Internet of Medical Things

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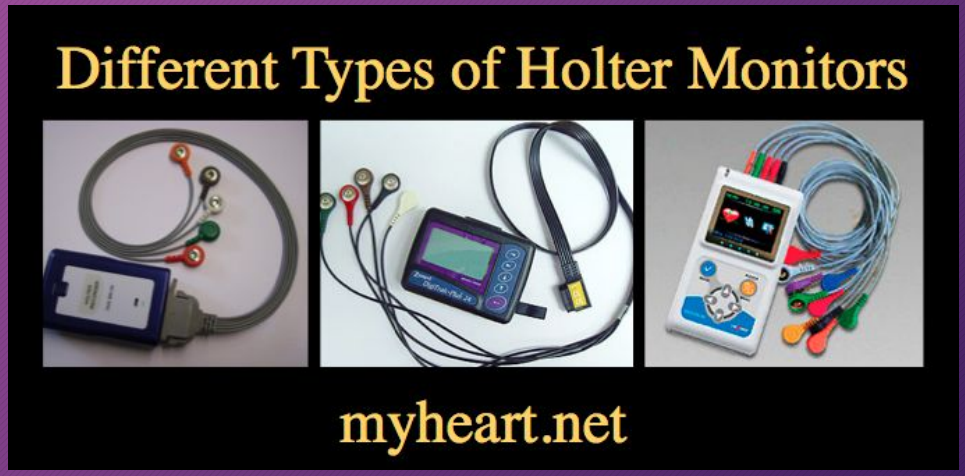
Introduction

- Wearable sensors and devices can be used to monitor chronic diseases continuously for early detection of symptoms as well as to capture acute and transient features that are difficult to be picked up during infrequent and ad hoc hospital visits.

Short-time and sporadic recording of ECG is often inadequate for detecting symptoms, while longer term ECG monitoring over several hours or even several days will provide better and accurate diagnosis.



Cardiovascular diseases

Cardiovascular diseases

17.3 Million death in 2008

30 % of global death

80 % of death in developing countries

23.3 million death by 2030

- CVDs are a collection of disorders of the cardiac system and blood vessels, including coronary heart disease, atrial fibrillation, heart failure, and peripheral arterial diseases.
- CVDs are mainly attributable to conventional risk factors, such as unhealthy diet, physical inactivity, tobacco use, and harmful use of alcohol.
- High BP, which is also known as hypertension, has been identified as a major dominant risk factor of CVDs, affecting 1 billion people globally

Monitoring Risk Factors of Cardiovascular Diseases

cuff-based design

cuff-less BP measurement

Monitoring Risk Factors of Cardiovascular Diseases

- It is now widely accepted that 24-hour ambulatory monitoring gives a better prediction of risk than office measurements and is useful for diagnosing white-coat hypertension.
- continuous BP measurements have the advantage of detecting BP variability
- Non-invasive BP monitoring using cuff based and cuff less

 The cuff less method utilizes the fact that the transmission speed of the pulse along the arteries is related to pressure-dependent mechanical properties of the artery wall and therefore can be used as an estimate of BP.

There are also wearable sensors developed for fitness control and smoking supervision to alert the user to change his lifestyle as obesity and smoking are two major risk factors of CVDs.

- The mobile personal trainer (MOPET) system has been investigated to supervise a physical fitness activity with motivation and health advice for the user.
- An automatic wearable cigarette tracker can detect smoking events through monitoring the cigarette-to-mouth hand gestures and recognize characteristic patterns of respiration during smoke inhalations. The system is flexible and non-invasive with applicability in free-living conditions over extended periods of time.

Diagnosis of Cardiovascular Diseases - Atrial fibrillation (AF)

- Atrial fibrillation (AF) is the most common type of cardiac arrhythmia, caused by rapid, disorganized electrical impulses of the heart.
- AF can lead to stroke and heart failure.
- The incidence of AF is higher in elderly adults, and is often a complication after cardiac surgery without accompanying symptoms
- AF can be diagnosed from ECG, usually with the absence of P waves, rapid heart rate and irregular heart rhythms.

