# CHAPTER-1. Bioengineering- An emerging trend in biology (An Introduction)

Bioengineering is also known Biological Engineering, is the study of applied engineering practices in general biology. It is the application of principles of biology and the tools of engineering to create accessible, visible and cost effective products. It provides the knowledge about pure and applied sciences like mass and heat transfer, kinetics, biocatalysts, biomechanics, bioinformatics, separation and purification processes, bioreactor design, surface science, fluid mechanics, thermodynamics, and polymer science.

Bioengineering is used in the design of medical devices, diagnostic equipment, biocompatible materials, renewable energy resources, ecological engineering, agricultural engineering, process engineering and catalysis, and other areas that improve the living standards of societies. It’s approach integrative, innovative, collaborative and interdisciplinary. It focuses on solving the problems left unanswered by engineering and physical and life science disciplines.

Bioengineering addresses unmet challenges that make a difference in the world. It creates devises and innovative solutions to open-ended, which can solve the unmet challenges in biology, health and medicine.

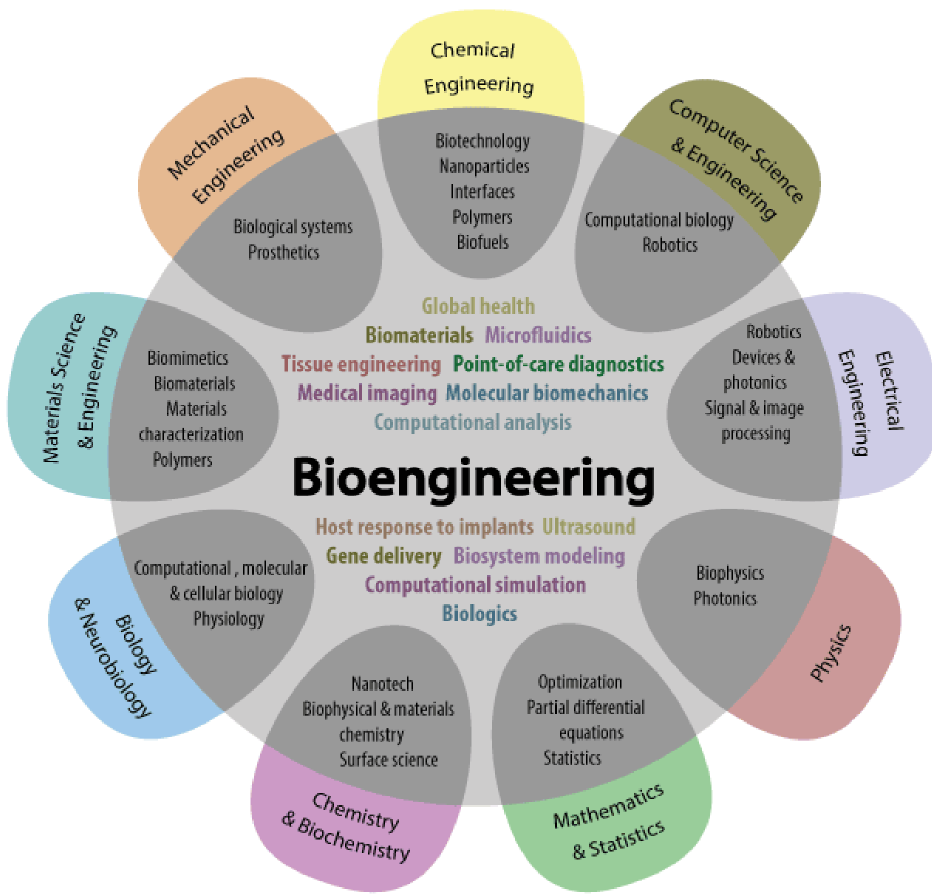


Fig. 1.1 Explanation of various field collaboration and related to Bioengineering.

Bioengineering is the only degree that bridges engineering, biology and physical science. By studying bioengineering, students participate in a truly unique academic experience. Fields such as Applied Mathematics, Computer Science and Engineering, and Electrical Engineering explore connections between engineering and the physical and quantitative sciences. Biochemistry and Oceanography form at the intersection of the life, physical and quantitative sciences. Civil and Environmental Engineering applies engineering principles to specific life science disciplines.

