of biological medium over earlier approaches such as interferometric architecture [5] or the six-port technique [6]. Here, using an example of glucose monitoring in the serum when certain diseases affect the human body, the Author illustrates the above conception.

The benefit of non-invasive diabetes management is illustrated by another author Megha C. Pande et al..[6], It concentrates on “NIR Spectroscopy,” which has been employed in the design of non-invasive biological detecting and clinical screening techniques. It is commonly known as monitoring the propagation or phosphorescence through blood flow can reveal trans-cutaneous variations in the volume of blood in the tissue.

Numerous approaches are employed to assess blood glucose sensing; various techniques have been employed depending on the methodology for sensing.

Figure 2 below clearly depicts them.

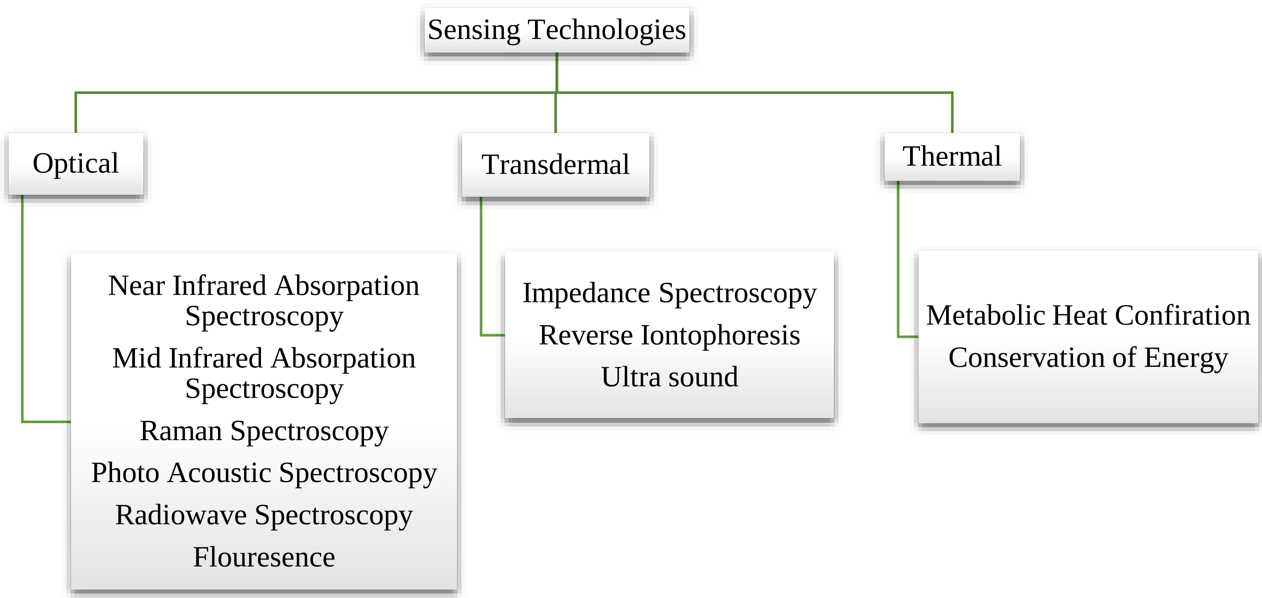


Figure 1. Classification of various Sensing Technologies

Authors Discussion of technologies and methodologies for bio-medical sensing of diverse tropical diseases

The diagnoses of these infectious diseases include serological tests of disease biomarkers such as proteins, antigens and the antibodies ray, physical tests as well as fungal and bacterial culture techniques. This includes the diagnosis of these tropical diseases.

This section discusses the sort of technology employed to identify topical infections from previous discussions. The authors Fatimah Ibrahim et al[14] propose several techniques in non-invasive biomedical engineering for distinct Tropical conditions. Several techniques to biomedical engineering are used to diagnose and treat.

Table 1: Addressing type of biomedical approach with respect to disease

Author Reference	**Type of Approach**	**Tropical Diseases**
Ibrahim F et al. [14]	BioelectricImpedance Analysis(BIA)	Dengue

