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REVIEW: VERSATILE APPLICATION OF BIOMEDICAL ENGINEERING IN DIFFERENT FIELDS

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ABSTRACT

The biomedical engineering is concerned with the amalgamation of medical science with engineering. Biomedical engineering tries to close the gap between engineering and medicine: It combines the design and problem-solving quality of engineering with medical and biological sciences to advance healthcare treatment, including diagnosis, monitoring, and therapy.Prominent biomedical engineering applications include the development of biocompatible prostheses, variou s diagnostic and therapeutic medical devices ranging from clinical equipment to microimplants, common imaging equipm ent such as MRIs and EEGs, regenerative tissue growth, pharmaceutical drugs and therapeutic biological.

This field provides the platform of designing the bio machines and bio-equipment's to serve mankind. Bioinformatics is the interdisciplinary field for computing the information related to field of biology and genetics for further analysis and designing of the software related to it. The medical implication of instruments and machines designed by complex engineering is the practical grounds of functioning of biomedical engineering. In this paper we have formulated the bifurcations and different applications of Biomedical engineering in various areas. The area of biomedical engineering is advancement in approach that covers the whole canvas of living sciences, material, and phenomenal sciences with the technology.

KEY WORDS- ***Genetic Engineering, Biomachine principle, Bionics, Biometric working. Clinical engineering, Neural engineering, Medicinal biotechnology.***

1. INTRODUCTION

The field of biomedical engineering is presently playing a crucial role for noticing, observing of all metabolic process occurring inside the living organisms. Organ on co-functioning forms organ system and their working sustains life in order to study these physiological processes their working mechanism, organ structure, position, size, location (anatomy) we need to take observe them at very minute and microscopic level for which there is immense requirement of the instruments that can scan the bodies in order to provide observable details. Biomedical Instrumentation Engineering involves developing new devices and procedures that solve medical and health-related problems by combining their recent advances knowledge in engineering, biology, and medicine to improve human health through cross-disciplinary activities that integrate the engineering sciences with the biomedical sciences and clinical practice. Biomedical engineers may spend their days designing electrical circuits and computer software for medical instrumentation

2. BIOMEDICAL ENGINEERING AREAS

Bioengineering includes various fields:

1. The acquisition of new knowledge and understanding of living systems through the innovative and substantive application of experimental and analytical techniques based on the engineering sciences.
2. The development of new devices, algorithms, processes and systems that advance biology and medicine and improve medical practice and health care deliver.
3. Biomedical engineers build artificial organs, limbs, knees, hips, heart valves and dental implants to replace lost function; others are growing living tissues to replace failing organs. The development of artificial body parts requires that biomedical engineers use chemistry and physics to develop durable materials that are compatible with a biological environment.

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4. Biomedical engineers are also working to develop wireless technology that will allow patients and doctors to communicate over long distances.

Diagnosis of diseases, disabilities present inside body is observed and cured by the biomedical instruments, the broader perspectives of biomedical engineering is described I this research paper. But more often, sub-disciplines within BME are classified by their association(s) with other more established engineering fields, which can include[1]:

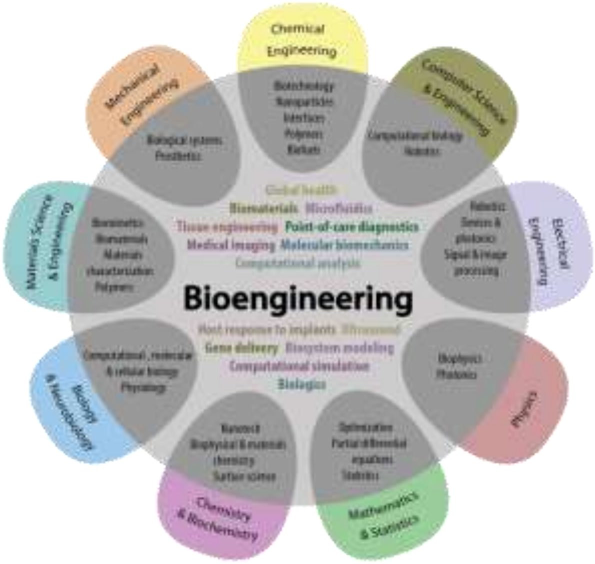

Fig.1-Different Biomedical engineering Areas

• **Bio-Chemical engineering** -
BCE is associated with biochemical, cellular, molecular and tissue engineering, biomaterials, and bio-transport.

• **Bio-Electrical engineering and Bio-Computer Science**
This is usually associated with bioelectrical and neural engineering, bioinstrumentation, biomedical imaging, and medical devices. This also tends to encompass optics and optical engineering - biomedical optics, bioinformatics, imaging and related medical devices.