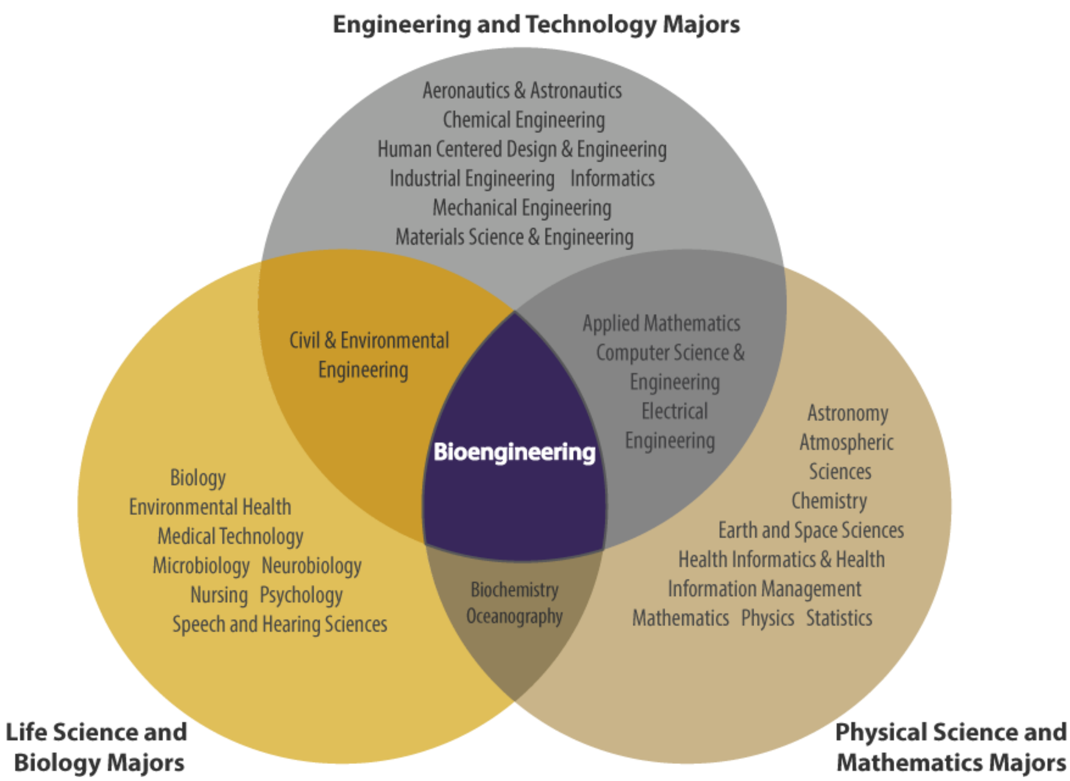


Fig. 1.2 Representation of Bioengineering connecting with Technology, Biology and Mathematics Disciplines.

Bioengineering is the application of engineering knowledge to the fields of medicine and biology. It is a discipline that applies engineering principles of design and analysis to biological systems and biomedical technologies.

The bioengineer must be well grounded in biology and have engineering knowledge that is broad, drawing upon electrical, chemical, mechanical, and other engineering disciplines. The bioengineer may work in any of a large range of areas. One of these is the provision of artificial means to assist defective body functions—such as hearing aids, artificial limbs, and supportive or substitute organs. In another direction, the bioengineer may use engineering methods to achieve biosynthesis of animal or plant products—such as for fermentation processes.

A bioengineer works on general theory that can be apply to various areas of natural sciences to solve various problems at different levels. They strive to create products, or to modify and control biological systems. They work with doctors, clinical professionals, and researchers. They use traditional engineering principles and techniques to admit biological processes; like to replace, to enhance, to sustain, or to predict chemical and mechanical processes in a biological system. They are trained in fundamentals of both biology and engineering, which may include elements of electrical and mechanical engineering, computer science, materials science, chemistry, and biology. This breadth allows students and faculty to specialize in their areas of interest and collaborate widely with researchers in allied fields.

Examples of bioengineering research include bacteria engineered to produce chemicals, new medical imaging technology, portable and rapid disease diagnostic devices, prosthetics, biopharmaceuticals, and tissue-engineered organs. Bioengineering overlaps substantially with biotechnology and the biomedical sciences in a way analogous to how various other forms of engineering and technology relate to various other sciences (like space technology to kinetics and astrophysics).