Priyanka shrama et al. [15]	Decision Support system	
Mohit Arora et al. [16]	Echo cardio graphy	
Dr. Hasan Sadikin et al. [17]	Electro cardio Graphy	
V sravani et al. [18]	Imaging: Ultrasonic	
Amir M. Foudeh et al. [19]	Micro Fluidics and Lab on a chip	
J F Lancaster et al. [20]	Laser Doppler Velocimetry	
Leila Syedmoradi et al. [21]	Paper based Diagnostics	
Delia B. Bethell et al. [22]	Plethysmo Graphy	
Ibrahim F et al. et al. [23]	Bioelectric Impedance Analysis	Malaria
Surasak Kasetsirikul et al. [24]	Die electro Pharoses	
Pallavi T. Suradkar et al. [25]	Image processing	
Shouki Yatsushiro et al. [30]	Micro Array chip	
Amir M. Foudeh et al. [19]	Micro Fluidics and Lab on a chip	
Leila Syedmoradi et al. [21]	Paper based Diagnostics	
Ibrahim F et al. [14]	Bioelectric Impedance Analysis	Cholera
Amir M. Foudeh et al. [19]	Micro Fluidics and Lab on a chip	
Vivek KumarSahet al. [25]	CT and MRI Scans	Schistosomiasis
Sabriye Sennur Bilgin MD et al. [26]	Ultrasonic Imaging	
Frederik j. Slim et al. [27]	CT and MRI Scans	Lymphatic and Leprosy
Justin T. Baca et al.[28]	Biosensor	Ebola,
María-Isabel et al. [31]		Chagas

The previous researchers [33] discuss how miniaturized microwaves biosensors are more effective than conventional X-rays and non-invasion microwave sensors. And this study provides the possibility of developing these microwaves detectors, either label-free.

Another researcher X. Liu shows a novel gauze-based, flexible, mechanically resilient, and the weaved-material compatible electrolyzer. This article [34] concentrated on the fabrication of electrochemical sensors on glass substrates such as polymer composites and textiles for Iivitro diagnostics and non-invasive health monitoring.

In this article[35] Electrochemical interfacial impedance spectroscopy (EIS) aims to investigate different surfaces and electrolytic processes used on the use of DNA chips and bio-sensors. And the author M. Rosu-Hamzescu et al. exhibit the two-electrode configuration, enable for cell-cultural impedance monitoring and disclose biological process characteristics, such as cellular adhesion, sustainability, development, motility, morphogenesis, and internal tissue activity.

Author D. Sathyanath et al. describes this study [36] as a non/minimally invasive control system on blood glucose a microwave-based sensor – Split Ring Resonator (SRR) and its complementary design (CSRR). Fluctuations in glucose-related dielectric blood constants are exploredhere.

C. Huang et al. have devised adaptable deep-tissue imaging systems that employ diffuse, near-infrared correlation methods. They developed a setup for non-contact Speckle contrast called a diffuse correlation interferometry.

In this article, N. Chudpooti et al. [38] present a miniaturised lab-on-a-waveguide liquid-mixture sensor. In biological applications, this enables the highly exact characterization of nanolitres of fluid samples. This nano fluidic-integrated millimetre-wave sensor's design is based on a near-field transmission-line technique done by a single loop slot antenna working at 91 GHz. A similar effect is achieved in the lid of a WR-10 laser photo compositional waveguide..

In this paper, D. Mishra et al. developed a non-contact, non-invasive, real-time device called a "polarised imaging-based integrated system for SpO2 monitoring" [39]. Unlike existing SpO2 measurement techniques, the proposed method makes use of a single light source.

P. Tripathy et al. [40] offer a simulation-based approach for evaluating the ZnO-based piezoelectric MEMS blood glucose sensing receiver for ZnO-based applications. As a result, the approach is so varied. The simulated findings demonstrate that for different glucose density levels in biological fluids, different pressure levels are recognized at the receiving end and that the relevant pressure values are converted into voltages using the piezoelectric principle.

This study article [51] discusses the emerging need for sophisticated biomedical sensors and equipment for diagnosis, monitoring, and therapy. Also, it gives an overview of some recent advancements in optical biomedical sensing technologies. The kinds, applications, and distinct advantages of new optical sensors for biomedical applications are discussed in this study.

Fiber Optic Blood glucose sensor	•Blood gases
Haemodynamic Monitor	•Oximeter parameter •Cardiovascular system
NIR Oxymeter	•Hemoglobin concentration •Blood oxygen concentration
Optical fiber ECG and EEG	•ECG and EEG
Optical fiber pressure sensor	•Monitor lung and bladder pressure
Optical fiber immunosensor	•Drug sensing and blood protein sensing
Fiber optic Radiation Dosimetry	•To monitor Low dose ionising radiation in radio therapy
Optical fiber Breath sensor	•Beath measurment and BCG(Ballisto cardio Gram)
X-Ray Dosimeter	•Dose of ionozing X-ray Radiation
Distributed Feedback Laser Biosensor	•To detect cytokine Tumor Necrosis Factor(TNF)
DNA Hybrid Optical Fiber	•To Detect DNA
Optical Pulse Pressure sensor	•To Monitor Blood Volume pulse through skin

Figure 2. Shows the some of the Novel Optical Biomedical sensors with its Applications[42-50]

The study[52] provides a capacitive electrocardiogram (ECG) method for non-invasive measurements of ECG without involving direct contact with the skin. The results of the study show that hygroscopic FEEP measurement of ECG signals with a more precise SNR ratio is rapid.