• **Bio- Mechanical engineering** –
It deals with biomechanics, bio-transport, medical devices, and modelling of biological systems, like soft tissue mechanics. One more way to sub-classify the discipline is on the basis of the products created.[2]

3. RESEARCH STRATEGIES AND TECHNOLOGIES IN BIOMEDICINE

- The Biomedical Engineering Research Strategy identifies three priority research themes and one emerging research theme-
- To invent and implement technologies that will keep people healthy and minimize complications from diseases, while also helping predict injury and illness.
- To develop more accurate imaging and diagnostics to detect disease earlier, provide biomarkers for evaluating new therapies, and enable personalized treatments optimized for the individual patient.
- To develop high-quality, long-lasting treatments for injury and disease, based on stem cells, targeted drugs and novel devices.
- To deliver research built on our emerging strengths, using engineering tools and approaches to improve patient flow through the health care system

As biomedical engineering being a inter discipline aspect of biology, medicine and technology respect so these technology in terms of physiology is of various types described below-

Cardiology Technology

It deals with the production of drugs, study of heart (cardio-physiology), and diagnosis of problem related with cardiovascular systems by making instruments for it, like electrocardiogram

Neural Technology

It deals with the production the drugs, study of nervous system (neural-physiology) and diagnosis of neural problems by designing equipment's for it, like CT scanning technique

Orthopedic Technology

It deals with the production of drugs, study of physiological aspects of bones, diagnosis of problems related to it

Cancer Technology

It deals with the formulation of all technology in order to study the formation, behavior and results of oncogenic cells formations.

4. VERSATILE APPLICATIONS OF BIOMEDICAL ENGINEERING

It involves the probabilistic prediction of e of diseases which can affect health severely and provides tools to deal with them in order to reduce them. These tools are functional at ultra-microscopic level and hence involve engineering applications are used at very large scale[3]. There is an old saying that "technology acquires all right thing, for all wrong things", this is evenly applicable for the genetic engineering. Genetic engineering challenges all metabolic malfunctions in order to prevent humans from various kinds of genetic disorders.[4] Genetic engineering provides the place to deal with the genetic makeup of organisms and to mould it in accordance with our needs. Recently, genetic engineering has thrived towards changing the traits and characters of offspring to be produced.

- **BIOMETRICS**

Biometrics another interesting application of biomedical engineering deals with the provision of database that stores the unique features of individual for their recognition that are under surveillance.[5]Recently from last few years it is widely used in corporate organization, to keep regular accounts of their employees. Biometrics authentication (or realistic authentication) is used in computer science as a form of identification and access control.[6, 7]

Many different aspects of human physiology, chemistry or behavior can be used for biometric authentication. The selection of a particular biometric for use in a specific application involves a weighting of several factors. Jain et al. (1999)[8] identified seven such factors to be used when assessing the suitability of any trait for use in biometric authentication.

1. Universality means that every person using a system should possess the trait.
2. Uniqueness means the trait should be sufficiently different for individuals in the relevant population such that they can be distinguished from one another.
3. Permanence relates to the manner in which a trait varies over time. More specifically, a trait with 'good' permanence will be reasonably invariant over time with respect to the specific matching algorithm.
4. Measurability (collectability) relates to the ease of acquisition or measurement of the trait. In addition, acquired data should be in a form that permits subsequent processing and extraction of the relevant feature sets.
5. Performance relates to the accuracy, speed, and robustness of technology used (see performance section for more details).
6. Acceptability relates to how well individuals in the relevant population accept the technology such that they are willing to have their biometric trait captured and assessed.
7. Circumvention relates to the ease with which a trait might be imitated using an artifact or substitute.

There are four general steps a biometric system takes to perform identification and verification −

- Acquire live sample from candidate. (using sensors)
- Extract prominent features from sample. (using processing unit)
- Compare live sample with samples stored in database. (using algorithms)
- Present the decision. (Accept or reject the candidate.)

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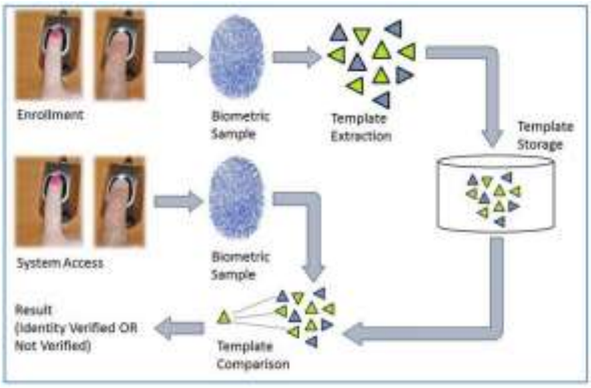

Fig.2Working of Biometric System

Biometric Template − It is a digital reference of the distinct characteristics that are extracted from a biometric sample.

Candidate/Subject − A person who enters his biometric sample.

Closed-Set Identification − The person is known to be existing in the database.

Enrolment − It is when a candidate uses a biometric system for the first time, it records the basic information such as name, address, etc. and then records the candidate's biometric trait.

False Acceptance Rate (FAR) − It is the measure of possibility that a biometric system will incorrectly identify an unauthorized user as a valid user.

FAR = Number of False Acceptances\Number of Identification Attempts

A biometric system providing **low FAR ensures high security**.

False Reject Rate (FRR) − It is the measure of possibility that the biometric system will incorrectly reject an authorized user as an invalid user.

FRR = Number of False Rejections\Number of Identification Attempts

Open-Set Identification − The person is not guaranteed to be existing in the database.