## 1.1. History

Before World War II the field of bioengineering was unknown and small in communication and interaction existed between the engineer and the life science professionals. But few exceptions are also there to be noted. The agricultural engineer and the chemical engineer, involved in fermentation processes are known as bioengineers because they deal with biological systems and work with biologists to modify the process for creating new variants. The civil engineer, specializing in sanitation, has applied biological principles in creating aseptic environment for their work. For the development of artificial limbs Mechanical Engineers had been worked with the Medical Professionals since many years. They also worked in another area of mechanical engineering that falls in the field of bioengineering. In the early 1920s engineers and physiologists were employed by the American Society of Heating and Ventilating Engineers to study the effects of temperature and humidity on humans and to provide design criteria for heating and air-conditioning systems.

The term was coined by British scientist Heinz Wolff in 1954 at the National Institute for Medical Research. This was the first time Bioengineering was recognized as its own branch at a university. Electrical engineering was the early focus of this discipline, due to work with medical devices and machinery during this time.

There are many more examples of interaction between biology and engineering, particularly in the medical and life-support fields. There is an increasing in the role of an engineer can play in several of the biological fields, including human medicine. Awareness of the contributions of biological science which can solve the problems of engineers is also noticeable.

In the 1950s bioengineering meetings were dominated by sessions devoted to medical electronics which gives credit to electrical engineers. Medical instrumentation and medical electronics continue to be major areas of interest, but biological modeling, blood-flow dynamics, prosthetics, biomechanics (dynamics of body motion and strength of materials), biological heat transfer, biomaterials, and other areas are also attract a wide range of particulars.

Bioengineering developed out of specific desires or needs, the desire of surgeons to bypass the heart, the need for replacement organs, the requirement for life support in space and many more. In most cases the early interaction and education were a result of personal contacts between physician, or physiologist, and engineer.

When engineers and life scientists started working together, they recognized that the engineers didn't know enough about the actual biology behind their work. To resolve this problem, engineers who wanted to get into biological engineering devoted more time to studying the processes of biology, psychology, and medicine.

The first biological engineering program in the United States was started at University of California, San Diego in 1966. More recent programs have been launched at MIT and Utah State University. Many old agricultural engineering departments in universities over the world have re-branded themselves as agricultural and biological engineering or agricultural and bio systems engineering.

According to Professor Doug Lauffenburger of MIT, biological engineering has a broad base which applies engineering principles to an enormous range of size and complexities of systems, ranging from the molecular level (molecular biology, biochemistry, microbiology, pharmacology, cytology, immunology and, neuroscience) to cellular and tissue level (including devices and sensors), to whole macroscopic organisms (plants, animals), and even to biomes and ecosystems.

## 1.2. Role of bioengineering in the field of medical Science:-

1. "Smart" therapies for cancer.
2. Biocompatible implants that resist infection.
3. Nanoparticle contrast agents for enhanced imaging.
4. Paper-based diagnostics for home healthcare and global health.
5. Adaptable prosthetics for amputees.
6. Engineered heart cells for improved cardiac function post-heart attack.
7. Biomimetic materials to prevent gut infections.
8. Miniature cell culture tools for studying neurobiology.
9. Synthetic organisms for biofuels.
10. "Catch" bonds for novel adhesives.

11. Photonic biosensors for blood typing.
12. High intensity focused ultrasound to stop bleeding.
13. Computational methods for assessing brain growth and development.
14. DNA, protein and glycan microarrays for drug development.
15. Technologies for neuro-rehabilitation.
16. Cardiac damage and failure.
17. Diagnosing various diseases.

## 1.3. As a Bioengineer, one can do following:-

1. **Solving open-ended problems:** You can develop novel solutions to solving the real-world problems.
2. **Quantitative approach:** You can employ quantitative tools, including simulation and mathematical modeling.
3. **Biology, health & medicine:** You can solve problems in biology, health and medicine to improve human live.
4. **Independent research & design:** You can conduct independent research and design

projects (*in vitro*, *in vivo* or *in silico*) mentored by leading bioengineers.

5. **Hands-on learning:** You can enjoy learning by doing, through labs, projects and research.
6. **Team-based problem solving:** You can enjoy working with smart, mature and diverse team members to solve problems creatively.
7. **Broad knowledge:** You can acquire broad knowledge spanning engineering and the physical and biological sciences.
8. **Cohort experience:** You can progress sequentially through a core curriculum with a cohesive, talented cohort of Bio-E peers.