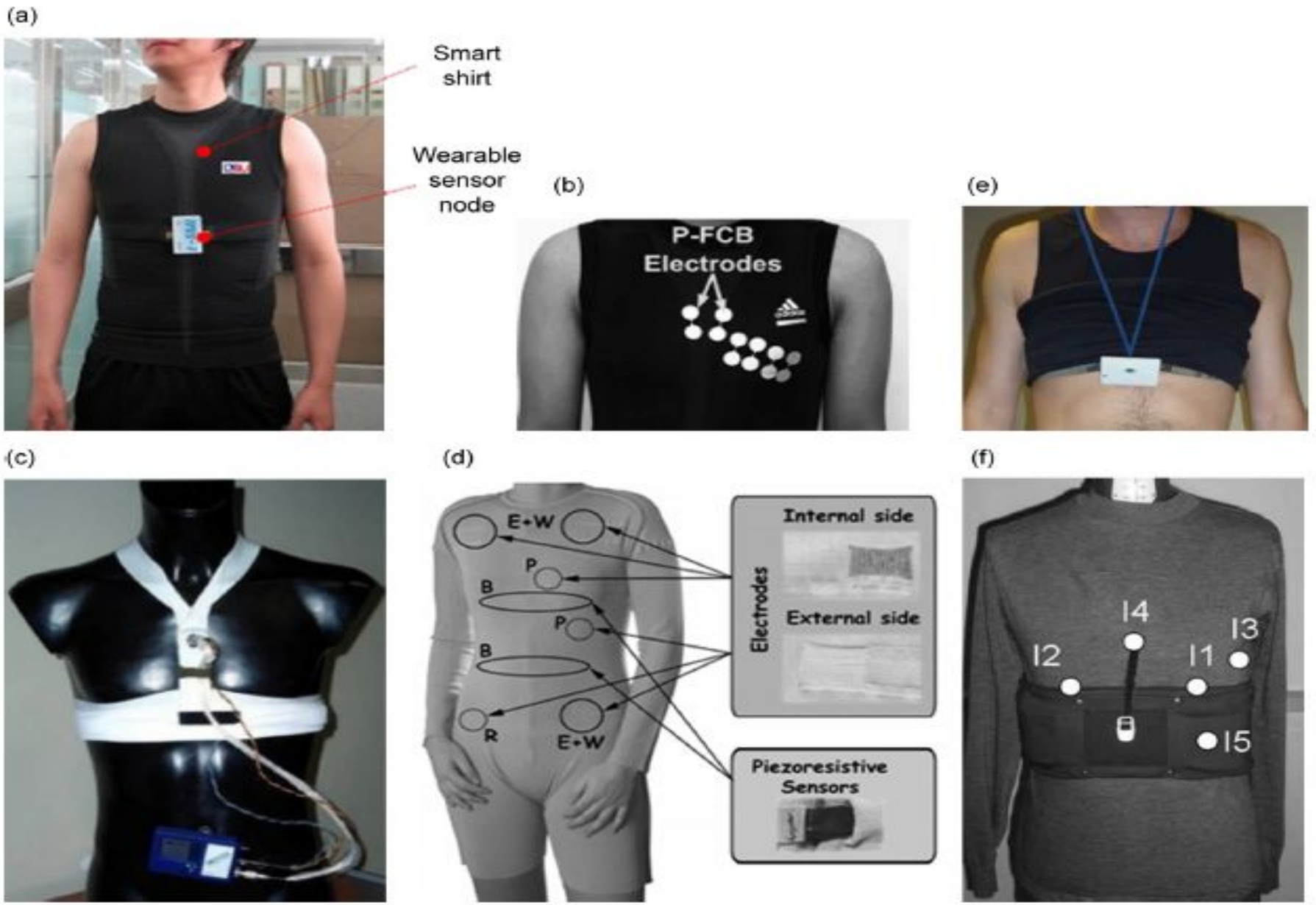


FIGURE 2 Wearable garments for ECG monitoring. Smart shirts [11], planar-fashionable shirt [18], Biotex [19], Lobin [21], Wealthy [22], and Protex [23].

Collecting ECG through Fabrics based sensors

- In addition to the diagnosis of AF, ECG can be measure using Wearable systems for collecting ECG have been developed from e-textile materials, e.g., in the form of smart shirts.
- The fabric-based active electrodes have been developed to embed into clothing for ECG monitoring.
- Many of these systems have integrated sensor design to allow them to measure not only ECG but also other physiological signals such as photoplethysmogram (PPG) and respiration.