The biometric sample is acquired from candidate user. The prominent features are extracted from the sample and it is then compared with all the samples stored in the database. When the input sample matches with one of the samples in the database, the biometric system allows the person to access the resources; otherwise prohibits. Proper biometric use is very application dependent. Certain biometrics will be better than others based on the required levels of convenience and security[9] No single biometric will meet all the requirements of every possible application.[10]This provides unique identity to particular individual by the use of their physical traits like finger prints; eye prints and hence, maintains their records. Recently this technique used in forensic department. In recent times, biometrics based on brain (electroencephalogram) and heart (electrocardiogram) signals have emerged.[11,12]The research group at University of Kent led by Ramaswamy Palaniappan has shown that people have certain distinct brain and heart patterns that are specific for each individual.

- **BIOMACHINES[13]**

Biomechanics is the study of the structure, function and motion of the mechanical aspects of biological systems, at any level from whole organisms to organs, cells and cell organelles,[14]using the methods of mechanics.[15]The study of biomechanics ranges from the inner workings of a cell to the movement and development of limbs, to the mechanical properties of soft tissue, and bones.

The basic principles of synthetic biology is used to design biomachine. This means designing artificial cells by combining elements or modules from existing biology. In our case, instead of designing alive cell by reprogramming it, we decided to design very simplified artificial cells from scratch. As well to avoid any unexpected variation in composition and modification in time our artificial cells are not alive. Although 100% made of biological compounds they are more biochemical constructions than alive systems. Biomarkers such as metabolites, proteins, etc. are captured by our Biomachine. The artificial biochemical network is encapsulated into a bilayer membrane vesicle. When the right combination of biomarkers quantities is identified then a qualitative response is provided.

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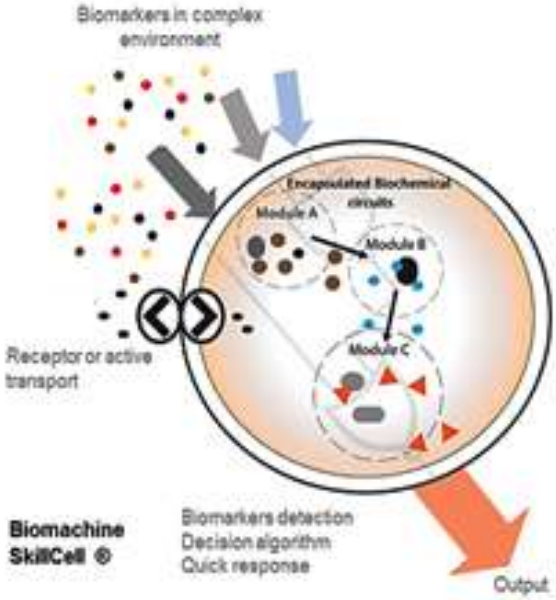

Fig. 3 Biomachine principle or medical diagnosis.

Some simple examples of biomechanics research include the investigation of the forces that act on limbs, the aerodynamics of bird and insect flight, the hydrodynamics of swimming in fish, and locomotion in general across all forms of life, from individual cells to whole organisms. It plays a vital role to improve the design and produce successful biomaterials for medical and clinical purposes. One such example is in tissue engineered cartilage.[16]Biomedical engineering has provided various useful instruments and equipment to serve the mankind. Today we can't imagine the diagnosis without use of MRI technique (magnetic Resonance imaging), sonography and ultrasonography, elctrocardiography CT Scanning. These machines work at microelectronic levels that to with great accuracy for identification of physiological impairment.

- **BIOLOGICALLY INSPIRED ENGINEERING**

It is technique which is important to replace the organs that go under any kind of impairment and disorders by the organs which are artificially sculptured and work similarly, with in the body as a normal natural organ would work in body. Recently, a group of researchers at Harvard University developed an innovative, anatomically designed device that could help rehabilitate patients suffering from ankle and foot disorders. Unlike traditional exoskeletons, which are rigid and restrict full range-of-motion, this prototype incorporates a unique combination of soft materials, sensors, pneumatic artificial muscles (PAMs), and control software to provide support and allow for natural movement[17].