Table 2: Literature Survey on Technology

Author Reference	**Year**	**Technology**	**Application**
Sathya S, Muruganand S[62]	2020	Capacitive based Interdigitated electrodes (IDE)	Biosensor for diseases diagnosis
Likhite R, Banerjee et.al[61]	2019	Capacitive sensing	Humidity and gas sensing
N.Chudpooti et al.[38]	2018	Lab on a Waveguide- Liquid Mixture Sensor	Nano Liter Liquid Characterization
X.Liu et al. [34]	2017	Electrochemical sensor(MEMS)	Diagnosing and HealthMonitoring
M,Rosu-Hamzescu et al. [36]	2017	EIS(Electrochemical impedance Spectroscopy)	Health Monitoring, dermatological application
D. Mehta et al.	2017	Silver Enhanced Infrared	Palp Moment

		Reflectance Technique	
C. Huang et al.[37]	2017	Near Infrared Diffuse Technique	Blood Flow Imaging
A.Mansoorifar et al.[39]	2017	Dielectric Spectroscopy	Dielectric Properties of Biological cells
D.Mishra et al.[39]	2017	Polarizing Imaging with Single Light Source	Monitoring SpO_2
H. P. Tripathy et al.[40]	2017	Ultrasonic MEMS	Glucose Sensing
Shanwen Luo et al.[53]	2017	Microwave Imaging	Early breast Tumor Detection
P. satyanath et l.[36]	2015	Split Ring resonantor(SRR)	Glucose Monitoring
G. Goarin et al. [33]	2015	Microwave Bio sensor	Health monitoring
Justin T Baca et al.[28]	2015	SAW sensor	Ebola Detection
D. K. Kamat et al. [29]	2014	Bio impedance Technique	Blood Glucose Measurement
Shouki Yatsushiro et al.[30]	2010	Cell Micro Array Chip	Malaria Infection

Of course, several of the Author' discussions on the detection of tropical infections provided here have made advances in recent years; nevertheless, ongoing efforts must be undertaken to better evaluate and enhance the efficacy of existing biomedical techniques. However the 21st century, because of their tiny production technology, compact size, power efficiency and high functionality, BioMEMS-/NEMS sensors revolutionized the healthcare sector, like that of semiconductor devices for the electronics industry in the past century.

2. MEMS/NEMS TECHNOLOGY IN BIOMEDICAL APPLICATIONS

MEMS (Micro-Electro-Mechanical Systems) are small devices and fit for the intended through micro-machining techniques. The basic dimensions of MEMS devices range from 100 nm to 1000 m. (or 1mm). MEMS technology is a predecessor to the more well-known discipline of Nanotechnology, which relates to science, engineering, and technology on a dimension 100 nm and as microscopic as the atomic scale. MEMS devices with millimetre-scale dimensions are also known as mesoscale MEMS devices. Figure 1 illustrates the necessary dimensional scale together with biological material.

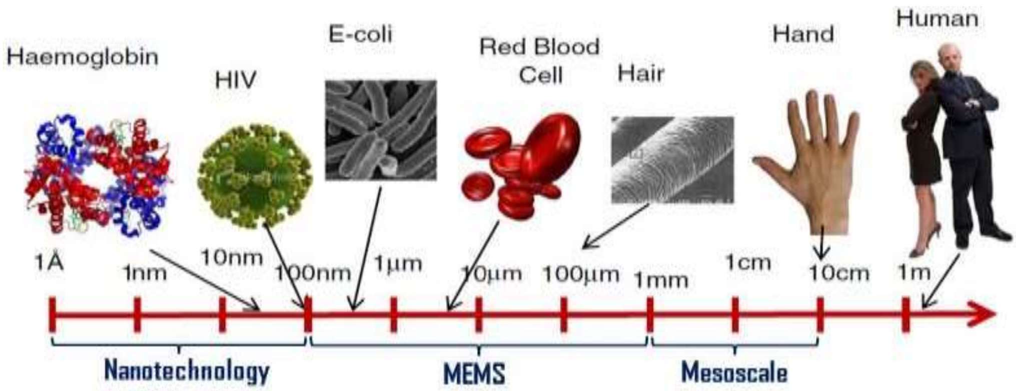


Figure 3. Dimension MEMS and Nanotechnology
(Source: https://engineeringproductdesign.com/mems-micro-electro-mechanical-system/)

the global BioMEMS market is expected to almost triple in size, from $1.9 billion in 2012 to $6.6 billion in 2018[54].