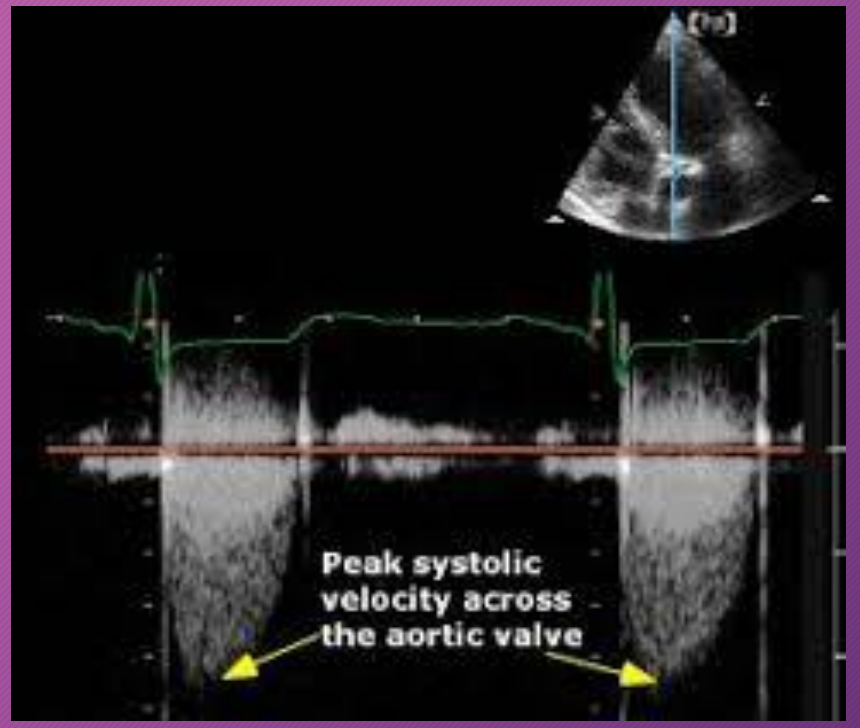
Diagnosis of Cardiovascular Diseases - coronary artery atherosclerosis

- Coronary heart disease (CHD), also known as coronary artery atherosclerosis, is caused by the blockages of blood vessels of the heart resulting in chest pain due to a lack of blood supply to the heart, i.e., angina.
- With uncontrolled blockage, parts of the heart may die, resulting in myocardial infarction (MI).
- CHD can also be asymptomatic and can lead to sudden deaths as a result of rupture of atherosclerotic plaque.
- Major risk factors of CHD include age, high BP, smoking, and diabetes.
- It has been reported that the baseline ECG abnormalities and pulse pressure can be used for screening risks of CHD.

Diagnosis of Cardiovascular Diseases - Peripheral arteries disease (PAD)

- Peripheral arteries disease (PAD) is a slowly progressive disease mainly due to atherosclerosis and further affects vessels such as the aorta and arteries of the lower extremities. PAD can lead to CAD, stroke, MI, and death from other vascular causes. Hypertension, diabetes, and smoking are the key risk factors associated with PAD
- Ankle-brachial index (ABI), the ratio of the BP in the lower legs to the BP in the arms, is a widely used index to assess asymptomatic PAD. PAD is determined with ABI < 0.9 in either of the lower limbs.
- As technology for sensing PPG becomes mature, it is possible to build wearable systems for diagnosis of PAD, which is a promising alternative to the more costly and less convenient measurement method of ABI by continuous-wave Doppler.