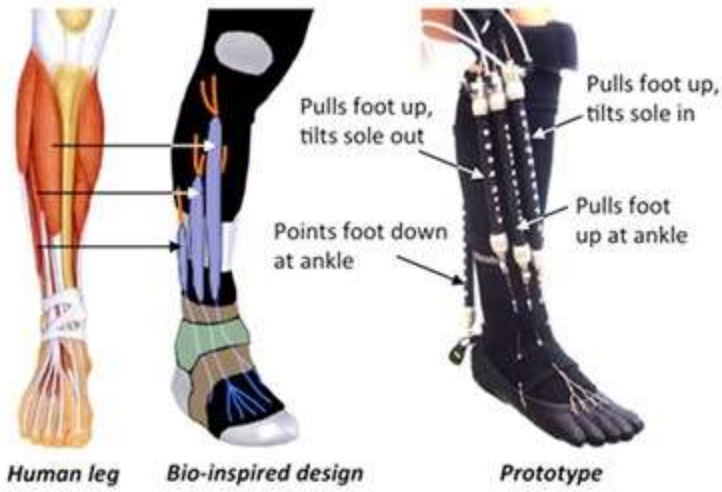

Fig.4 Engineering A Biologically Inspired, Soft Orthotic Device

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The study of bionics often emphasizes implementing a function found in nature rather than imitating biological structures. For example, in computer science, cybernetics tries to model the feedback and control mechanisms that are inherent in intelligent behavior, while artificial intelligence tries to model the intelligent function regardless of the particular way it can be achieved.
It is the application of biological methods and systems found in nature to the study and design of engineering systems and modern technology.[18]This is advantageous over the replacement surgery of impaired organs by other organ from living organisms because that causes lot of problems like selection of suitable donor, secondly it causes the person doomed to consume the immune-suppressant lifelong. In robotics, bionics and biomimetics are used to apply the way animals move to the design of robots. BionicKangaroo was based on the movements and physiology of kangaroos. Some paints and roof tiles have been engineered to be self-cleaning by copying the mechanism from the Nelumbo lotus.[19]Nanostructures and physical mechanisms that produce the shining color of butterfly wings were reproduced in silicon by Greg Parker, professor of Electronics and Computer Science at the University of Southampton and research student Luca Plattner in the field of photonics, which is electronics using photons as the information carrier instead of electrons.

- **CLINICAL ENGINEERING**

This is the mode to make a technician acknowledged to the application of the biomedical engineering, so that they can deal with the equipments and serve the medical services. The role of the clinical engineers is to logistically handle the machines in order to maintain the accuracy of work. Clinical engineers also advise medical device producers regarding prospective design improvements based on clinical experiences, as well as monitor the progression of the state-of-the-art in order to redirect hospital procurement patterns accordingly. The first modern professional intersociety engineering meeting to be focused on the application of engineering in medicine was probably held in 1948, according to the Alliance for Engineering in Medicine and Biology.[20]

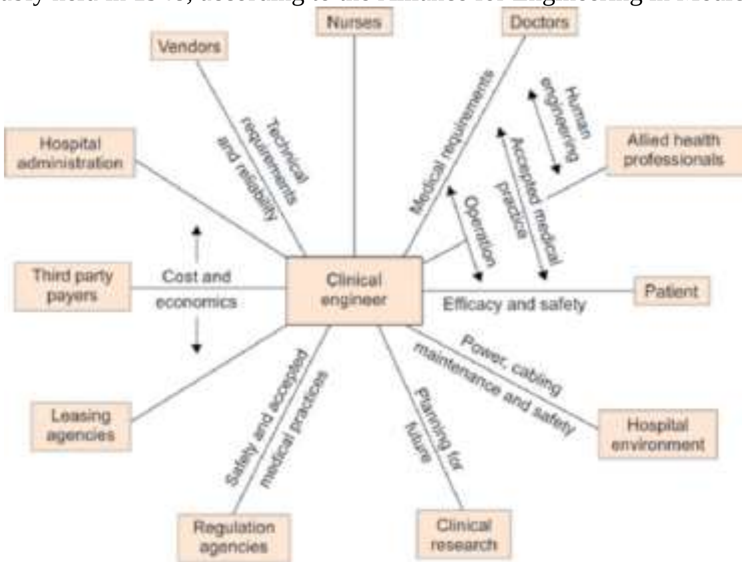

Fig. 5: Diagram illustrating the range of interactions in which a clinical engineer might be required to engage in a hospital setting

- **NEURAL ENGINEERING**

This is an inter discipline that uses engineering techniques to design instruments that can be advantageous to study the neural activities effectively. The field of neural engineering draws on the fields of computational neuroscience, experimental neuroscience, clinical neurology, electrical engineering and signal processing of living neural tissue, and encompasses elements from robotics, cybernetics, computer engineering, neural tissue engineering, materials science, and nanotechnology.[21]Neural engineers are uniquely qualified to solve design problems at the interface of living neural tissue and non-living constructs.
The main principles of the Neural Engineering Framework (NEF) are[22]-
(A) By the representation principle, signals are encoded in neural populations based on the tuning curve of each neuron (top). The tuning curve describes how active a neuron is given some input signal. If we drive the eight neurons in the top panel with the input signal in the middle panel, we see the spike trains in the bottom panel.
(B) By the representation principle, the spiking activity of a neural population can be decoded to recover the original input signal, or some transformation of that input signal. First, the firing pattern shown in the top panel is filtered with a decaying exponential filter (middle panel). The filtered activity is then summed together with a

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set of weights that approximates the input signal (bottom panel, green) and the cosine of the input signal (bottom panel, purple).

(C) A sine wave is encoded by population A (top panel); the negative of that signal is projected to population B (middle panel) and the square of that signal is projected to population C (bottom panel). By the transformation principle, populations of neurons can send signals to another population by decoding the desired function from the first population and then encoding the decoded estimate into the second population. These two steps can be combined into a single step by calculating a set of weights that describe the strength of the connections between each neuron in the first population and each neuron in the second population.

(D) A neurally implemented dynamical system has negative feedback across its two dimensions, resulting in a harmonic oscillator. The oscillator is plotted across time (top) and in state space (bottom). By the dynamics principle, signals being represented by population of neurons can be thought of as state variables in a dynamical system.