## 1.4. Branches of Bioengineering:-

1. **Medical engineering:** Medical engineering concerns the application of engineering principles to medical problems, including the replacement of damaged organs, instrumentation, and the systems of health care, including diagnostic applications of computers.
2. **Agricultural engineering:** This includes the application of engineering principles to the problems of biological production and to the

external operations and environment that influence this production.

3. **Bionics:** Bionics is the study of living systems so that the knowledge gained can be applied to the design of physical systems. Learn the use of chemistry in making fake meats as an alternative to livestock meat.
4. **Biochemical engineering:** Biochemical engineering includes fermentation engineering, application of engineering principles to microscopic biological systems that are used to create new products by synthesis, including the production of protein from suitable raw materials.
5. **Human-factors engineering:** This concerns the application of engineering, physiology, and psychology to the optimization of the human–machine relationship.
6. **Environmental health engineering:** Also called bioenvironmental engineering, this field concerns the application of engineering principles to the control of the environment for the health, comfort, and safety of human beings. It includes the field of life-support systems for the exploration of outer space and the ocean.
7. **Genetic engineering:** Genetic engineering is concerned with the artificial manipulation, modification, and recombination

of deoxyribonucleic acid (DNA) or other nucleic acid molecules in order to modify an organism. The techniques employed in this field have led to the production of medically important products, including human insulin, human growth hormone, and hepatitis-B vaccine.

## 1.5. Sub- Branches:-

Modeling of the spread of disease using Cellular Automata and Nearest Neighbor Interactions

Depending on the institution and particular definitional boundaries employed, some major branches of bioengineering may be categorized as (note these may overlap):

- **Biomedical engineering:** application of engineering principles and design concepts to medicine and biology for healthcare purposes.
  - Tissue engineering
  - Neural engineering
  - Pharmaceutical engineering
  - Clinical engineering
  - Biomechanics
- **Biochemical engineering:** fermentation engineering, application of engineering principles to microscopic biological systems that are used to create new products

by synthesis, including the production of protein from suitable raw materials.

- **Biological systems engineering:** application of engineering principles and design concepts to agriculture, food sciences, and ecosystems.
- **Bioprocess engineering:** develops technology to monitor the conditions of where a particular process takes place, (Ex: bioprocess design, bio-catalysis, bio-separation, bioenergy)
- **Environmental health engineering:** application of engineering principles to the control of the environment for the health, comfort, and safety of human beings. It includes the field of life-support systems for the exploration of outer space and the ocean.
- **Human factors and ergonomics engineering:** application of engineering, physiology, and psychology to the optimization of the human–machine relationship. (Ex: physical ergonomics, cognitive ergonomics, human–computer interaction)
- **Biotechnology:** the use of living systems and organisms to develop or make products. (Ex: pharmaceuticals, Bioinformatics, Genetic engineering).
- **Biomimetic:** the imitation of models, systems, and elements of nature for the purpose of solving complex human problems. (Ex: Velcro, designed after George de Mestral noticed how easily burs stuck to a dog's hair).

- **Bioelectrical engineering:** Living cells and tissues are incorporated into micro-devices, which are incorporated into micro-devices, which are then used to study mechanisms of thought and memory, mechanical properties of cells, or applications in bio-sensing and drug screening.
- **Biomechanical engineering:** is the application of mechanical engineering principals and biology to determine how these areas relate and how they can be integrated to potentially improve human health.
- **Bionics:** an integration of Biomedical focused more on the robotics and assisted technologies. (Ex: prosthetics)
- **Bio-printing:** utilizing biomaterials to print organs and new tissues
- **Bio-robotics:** (Ex: electrical prosthetics)
- **Systems biology:** Molecules, cells, organs, and organisms are all investigated in terms of their interactions and behaviors.

## 1.6. Roles of bioengineering in medical science:-

### Four ways Biomedical Engineering has enhanced healthcare are:-

Now, Biomedical Engineers are become able to operate in an environment that inspires creativity more than ever, to allow them to create solutions for a vast range of health issues. These four ways that Biomedical Engineers transformed and enhanced the healthcare services are:-

## 1. Inventions

The development of prosthetics limbs, artificial hearts, livers, bionic contacts lenses and the camera pill-that contains a colour camera, battery, light and transmitter to be able to capture internal processes - are just a few of the many incredible healthcare inventions that Biomedical Engineers have developed in recent years.