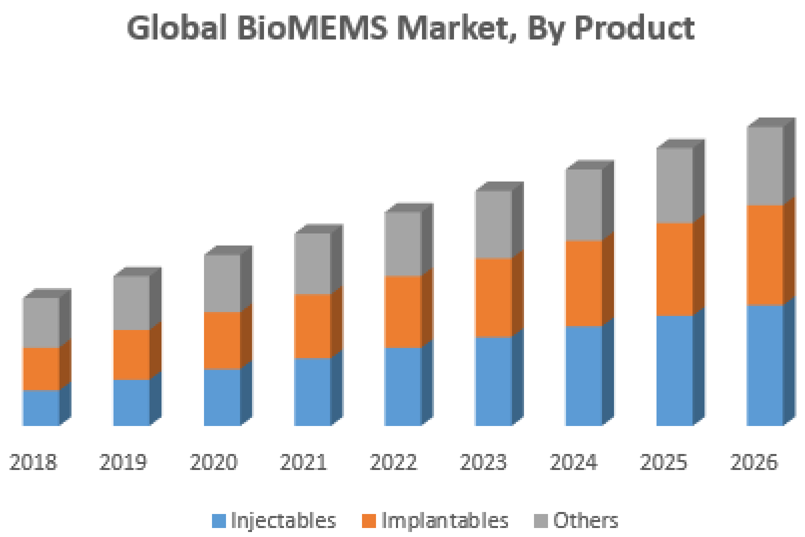


Figure 4. BioMEMS market forecast by Yole Development [54].
(Source: https://articlerockstars.com/global-biomems-market-industry-analysis-and-forecast-2019-2026/).

2.1 BioMEMS/NEMS in Detection of Tropical diseases:

In the last decade, recent research and studies have established and produced a variety of bioengineering approaches with the objective of addressing the barriers faced in the evaluation of tropical ailments. BioMEMS/NEMS devices, on the other hand, have developed as valuable tools for assessing medical and biological mechanisms in recent years. This study is based on the latest scientific methods to the most widely used tropical illnesses, such as dengue fever, malaria, cholera, schistosomia, lymph filariasis, Ebola, leprosy, leishmaniasis, and American trypanosomiasis (Chagas). Dengue fever is one of these tropical illnesses that has spread rapidly throughout the world in recent decades. [58]

In 2016, there were broad dengue epidemics worldwide. Around 2.38 million cases were reported by the Region of Americas. Brazil alone provided slightly fewer than 1.5 million cases, three times more than in 2014. The Western Pacific Region reported about 375000 suspected dengue cases in 2016, with the Philippines reporting 176 411 cases and Malaysia reporting 100 028 cases, showing a comparable burden for both countries compared to the previous year. Over 7000 people are suspected of being unwell in the Solomon Islands, where an outbreak has been detected. Burkina Faso reported a small dengue epidemic in the African Region, with 1061 probable cases [58]. Every year, around 500 000 people with severe dengue hospitalization, and approximately 2.5% of those infected dies. Micro-Electro-Mechanical Systems (MEMS) are a rapid technology that has carried many concepts in the healthcare areas. MEMS has a wide range of applications in biomedicine. If tropical illnesses can be identified using MEMS/NEMS bio-sensors, it will be a milestone in the biomedical area, and a kit similar to LOC might be developed (Lab on Chip).

2.2 BioMEMS applications:

A few current BioMEMS applications are discussed in this section.

2.2.1 Pressure sensors with MEMS technology: In the 1980s, the first MEMS devices utilised in the biomedical industry were reusable blood pressure sensors. These sensors are used in a wide range of medical procedures such as angioplasty and the measurement of disposable blood pressure and intraocular and intracranial pressure. Biomedical pressure sensors are manufactured by CardioMEMS, Freescale Semiconductor, GE Sensing, Measurement Specialties, Omron and Sensimed AG. WHO lists glaucoma as the world's second-biggest cause of blindness after cataracts. Glaucoma sufferers have their IOP continuously monitored using MEMS implanted pressure sensors. The IOP of a typical eye ranges from 10 to 22 mmHg. Glaucoma is thought to be caused by elevated IOP (more than 22 mmHg) and fluctuating IOP. Glaucoma, which is typically painless and symptomless, can destroy the visual nerve irreversibly and permanently. Initially, peripheral vision is affected, and blindness may result if treatment is not received promptly. An ASIC microprocessor is integrated into a reusable contact lens with a MEMS strain-gage pressure sensor (2mmx2mm chip). For measuring corneal curvature changes in response to IOP, the MEMS sensor incorporates a circular active outer ring and passive strain gauges (strain gauges). It gets power from the external monitoring system and transmits information back to it through its loop antenna.