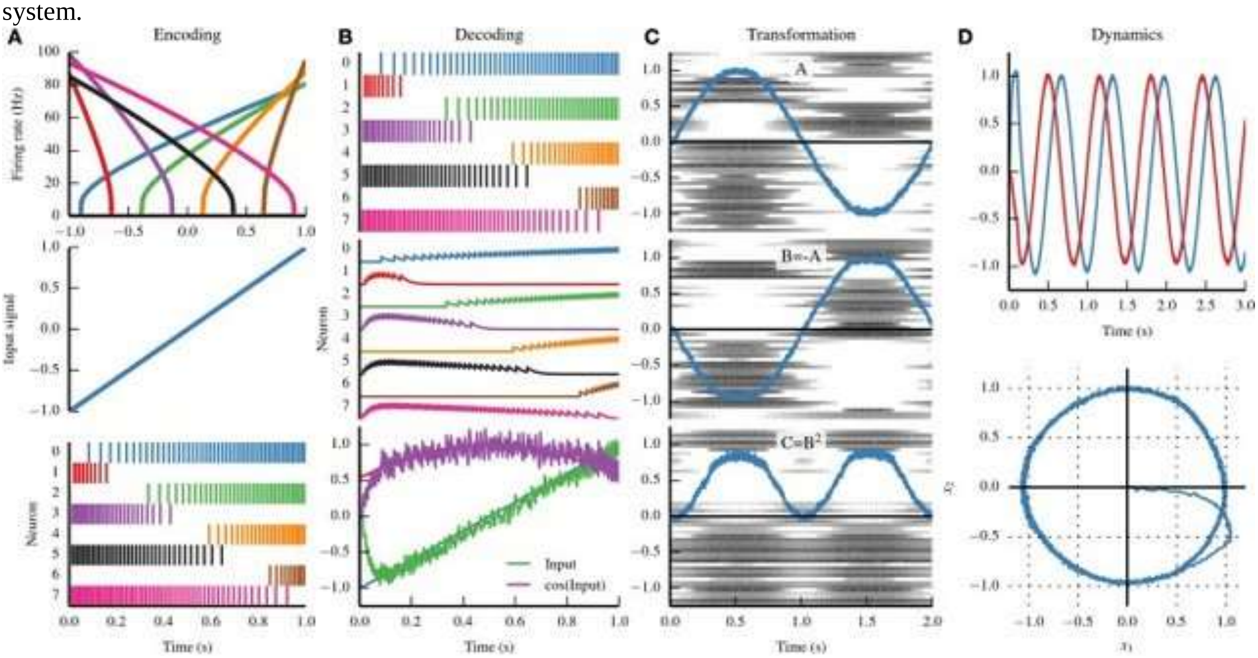

Fig. 6 Summary of the three principles of the Neural Engineering Framework (NEF)

- **TISSUE ENGINEERING**

Tissue engineering like other genetic engineering is a part of biotechnology. According to Langer and Vacanti, Tissue engineering is an interdisciplinary field that applies the principles of engineering and life sciences toward the development of biological substitutes that restore, maintain, or improve [Biological tissue] function or a whole organ[23]

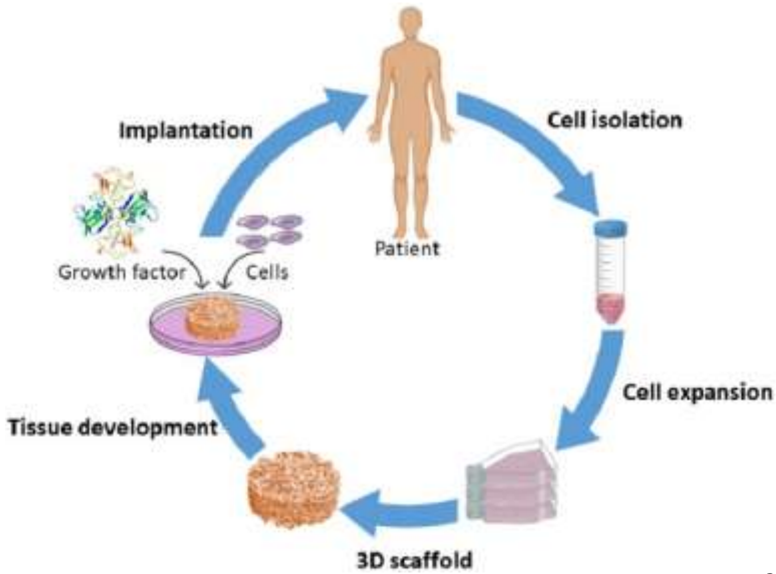

Fig. 7. Schematic of the scaffold-based tissue engineering approach[24]