Continuous-wave Doppler



Variations of PPG sensors

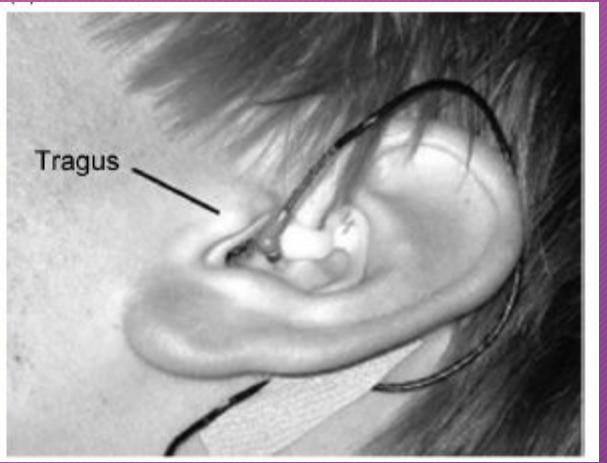
- In addition to measuring ABI, wearable systems comprised of PPG sensors can also provide a patient's heart rate, oxygen saturation, and heart rate variability.
- PPG detects blood volume changes in the micro-vascular bed of tissue.
- It has the advantages of being miniature and lightweight.

Variations of PPG sensor

- Various PPG wearable systems have been developed based on different configurations, e.g., in the form of a ring, ear-wearable gadget, eyeglass, and garment.
- One of the pioneer developments in wearable devices is the PPG sensor ring developed by Asada et al.

Variations of PPG sensor

- Several studies focused on PPG monitoring systems as ear-worn devices, such as the wearable in-ear measuring system (IN-MONIT) with micro-optic reflective sensor , a motion-tolerant magnetic earring sensor with an adaptive noise cancellation method , and an earphone system connected to a mobile phone have been done.



Variations of PPG Sensors

- Wearable systems in the form of garments with sensors embedded in a hat, glove, and sock have also been developed.
- Objects such as eyeglasses are also a good platform for PPG monitoring with discomfort reduced by clips to the finger or ear.

NEUROLOGICAL DISEASES

Need of monitoring devices

- Neurological diseases such as Parkinson’s disease and stroke are amongst the major causes of disability.
- Neurological rehabilitation provides therapeutic exercise to help patients to restore motor functions.
- Due to the shortage of hospital-centered rehabilitation resources, home-based rehabilitation therapies have gained interest.
- In this respect, wearable devices can play a role by providing remote monitoring in home settings of the mobility and physical functioning of patients with neurological disorders.
- It can significantly reduce healthcare cost and is useful in early symptom detection, which makes prompt and effective intervention possible.

Need of monitoring devices

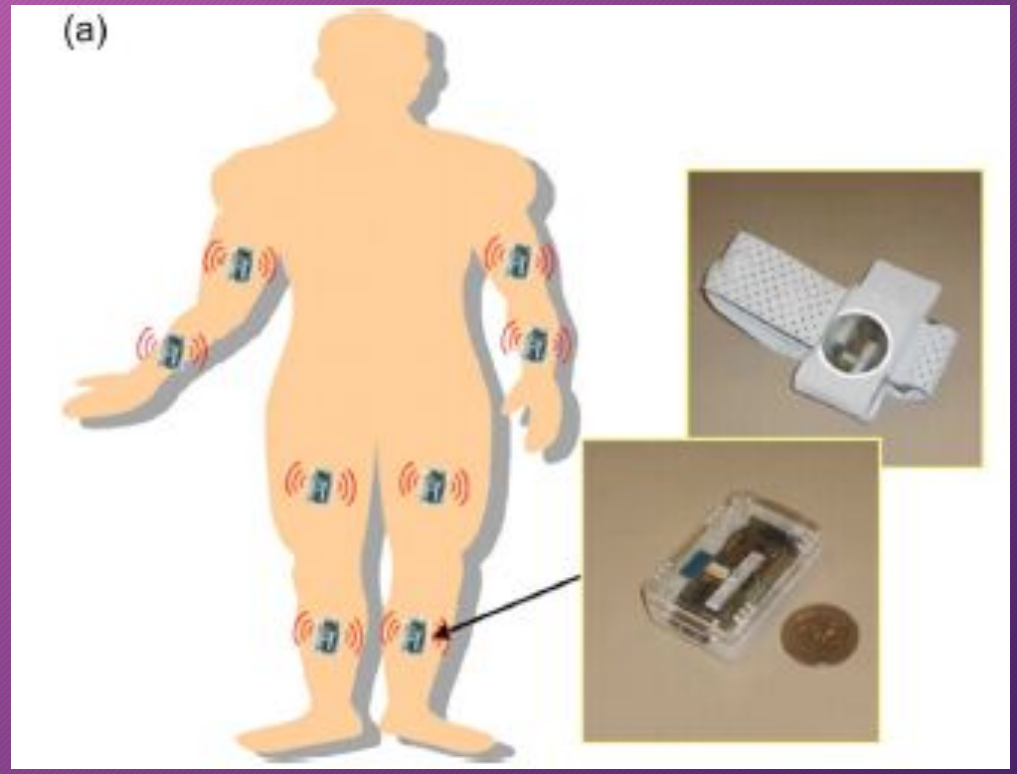
- Most importantly, incorporated with actuators, wearable devices (or wearable robots) can be used as rehabilitative and assistive devices for disabled people for the treatment of motor disorders.
- Wearable devices can be used for the prediction of sudden unexpected events related to chronic neurological diseases such as seizures.
- By continuous monitoring with wearable devices, some transient and covert features or symptoms related to these acute events can be captured for the understanding of pathology and the prediction of incidents.