## 2. Medicine

The research into bodily functions can also lead to developing new medicines and drugs to aid our health and treat diseases including cancer. New medicine also to solve long-term health problems, such as laser surgery, can also be accredited to the work of Bioengineers.

## 3. Tools and Devices

Bioengineers work together with other healthcare professionals, such as doctors, nurses, surgeons and technicians, to tackle health issues that they all come across. This has led to the creation of vital tools and devices such as MRI machines, dialysis machines, diagnostic equipment and ultrasound.

## 4. Biological processes

Biomedical engineers study the movement and signals of the body, to understand why it functions the way that it does and how biological systems work. From this, new technology such as wearable sensors and pacemakers have been produced to give patients comfort whilst monitoring health conditions remotely and in real-time. Hemodialysis is a process of purifying the blood of a person whose kidneys are not working normally.

Biomedical engineering (BME) or medical engineering is the application of engineering principles and design concepts to medicine and biology for healthcare purposes (e.g., diagnostic or therapeutic). It is also traditionally logical sciences to advance health care treatment, including diagnosis, monitoring, and therapy.

Much of the work in biomedical engineering consists of research and development, spanning a broad array of subfields (see below).

## 1.7 Some Other Field included in Bioengineering:-

### 1. Bioinformatics

It is an interdisciplinary field that develops methods and software tools for understanding biological data. As an interdisciplinary field of science, bioinformatics combines computer science, statistics, mathematics, and engineering to analyze and interpret biological data.

Bioinformatics is considered both an umbrella term for the body of biological studies that use computer programming as part of their methodology, as well as a reference to specific analysis "pipelines" that are repeatedly used, particularly in the field of genomics. Common uses of bioinformatics include the identification of candidate genes and nucleotides (SNPs).

Often, such identification is made with the aim of better understanding the genetic basis of disease, unique adaptations, desirable properties (esp. in agricultural species), or differences between populations. In a less formal way, bioinformatics also tries to understand the organizational principles within nucleic acid and protein sequences.

## 2. Biomechanics

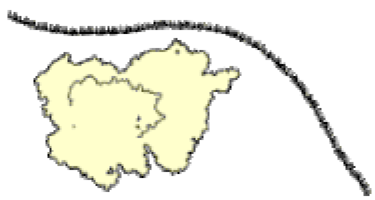

Fig. 1.3. A ribosome is a biological machine that utilizes protein dynamics.

Biomechanics is the study of the structure and function of the mechanical aspects of biological systems, at any level from whole organisms to organs, cells and cell organelles, using the methods of mechanics.

## 3. Biomaterial Science/ Biomaterials Engineering

A biomaterial is any matter, surface, or construct that interacts with living systems. As a science, bio-materials are about fifty years old. The study of biomaterials is called biomaterials science or biomaterials engineering. It has experienced steady and strong growth over its history, with many companies investing large amounts of money into the development of new products. Biomaterials science encompasses elements of medicine, biology, chemistry, tissue engineering and materials science.

## 4. Biomedical optics

Biomedical optics combines the principles of physics, engineering, and biology to study the interaction of biological tissue and light, and how this can be exploited for sensing, imaging, and treatment. It has a wide range of applications, including optical imaging, microscopy, ophthalmoscopy, spectroscopy, and therapy. Examples of biomedical optics techniques and technologies include optical coherence tomography (OCT), fluorescence microscopy, confocal microscopy, and photodynamic therapy (PDT). OCT, for example, uses light to create high-resolution, three-dimensional images of internal structures, such as the retina in the eye or the coronary arteries in the heart.

Fluorescence microscopy involves labeling specific molecules with fluorescent dyes and visualizing them using light, providing insights into biological processes and disease mechanisms. More recently, adaptive optics is helping imaging by correcting aberrations in biological tissue, enabling higher resolution imaging and improved accuracy in procedures such as laser surgery and retinal imaging.

## 5. Tissue engineering

Tissue engineering, like genetic engineering (see below), is a major segment of biotechnology – which overlaps significantly with BME.

One of the goals of tissue engineering is to create artificial organs (via biological material) for patients that need organ transplants. Biomedical engineers are currently researching methods of creating such organs. Researchers have grown solid jawbones and tracheas from human stem cells towards this end.

Several artificial urinary bladders have been grown in laboratories and transplanted successfully into human patients. Bio-artificial organs, which use both synthetic and biological component, are also a focus area in research, such as with hepatic assist devices that use liver cells within an artificial bioreactor construct.