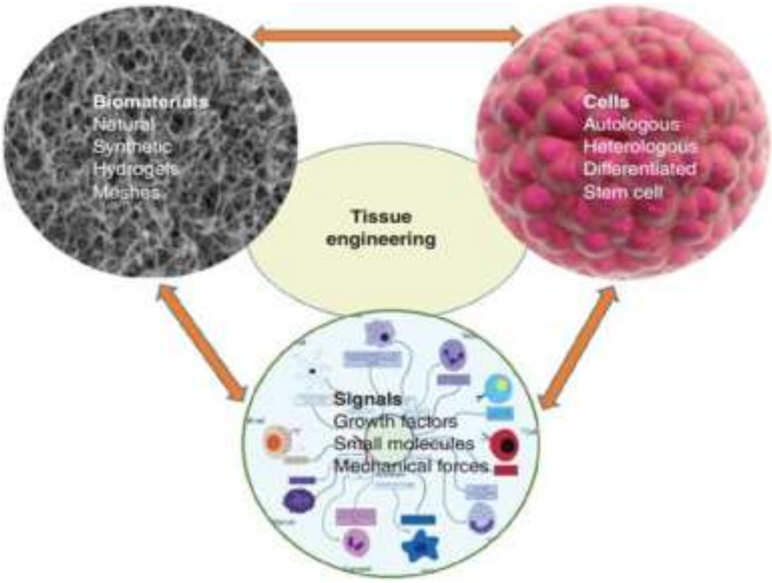

Fig. 8. The tissue engineering triad. A combination of cells cultured on a biomaterial scaffold with appropriate biophysical and chemical signals coordinate to recapitulate the desired tissue.[25]

Among the major challenges now facing tissue engineering is the need for more complex functionality, as well as both functional and biomechanical stability and vascularization in laboratory-grown tissues destined for transplantation. The continued success of tissue engineering and the eventual development of true human replacement parts will grow from the convergence of engineering and basic research advances in tissue, matrix, growth factor, stem cell, and developmental biology, as well as materials science and bioinformatics. Recently it is focusing on creation of organs similar to natural organs by artificial methods. Many researchers have made solid jaw bones and trachea from human stem cells recently many urinary bladders have been created in laboratories and are successfully transplanted[22, 23]

- **PARAMEDICAL ENGINEERING**

This is another inter discipline aspect that deals with the drug engineering its novel delivery, targeting and delivering[26-30]. It may also be defined as the part of technology that is correlated with the pharmacy. Implants are now used to deliver drugs in the patient body and deliver the particular content for a particular time period, like subcutaneous implants are present which even used as a contraceptive method for females who want to space a child which they can conceive by having unwanted intercourse.

- **BIOSENSORS**

The term "biosensor" was coined by Cammann,[31] and its definition was introduced by IUPAC. [32-34] it is a method to convert physical quantities and traits to the electric output. A good sensor should response to energy present in the measuring and should ignore all other traits. A sensor basically uses the energy input and then converts it into electric impulse for usage. These phenomenon forms the foundation of the electrophysiology. The materials used in biosensors are categorized into three groups based on their mechanisms: bio-catalytic group comprising enzymes, bio-affinity group including antibodies and nucleic acids, and microbe based containing micro-organisms.

A biosensor can be defined as an analytical device35-36 that combines a biological sensitive recognition element 37 (such as antibodies, nucleic acids, enzymes, or aptamers) immobilized on a physicochemical transducer, and connected to a detector to identify the presence of one or more specific analytes 38, their concentrations, and kinetics in a sample. The specificity and selectivity of the biosensor is determined by the catalytic or affinity properties of the biological recognition element. The signal originating from the interaction between the analyte of interest and the biological recognition element is then transformed by a transducer to an optical or electrical readout [39-40]. Biosensors are more favourable, reliable, accurate, cost effective, and easy to use compared to other conventional lab-based detection techniques 41 due to their portability, reusability, real-time response, and high specificity and selectivity. Figure 8 shows a schematic of the different parts in a

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biosensor. The two important parts that distinguish the biosensor for biological recognition are sensing element and the transducers.

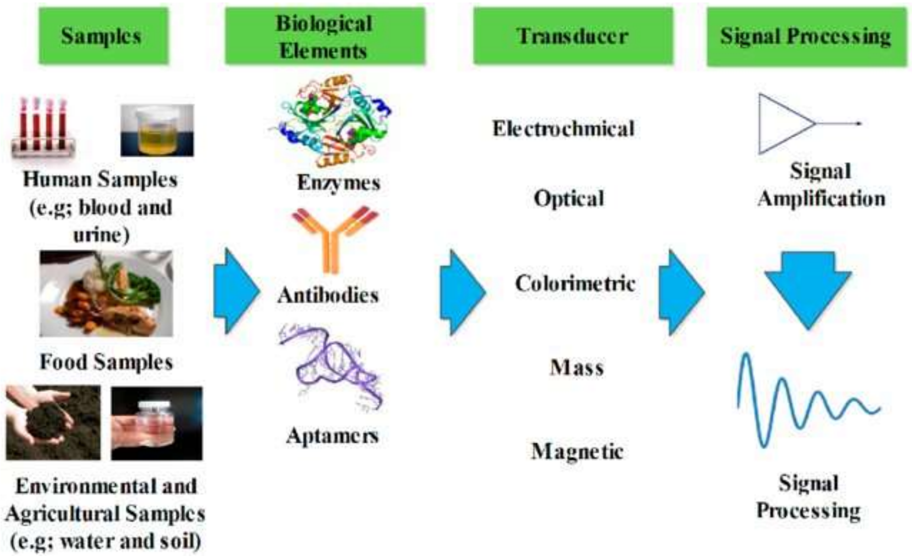

Fig. 9. Schematic of different parts of a biosensor including biological recognition elements, transducers, and detectors