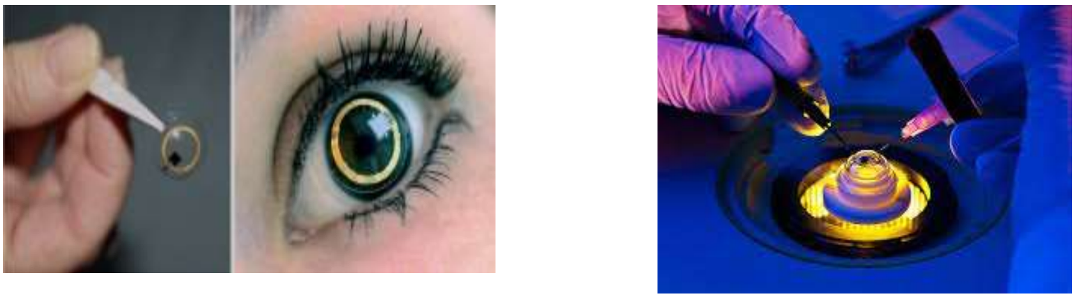


Figure 5. Sensimed's TriggerfishTM implantable MEMS IOP sensor
(Source: http://www.sensimed.com/).

2.2.2 Inertial MEMS Sensors: MEMS accelerometers are utilised in pacemakers and defibrillators. Heart attacks and cardiac arrest are substantial risks for some people who have abnormally rapid or chaotic heartbeats. The heart is shocked by an implanted defibrillator to reestablish a normal rhythm. Some people's hearts beat too slowly due to age or a hereditary disorder. A pacemaker transmits electrical impulses to the heart in order to maintain a normal heartbeat. Pacemakers in the past were fixed-rate devices. Advanced implants use MEMS accelerometers and may alter heart rate in response to the patient's physical activities. Medtronic is a prominent manufacturer of defibrillators and pacemakers based on MEMS technology, as well as other medical devices. Figure 7 depicts a Medtronic SureScan pacemaker with a MEMS accelerometer and the pacemaker being implanted within the body adjacent to the heart. Magnesium MRI compatible pacemaker (MRI).

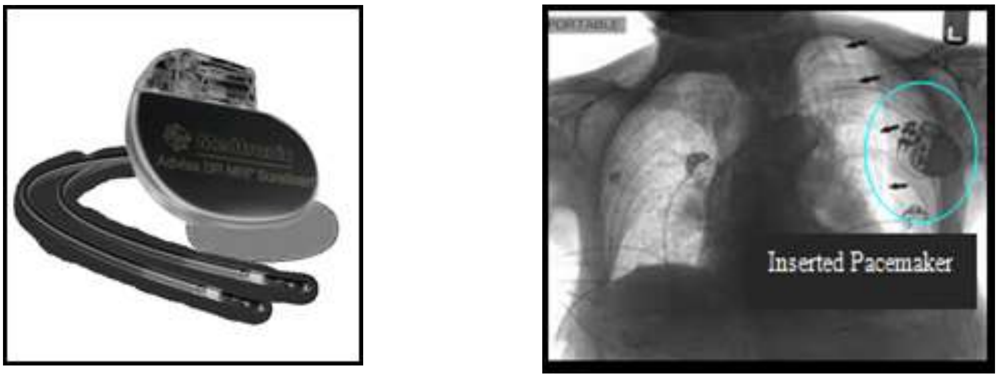


Figure 6:Medtronic’s Sure Scan pacemaker

2.2.3 MEMS Assistive listening transducer: Acoustic devices such as hearing aids receive, enhance, and transmit sound into the ear canal. Using a hearing aid, the user can hear better by compensating for their hearing loss. Hearing aids are approved by the Government in the United States since they are classified as medical devices. According to the National Institutes of Health (NIH), around 17% of American adults (36 million) have some degree of hearing loss. As people age, they tend to have more hearing loss. In the U. S., 2 to 3 out of every 1,000 infants are born deaf or hearing impaired.

According to studies, 80% of individuals who may benefit from a hearing aid do not use one. This is due to a lack of awareness of hearing loss and the social stigma associated with wearing hearing aids. Miniaturizing hearing aids without losing performance is therefore extremely desirable. Hearing aids that use MEMS technology have a smaller form factor, lower cost, and lower power consumption than those that do not. According to Analog Devices, a tiny MEMS microphone (7.3 mm3) appropriate for hearing aids may be found in Figure 8.