## 6. Genetic engineering

Genetic engineering, recombinant DNA technology, genetic modification/manipulation (GM) and gene splicing are terms that apply to the direct manipulation of an organism's genes. Unlike traditional breeding, an indirect method of genetic manipulation, genetic engineering utilizes modern tools such as molecular cloning and transformation to directly alter the structure and characteristics of target genes. Genetic engineering techniques have found success in numerous applications. Some examples include the improvement of crop technology (*not a medical application*, but see biological systems engineering), the manufacture of synthetic human insulin through the use of modified bacteria, the manufacture of erythropoietin in hamster ovary cells, and the production of new types of experimental mice (such as the onco mouse) for research.

## 7. Neural engineering

Neural engineering (also known as neural engineering) is a discipline that uses engineering techniques to understand, repair, replace, or enhance neural systems. Neural engineers are uniquely qualified to solve design problems at the interface of living neural tissue and non-living constructs.

## 8. Pharmaceutical engineering

Pharmaceutical engineering is an interdisciplinary science that includes drug engineering, novel drug delivery and targeting, pharmaceutical technology, unit operations of Chemical Engineering, and Pharmaceutical Analysis. It may be deemed as a part of pharmacy due to its focus on the use of technology on chemical agents in providing better medicinal treatment.

## 9. Hospital and medical devices

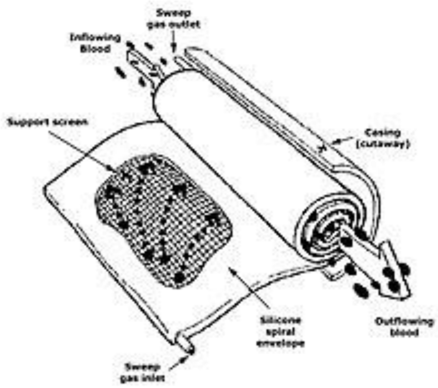


Fig. 1.4. Schematic of silicone membrane oxygenator.

This is an extremely broad category—essentially covering all health care products that do not achieve their intended results through predominantly chemical (e.g., pharmaceuticals) or biological (e.g., vaccines) means, and do not involve metabolism.

### A medical device is intended for use in:

- The diagnosis of disease or other conditions
- In the cure, mitigation, treatment, or prevention of disease.

Some examples include pacemakers, infusion pumps, the heart-lung machine, dialysis machines, artificial organs, implants, artificial limbs, corrective lenses, cochlear implants, ocular prosthetics, facial prosthetics, somato prosthetics, and dental implants.

## 10. Medical imaging

Medical/biomedical imaging is a major segment of medical devices. Medical imaging is the technique and process of imaging the interior of a body for clinical analysis and medical intervention, as well as visual This can involve utilizing ultrasound, magnetism, UV, radiology, and other means.

Alternatively, navigation-guided equipment utilizes electromagnetic tracking technology, such as catheter placement into the brain or feeding tube placement systems.

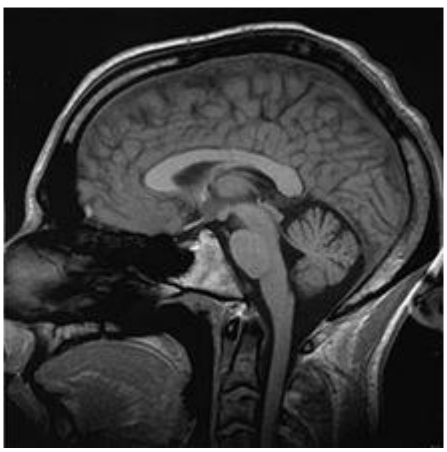

Fig. 1.5. An MRI scan of a human head, an example of a biomedical engineering application of electrical engineering to diagnostic imaging.

Imaging technologies are often essential to medical diagnosis, and are typically the most complex equipment found in a hospital including: fluoroscopy, magnetic resonance imaging (MRI), nuclear medicine, positron emission tomography (PET), PET-CT scans, projection radiography such as X-rays and CT scans, tomography, ultrasound, optical microscopy, and electron microscopy.

# 11. Medical implants

An implant is a kind of medical device made to replace and act as a missing biological structure (as compared with a transplant, which indicates transplanted biomedical tissue). The surface of implants that contact the body might be made of a biomedical material such as titanium, silicone or apatite depending on what is the most functional. In some cases, implants contain electronics, e.g. artificial pacemakers and cochlear implants.