These instruments have a wide range of applications ranging from clinical through to environmental and agricultural. The devices are also used in the food industry. Biosensors are used for the detection of pathogens in food. Presence of Escherichia coli in vegetables is a bio indicator of faecal contamination in food.42,43[33, 34] Glucose biosensors are widely used in clinical applications for diagnosis of diabetes mellitus, which requires precise control over blood-glucose levels.45[35] Blood-glucose biosensors usage at home accounts for 85% of the gigantic world market.46[36]Some examples of the fields that use biosensor technology include:
General healthcare monitoring
Screening for disease
Clinical analysis and diagnosis of disease
Veterinary and agricultural applications
Industrial processing and monitoring
Environmental pollution control

- **BIOTECHNOLOGY[47]**

Biotechnology is a broad field of the life sciences and applied sciences that is defined as any technological application using biological systems, living organisms, or derivatives thereof, to make or modify products or processes for the demands of humans[48].Biotechnology is defined as biology-based technology using organisms or their parts to make or modify products or to improve characteristics of plants, animals, and microorganisms for the demands of human beings. Biotechnology profoundly impacts various fields such as agriculture, animal husbandry and veterinary, industry, food science, pharmaceutics and medicine, environment, fine chemistry, biofuels, forensics, and nanotechnology.
In field of biotechnology biomedical engineers have recently formed the textiles for dressing that not only persist antifouling but also antibacterial values. By the use of bio nanotechnology micro electrodes have been designed for the stimulation of cortical neurons, these electrodes have also been implanted to stimulate the peripheral nerve. Micro fibril rich collagen sheets have been designed for proper delivery of drugs for a promising treatment of cancer. Collagen hydrolysates are used which can reduce pain of osteoarthritis.

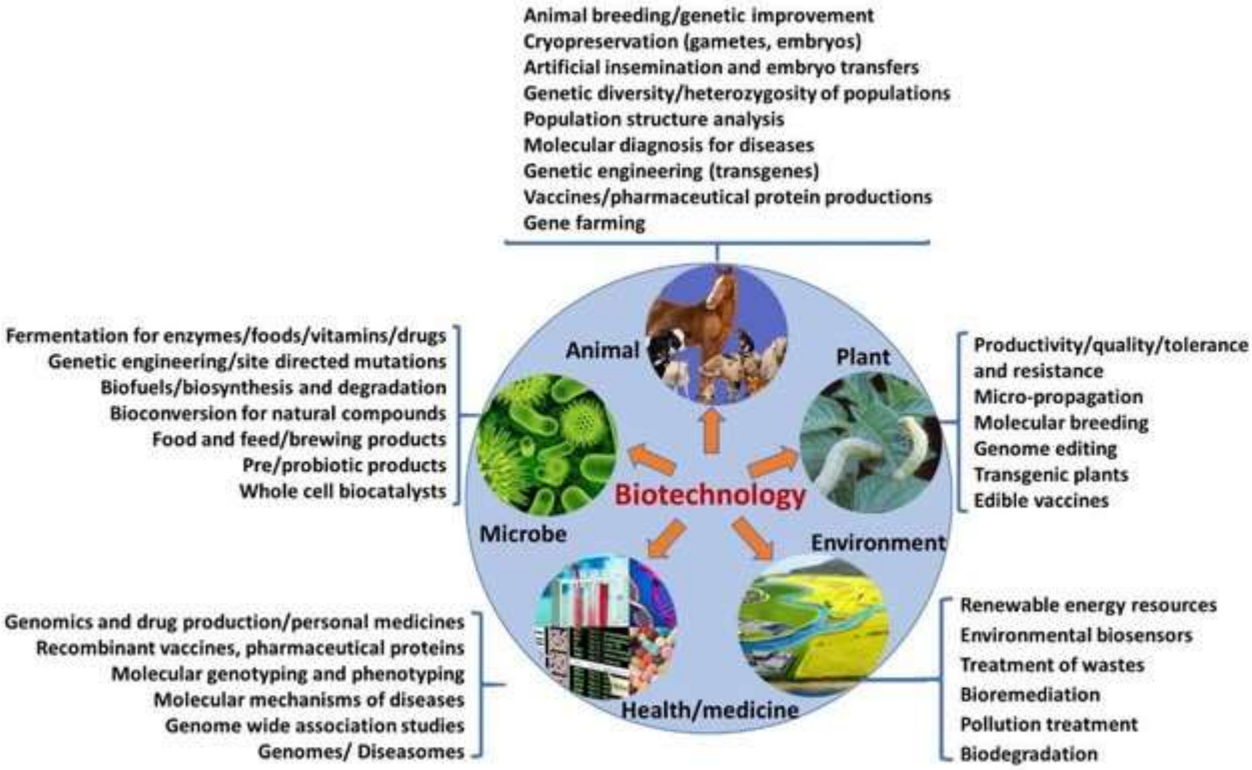

Fig.10. Major areas of biotechnology

- **NANOTECHNOLOGY[50,51]**

There is huge use of nanofibers in the biomedical engineering. at an average one of the major application of biofibres is in biomedical area only. It is used for the purpose of tissue engineering, drug delivery and wound healing. Tissue may be defined as a group of cells along with the extra cellular material (ECM). Due to large surface area and porosity the electrospunnofibers are used to successfully replace the extra cellular materials.