Motor Activity Monitoring

- Micro-electromechanical inertial sensors such as accelerometers (ACCs) and gyroscopes are widely adopted for the monitoring of motor activities.
- ACC sensors measure changes in velocity and displacement while gyroscopes measure changes in orientation such as rotational displacement, velocity, and acceleration.
- These sensors have been extensively used for the continuous and automatic monitoring of movement disorders and functional activities

SHIMMER

- Patel et al. first developed an integrated platform (SHIMMER) with a wearable system and algorithm to estimate the severity of three different Parkinson's symptoms (i.e., tremor, bradykinesia, and dyskinesia)



- Each sensor node in the SHIMMER platform consists of a triaxial ACC sensor, a microprocessor, a radio transmitter, and a MicroSD card slot.
- Three feature types, including root-meansquare value, the data range value, and two frequency-domain features, were extracted to estimate the clinical score from the ACC signals recorded from patients during ten different motor tasks.
- The platform showed promising estimation results in terms of clinical score compared to that derived from visual inspection of video recordings.

Web based SHIMMER

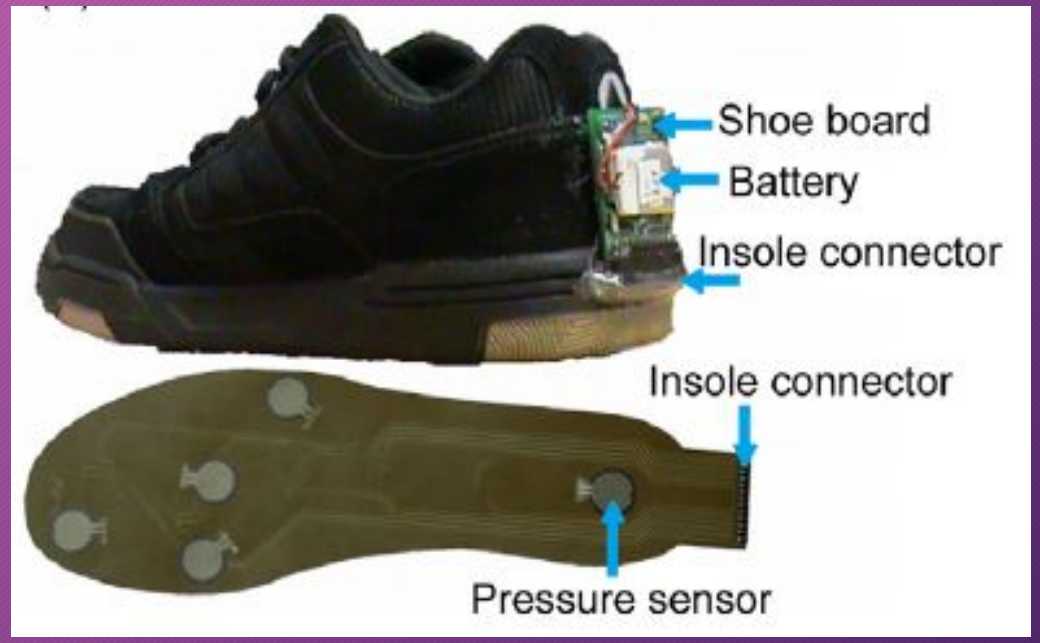
- Recently, the same research team developed a Web-based system (MercuryLive) based on SHIMMER for the monitoring of patients with Parkinson's disease in home settings.
- It contains three tiers, including central server, patient host, and clinician host.
- The clinician tier can access the sensor data to estimate the clinical score remotely.