Fig. 1.6. Artificial limbs: The right arm is an example of a prosthesis, and the left arm is an example of myoelectric control.

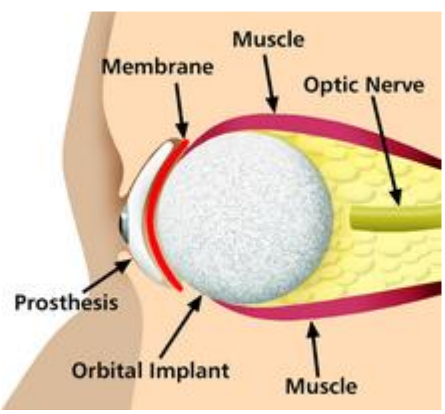


Fig. 1.7. A prosthetic eye, an example of a biomedical engineering application of mechanical engineering and biocompatible materials to ophthalmology.

## 12. Bionics

Artificial body part replacements are one of the many applications of bionics. Concerned with the intricate and thorough study of the properties and function of human body systems, bionics may be applied to solve some engineering problems. Careful study of the different functions and processes of the eyes, ears, and other organs paved the way for improved cameras, television, radio transmitters and receivers, and many other tools.

## 13. Biomedical sensors

In recent years biomedical sensors based in microwave technology have gained more attention. Different sensors can be manufactured for specific uses in both diagnosing and monitoring disease conditions, for example microwave sensors can be used as a complementary technique to X-ray to monitor lower extremity trauma. The sensor monitor the dielectric properties and can thus notice change in tissue (bone, muscle, fat etc.) under the skin so when measuring at different times during the healing process the response from the sensor will change as the trauma heals.

## 14. Clinical engineering

Clinical engineering is the branch of biomedical engineering dealing with the actual implementation of medical equipment and technologies in hospitals or other clinical settings. Clinical engineers also advise and collaborate with medical device producers regarding prospective design improvements based on clinical experiences, as well as monitor the progression of the state of the art so as to redirect procurement patterns accordingly.

Clinical engineering departments will sometimes hire not just biomedical engineers, but also industrial/systems engineers to help address operations research/optimization, human factors, cost analysis, etc. The clinical engineering department is constructed with a manager, supervisor, engineer, and technician. One engineer per eighty beds in the hospital is the ratio. Clinical engineers are also authorized to audit pharmaceutical and associated stores to monitor FDA recalls of invasive items.