- **BIOMEDICALS AND FOOD INDUSTRY[52,53]**

Pectin is highly known for its non-toxic nature, its low production cost and for its excellent capability of drug delivery. Pectin is used for delivery of drugs nasally, orally and vaginally and it is well accepted by the patients as well. Several other components designed by the use of pectin are used for targeting proteins and drugs like(hydrogels, films, microspores and nanoparticle).Polysaccrides(complex carbohydrates), are used recently for the preparation of the nanoparticle and is an excellent material for the synthesis of drugs. Naturally existing polymers have complete advantage over artificially synthesized once because of Compatibility in biological systems and its biodegradability, inspite of the fact that it lack in front of artificial polymers in terms of strength.
phycobilisome (PBPs) are widely used as a natural protein dye in various food and cosmetic industry. PC isolated from S. platensis is widely used as a natural pigment in food such as chewing gum, dairy products and jellies[54][47]. Although, having lower comparative stability in the presence of heat and light, PC is considered more versatile due to its health-beneficial effects than that of gardenia and indigo in jelly gum and coated soft candies[55][48]. PBPs are also used in many other food products such as fermented milk products, ice creams, soft drinks, desserts, sweet cake decoration, milk shakes, maintaining the color at room temperature.

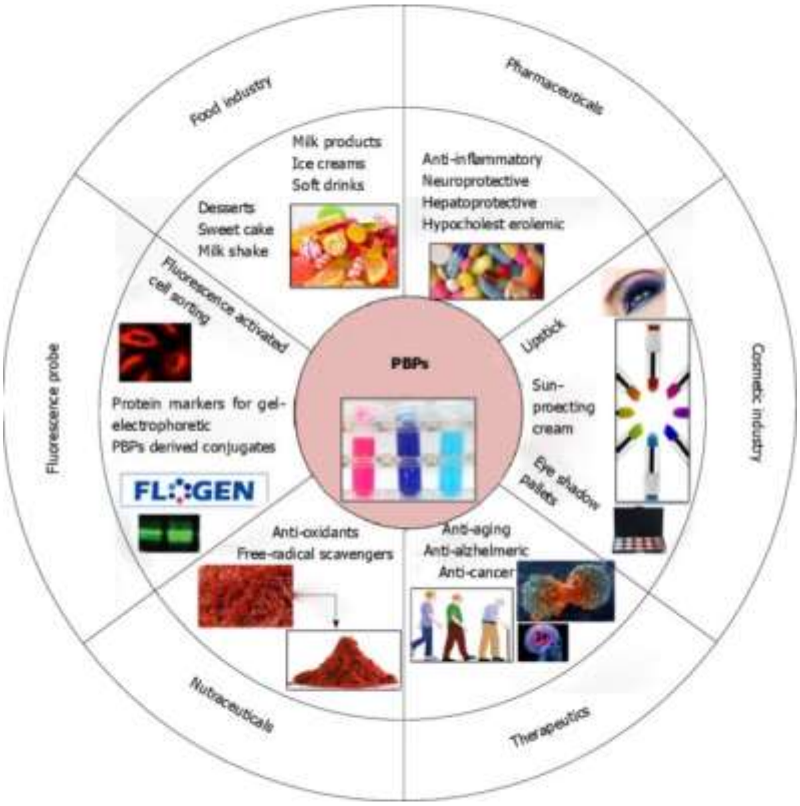

Fig.11 Application of phycobiliproteins in food, cosmetics, pharmaceutical and biomedical industries. PBPs: phycobiliptoteins.

V CHALLENGES

- Detection and monitoring technologies for improving whole body and mental health including personalized disease monitors, such as biosensors for real-time diagnostics, instruments for point-of-care testing, and technologies to assess body or organ function;
- Processes for preventing the risks associated with acute and chronic diseases, including engineering technologies and devices to support safe and healthy aging, assist with balance control to reduce the risk of falls, assist with navigation and location-tracking, and support mobility independence for seniors;
- Understanding and predicting the role of multiple inputs (such as diet and activity level) under normal and altered conditions (exercising, extended bed-rest) in developing, adolescent, mature and elderly populations. This could include subject-specific devices to provide guidance on activity levels to prevent chronic joint injuries based on oxygen consumption, joint movement and muscle activation patterns; and
- Investigating integrated (multi-system) mechanisms of healthy aging including cardiovascular, musculoskeletal, nervous and respiratory systems. Individuals with conditions such as diabetes, asthma, obesity or mental illness could be provided with devices with real-time feedback for physician consultation to enable activity modification based on blood levels of critical components (e.g., oxygen and insulin), heart rate, as well as local environmental factors (e.g. smog, altitude, temperature).

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