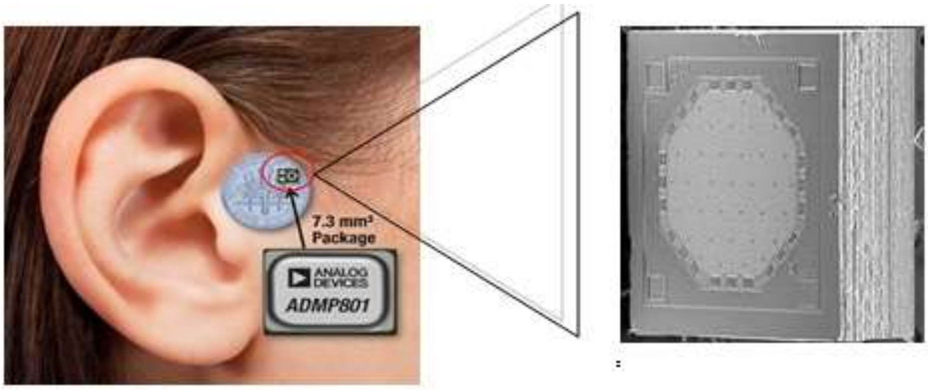
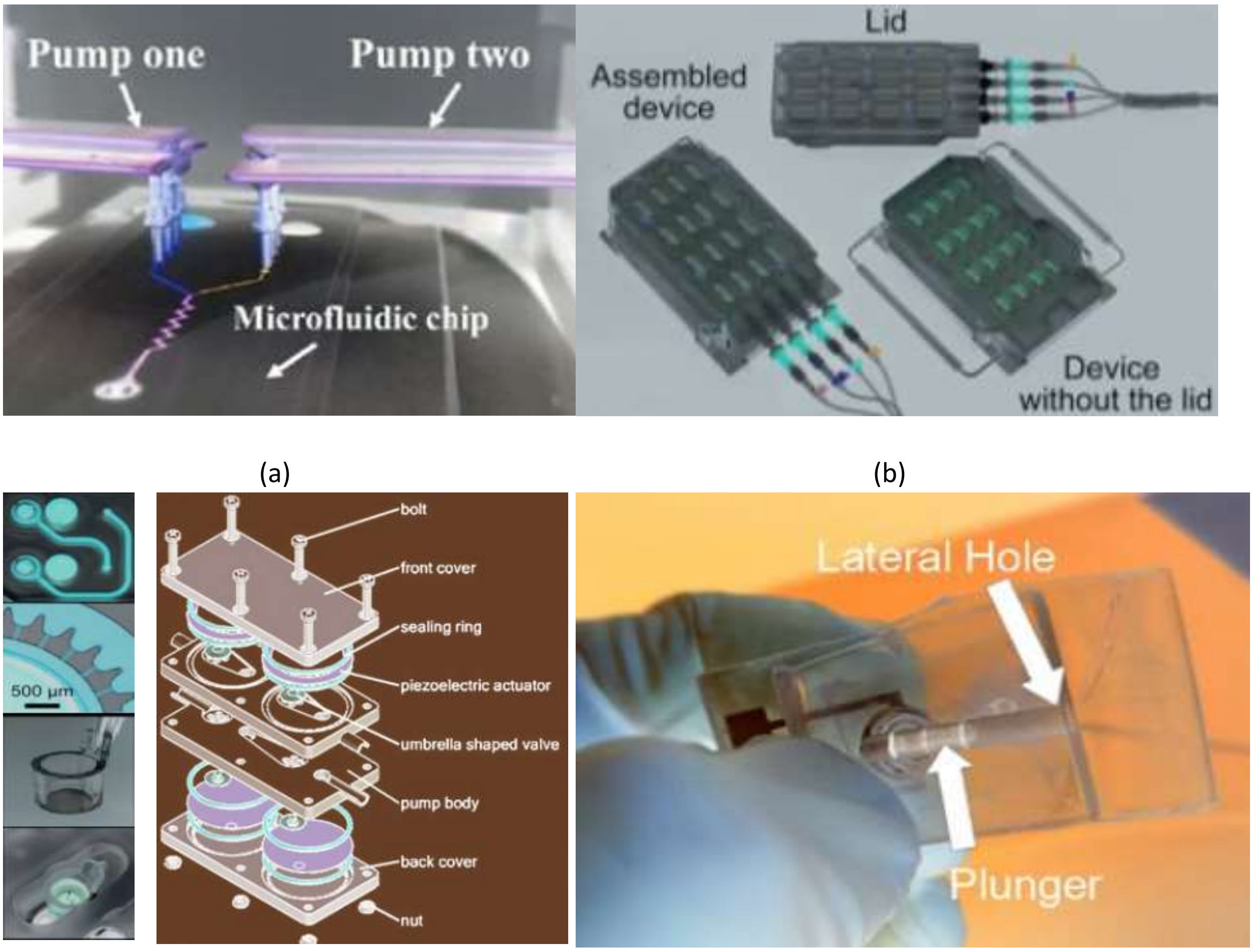


Figure 7. Analog Devices MEMS microphone for hearing-aid applications.
(Source: http://www.analog.com/).