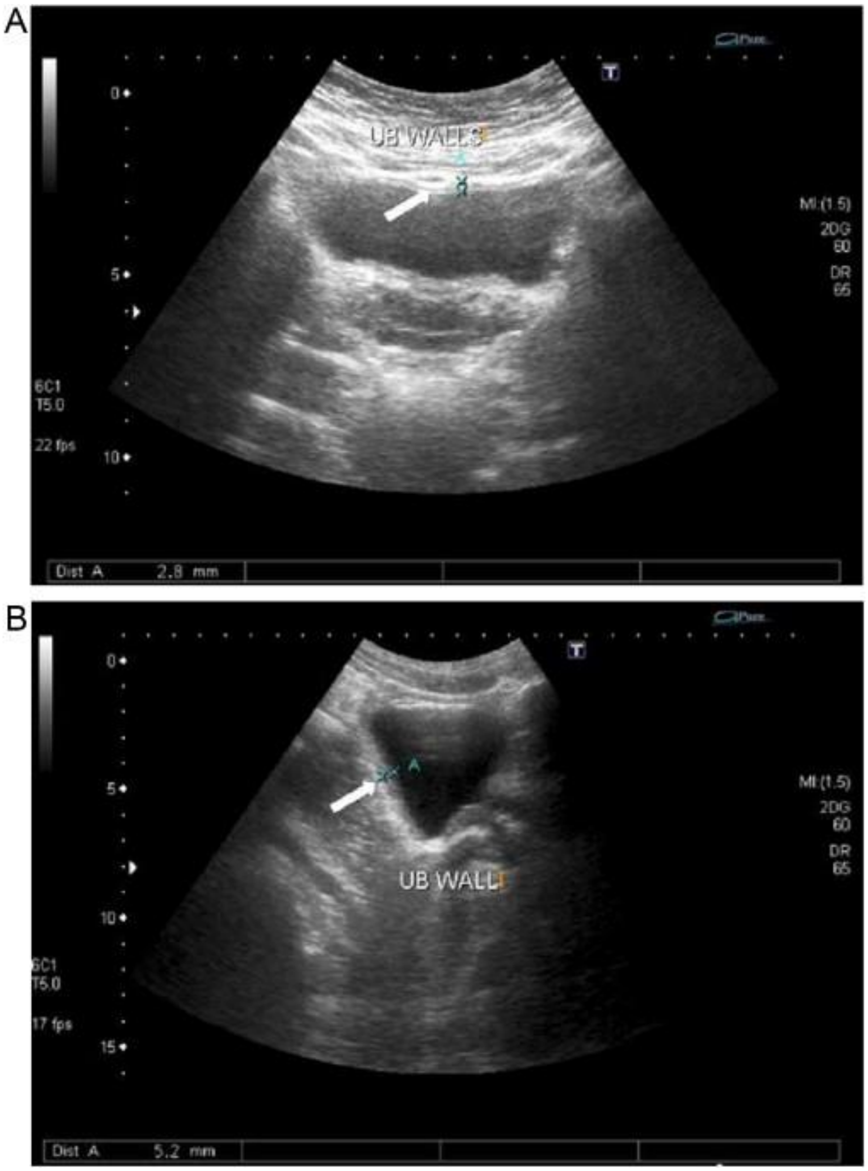


Fig. 1.8. Ultra-sound representation of urinary bladder (black butterfly-like shape) a hyperplastic prostate is an example of practical science and medical science working together.

# 15. Rehabilitation engineering

Rehabilitation engineering is the systematic application of engineering sciences to design, develop, adapt, test, evaluate, apply, and distribute technological solutions to problems confronted by individuals with disabilities. Functional areas addressed through rehabilitation engineering may include mobility, communications, hearing, vision, and cognition, and activities associated with employment, independent living, education, and integration into the community.

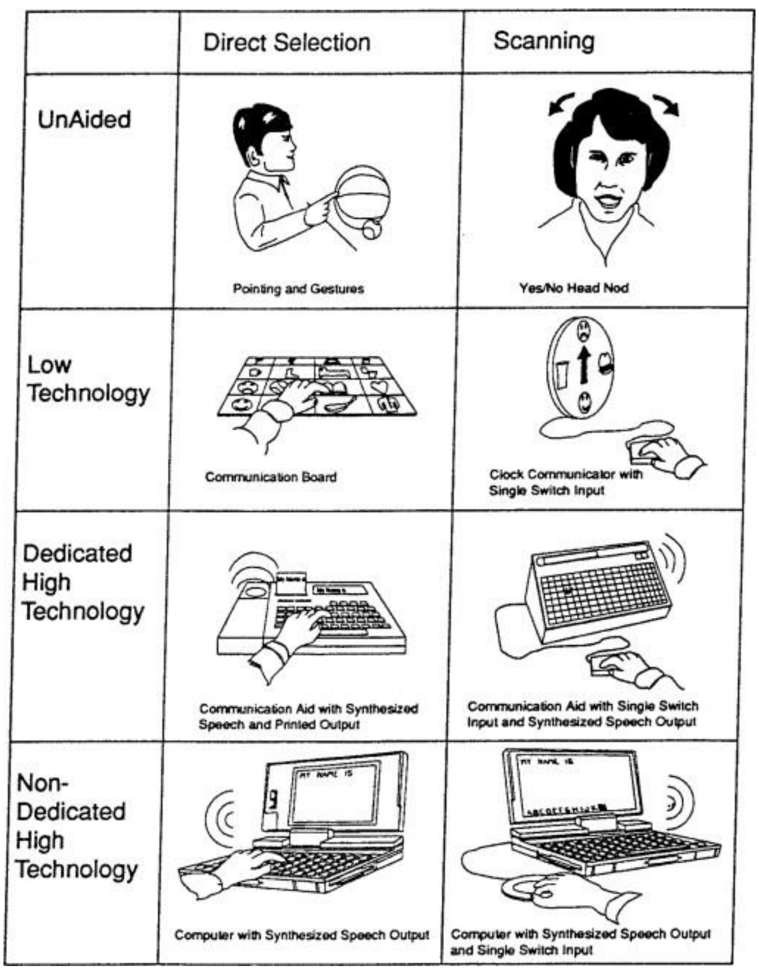


Fig. 1.9. Schematic representation of a hearing, vision, and cognition through Rehabilitation engineering.