Wearable sensor to access tremor

- Rigas adopted a set of wearable sensors to detect and assess tremor in a ubiquitous environment
- Two sets of features extracted from tremor activity (312 Hz component in the measured ACC signals) were incorporated into a hidden Markov model for tremor severity recognition, and the results showed high accuracy in tremor quantification and high specificity in distinguishing tremor activity from other motor symptoms.

Wearable Shoe

- designed for the rehabilitation of stroke patients



Textile based wearable sensor system

- A wearable system using a capacitive sensing method for locomotion monitoring and classification.
- The wearable strain-sensing shirt with conductive elastomers distributed over arm, forearm, and shoulders was designed for motion analysis in the context of neurological rehabilitation

Hybrid Sensor System

- The combination of EMG and ACC information is expected to significantly improve the classification of performance.
- Roy et al. investigated the feasibility of a hybrid-surface EMG (sEMG) and ACC wearable sensor system for automatic classification of daily activities in patients with stroke.
- The results showed that the hybrid configuration can achieve a mean sensitivity and specificity of 95% and 99.7% for the identification tasks and misclassification error of less than 10% for non-identification tasks.

Wearable sensor for daily activities

- Wearable systems can also be designed with real-time feedback to control human-machine interaction to assist daily activities for patients suffering from motor disorders.

Tremor Depression system

- A representative wearable robotic exoskeleton for orthotic tremor suppression (WOTAS) was designed to measure and suppress tremor by using two gyroscopes placed distally and proximally to the elbow joint.
- To depress tremor without affecting concomitant voluntary movement.
- one critical issue is tremor characterization, i.e., extracting instantaneous tremor parameters from the raw motion data to generate control command to drive a neuroprothesis or the human muscle itself in real time.

Other devices

- Similar wearable biofeedback systems have also been developed, such as an EMG-controlled exoskeletal orthosis wearable system for exercise training after stroke.
- wearable intelligent systems with real-time vibro-tactile feedback for the training of motor functions
- Posture correction in rehabilitative and protective applications.

Seizure Activity Monitoring for Epilepsy Patients

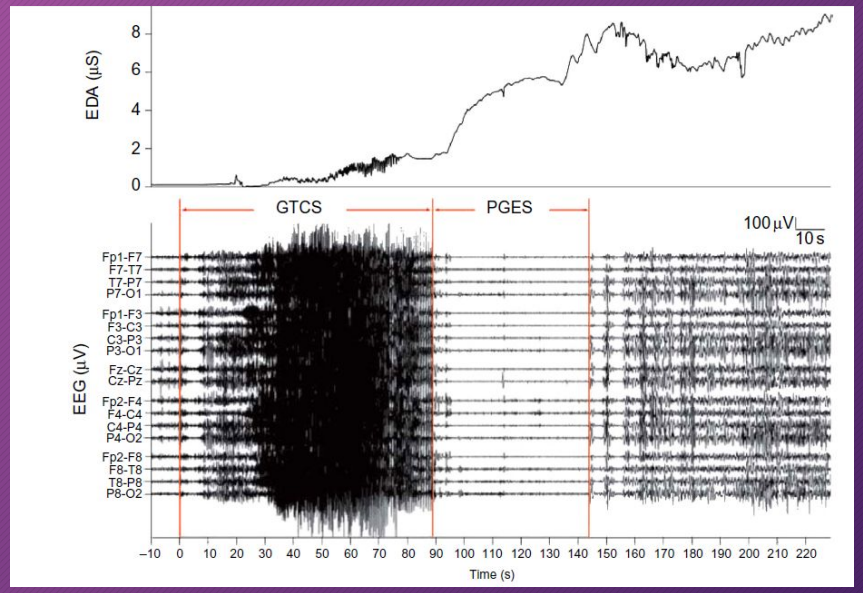
- Cardiac arrhythmia, respiratory dysfunction, dysregulation of systemic or cerebral circulation, and seizure-induced hormonal and metabolic changes can be potential pathomechanisms of the disease.
- EEG video hospital systems, which is a bulky system that greatly restricts the activities of the patient.
- Sensitivity and false alarm rate are the most important indices of wearable systems for these applications.