2.2.4 Microfluidics in diagnostics: Using nanolitersized quantities of fluid (microfluidics) to move, mix, and control, Needles, channels, valves, pumps, mixers, filters, sensors, reservoirs, and dispense rs are common components of a microfluidic system. Microfluidics enables medical diagnostics at th e bedside or the point of are (POC).

Even in underdeveloped nations, where access to centralised institutions is restricted and expensive, POC diagnostics is crucial for accurate diagnosis.Blood, urine, and saliva are used in a microfluidic de vice for POC diagnostics. ClearBlue, first-ever POC microfluidic technology for urine pregnancy testing, was launched by Unipath in 1985 and is currently available on the market. Chin et al. [59] have published a comprehensive review paper on the commercialisation of microfluidic devices for POC diagnostics. HIV/AIDS is one of the world's most serious public health issues, particularly in low- and middle-income nations. According to the WHO, 34 million individuals are infected with HIV, and around 7 million are amenable to antiretroviral therapy.



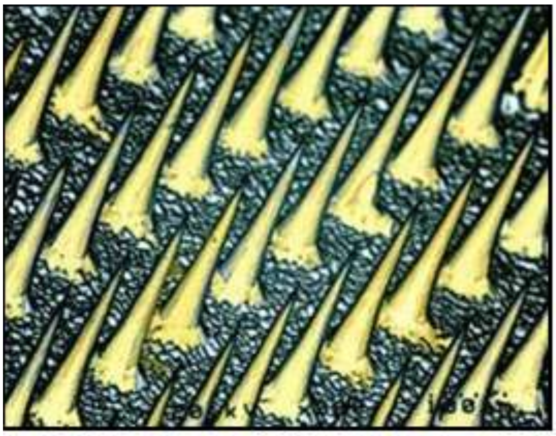
(a) (b)

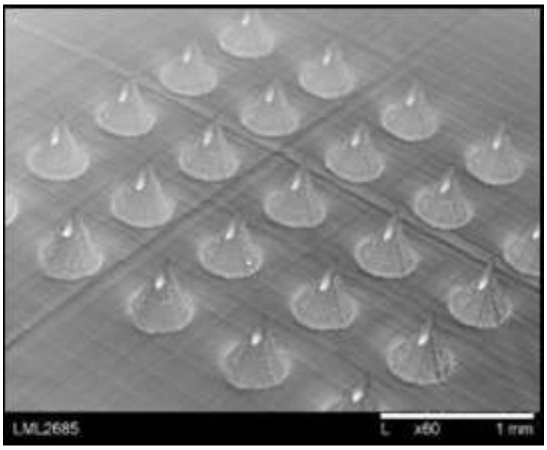
(c) (d) (e)

Figure **8.** Lab on Chip system components[63]. (a) Schematic of a piezo-actuated pump prototype. (b) Piezoelectric-actuator-based microfluidic pump module(c) Thermopneumatically actuated microchamber.(d) Pneumatically driven multi-organ-on-a-plate system, showing (top) culture device, (middle) microfluidic plates, (bottom left) culture unit and Laplace valves, and (bottom right) membrane insert and culture chamber.

2.2.5 Microfluidics for delivery of drugs: Biopharmaceutical methods such as triggered release, controlled discharge, and targeted delivery are made possible by microfluidics. Potential applications include epidermal drug delivery (e.g., microneedle arrays and needle-less jet-based system), implanted drug delivery devices (e.g., stimulant stents and insulin pump), e.g., micro-and nano–particles.

2.2.6 Micromachined Needles: The dimesions of micromachined needles smaller than 300 m may be manufactured with micromachining, which is not possible with traditional machining processes. Microneedles made using MEMS typically have a length of less than 1 millimetre. It has been utilised for medication delivery, bio-signal recording electrodes, blood extraction and fluid sampling as well as for chemotherapy and microdialysis. It is not uncommon to find microneedles incorporated into microfluidic devices. When microfluidic systems are utilised with microneedles, they are often combined and used together. It has been possible to create solid and hollow microneedles from silicon, glass, metals and polymers utilising micromachining techniques Some microneedles have cylindrical, pyramidal, candle-shaped, spike-shaped or spear-shaped bodies and tips. Other microneedles feature octagonal, pentagonal, hexagonal or rocket form bodies and tip morphologies (volcano, snake fang, cylindrical, canonical, micro-hypodermis and tapered). Silicon solid microneedles manufactured by reactive ion etching [60] are shown in Figure 11, as are polymer hollow microneedles created by laser milling[61].

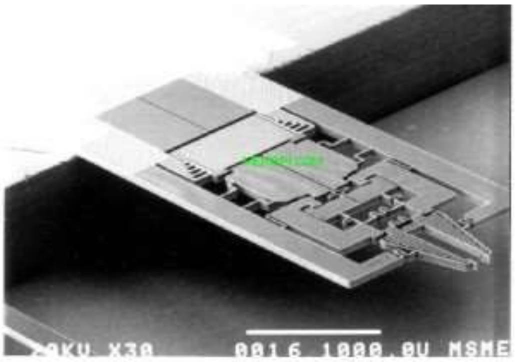


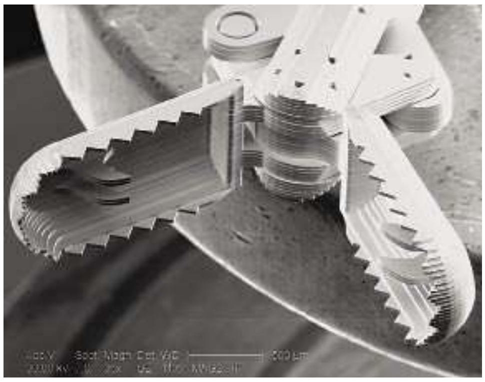


(a) (b)

Figure 9.Micromachined needles (a) silicon based solid needles. (Source: Henry et al. [60]).
(b) Micromachined needles: polymer based hollow needles.
(Source: http://www.lasermicromachining.com/).

2.2.7 Tools for microsurgery: By using conventional and instrumental approaches, surgery is used to cure illnesses and other disorders. The overwhelming trauma to the patient during surgery is generated by the surgeon's incisions to obtain access to the operative site. Surgery that is performed with extremely small incisions or occasionally through natural orifices is known as minimally invasive surgery (MIS). Some of the advantages of MIS over standard open surgery include decreased discomfort and scarring as well as shorter hospital stays and a speedier return to normal activities.





(a) (b)

Figure 10(a). Micromachined surgical tools: a pair of silicon MEMS tweezers.
(Source: http://www.memspi.com/) (b). Micro machined surgical tools: a pair of metal MEMS biopsy forceps.

(Source: http://www.microfabrica.com/).

2.2.8 MEMS Cardiovascular diagnosis: The disease remains the top cause of mortality in the World. One of the most frequent deadly cardiovascular diseases is blood vessel constriction caused by plaque accumulation, which can lead to a heart attack, stroke, and other major problems. The technique of angioplasty is used to restore normal blood flow via congested or blocked arteries.

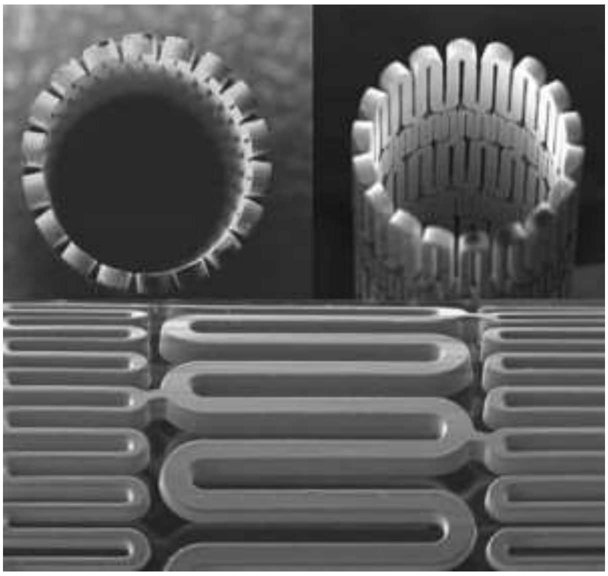


Figure 11. Micro machinedresorb able polymer stent. (Source: http://resonetics.com/)

A cardiac stent is placed by a catheter into a blood artery and subsequently inflated to widen the channel. Metal stents and polymer stents are the two main kinds of stents. Metal stents are the most common kind. There are 2 kinds of polyamide stents: resorbable and non- resorbable. Because it could be assimilated or eliminated in the body, the first kind is more desirable. Figure 13 il lustrates a laser-micromachined catheter made from a bio-resorbable material.

3. Conclusion

BioMEMS/NEMS based sensors will become very effective instruments for easuring biological and biomedical processes. BioMEMS sensors are revolutionising the biomedical sector in the 21st century, just like semiconductor devices revolutionised the electronics industry in the previous century. As the market trend indicates, there are several prospects for MEMS/NEMS in the biomedical industry. However, the FDA clearance procedure, which is required for some applications, can create considerable delays in the introduction of novel BioMEMS devices to the market. Certain tools discussed here it has apparently included significant progress in recent years but continuous efforts need to be made in order to better investigate existing bio-sensors and to enhance their performance. The study presented in this paper provides useful starting guidelines for developing reliable, compact and cost-efficient MEMS-based bio-sensor systems.

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