Wearable device for seizure detection

- A user-friendly designed wrist-type device for seizure detection was developed by Danish Care Technology ApS, which contains a three-axis ACC sensor, a microprocessor, and battery.

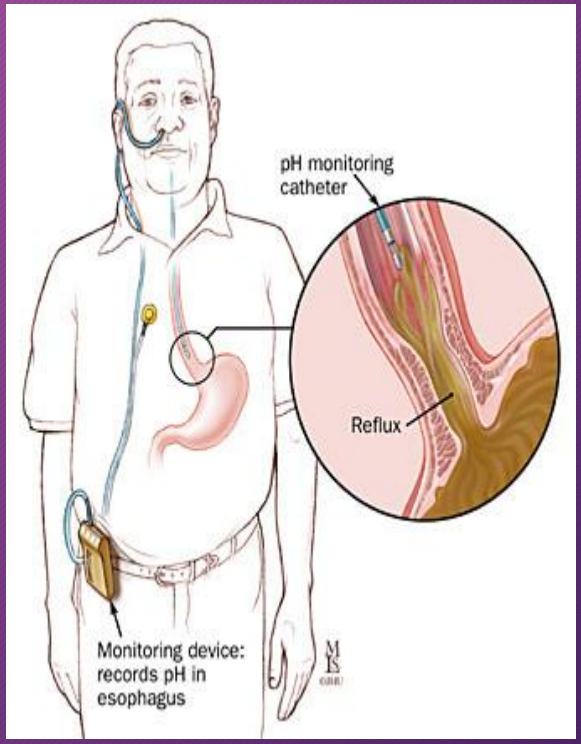
- A number of clinical studies have been conducted to validate the feasibility and accuracy of this sort of wearable device.
- In a prospective multi-center study including 73 patients of generalized tonic-clonic seizures (GTCS), this wrist-type device showed a mean sensitivity of 91% and a false alarm rate of 0.2/day.
- Another clinical study showed that a bracelet alarm device with a three-axis for epilepsy monitoring could identify tonic, clonic, and tonic-clonic seizures with similar sensitivity (20 of 22 seizures) and low false alarm rate (8 false alarms during 1,692 hours of monitoring).

- wrist-worn device with skin conductance electrodes (Ag/AgCl and conductive fabric electrodes) for long-term electrodermal activity (EDA) recordings reflect sympathetic nerve activities.



GASTROINTESTINAL DISEASES

- Conventionally, sensing inside the GI tract is accomplished by implantable devices, e.g., esophageal pH monitoring, which is the gold standard for diagnosing gastroesophageal reflux disease (GERD)
- 24-hour ambulatory pH monitoring are frequently needed before therapy is initiated
- Ambulatory wireless pH monitoring - can be clipped to the lining of the esophagus for continuously measuring pH over a 48-hour period in an ambulatory setting such that acid reflux variables, including total reflux time, number of reflux episodes, and total percentage time of pH,4, can be estimated and collected as the symptom-association probability scores for the diagnosis of GERD



- Recent advances in flexible optoelectronics, however, have opened up a new direction for designing wearable sensors to be worn non-invasively on irregular body surfaces or the GI wall for the early and prompt detection of diseases.

On-Body Wearable Sensor Design Based on Flexible Electronics

- Wearable sensors can be fabricated on flexible substrate with a reasonable degree of stretchability such that they can conform to the complex and intricate body surface.
- High pressure sensitivity sensor based on flexible polymer transistor for measuring blood pressure and multi-sensor epidermal electronics system (EES) based on flexible silicone substrate.
- The integrated EES is designed with temperature sensor and electrodes for measuring ECG/EMG with an aim to adhering to the human skin for monitoring health conditions in our daily lives.
- An ultra-thin sensing film for mobile electronics application, healthcare, and biomedical systems has also been proposed

In-Body Chemical and Biological Flexible Sensors and Systems

- Chemical and biological sensors are widely used in many different medical fields, including the sensing of pH inside the GI tract.
- Chemical sensors measure concentration of a specific component of a chemical reaction while a biological sensor is used to detect analytes, such as proteins, DNA, and antibodies based on physiochemical measurements.