# Introduction to Biomechatronics

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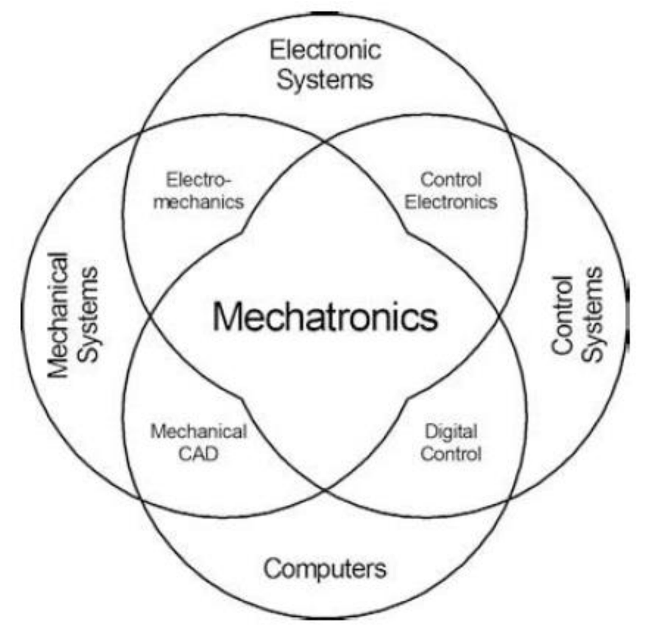
MEKATRONİK MÜHENDİSLİĞİ BÖLÜMÜ

# INTRODUCTION

- *Mechatronic engineering is the synergistic combination of mechanical, electronic, computer,* and control systems along with a dash of systems engineering as illustrated in Figure 1-1. This interdisciplinary combination brings together the requisite technology and skills to design new and to improve existing electromechanical systems.



# INTRODUCTION

- Biomechatronics is the application of mechatronic engineering to human biology, and, as such, it forms an important subset of the overall biomedical engineering discipline.
- As with mechatronics, which is often synonymous with robotics, biomechatronics is often thought of as restricted to the development of prosthetic limbs. However, in reality, biomechatronics covers a much wider genre than this, and along with prosthetic limbs this course examines some of the more interesting applications including those related to
  - hearing,
  - respiration,
  - vision,
  - and the cardiovascular system.

# BIOMECHATRONIC SYSTEMS

- Ultimately, biomechatronics can be thought of in a similar manner to any other engineering system with one of its elements, generally the most complex one, being the human being.
- Unfortunately, the human element is not only the most complex and least understood but also the most difficult to interface to.
- The **human body** is not a simple machine, but an amazingly complex **chaotic** system.
- The defininig characteristics of Chaos are
  - A deterministic rule
  - Unpredictable outcomes due to an exponenetial sensitivity to initial data

# BIOMECHATRONIC SYSTEMS

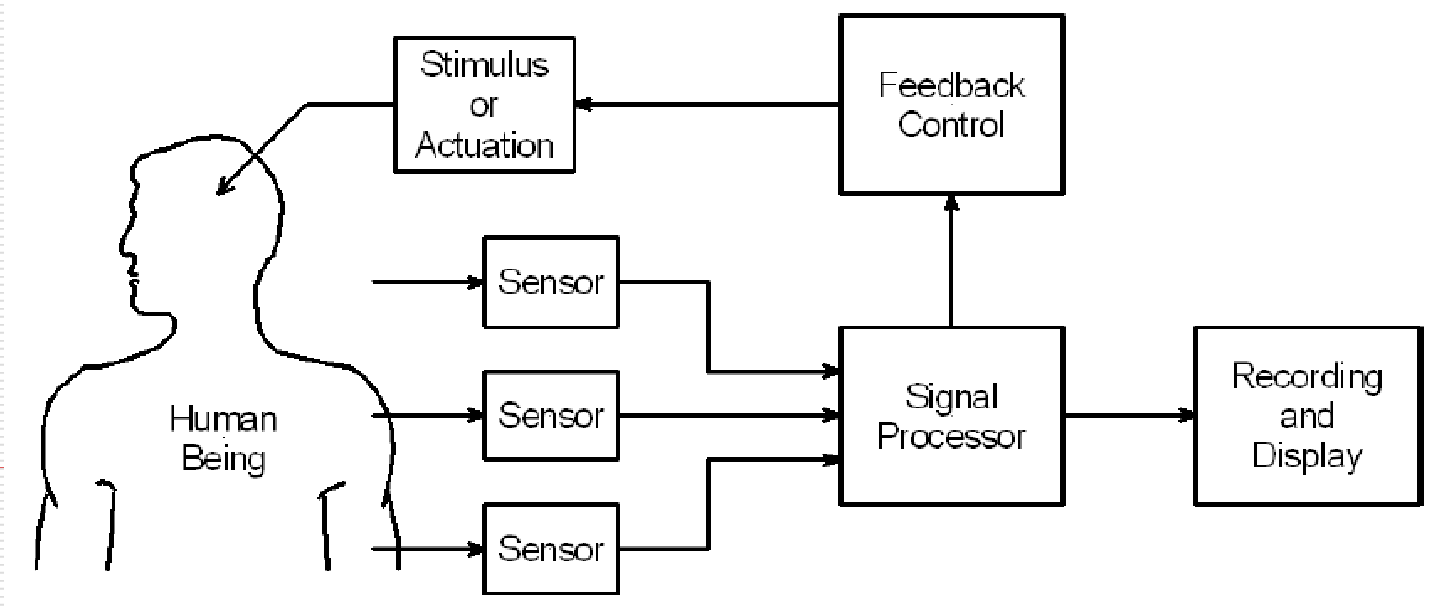
- Attempts to measure and stimulate the human body are **not completely deterministic**, and repeated application of a set of inputs will **not always produce the same response**. In fact, even when under conscious control, responses (or actions) are seldom identical.
- Consider, for example, the best sportsmen in the world: With practice and talent they are able to produce fairly **repeatable performances**, but subtle changes in **initial conditions**, within and external to their bodies, results in some variations.
- This uncertainty is manifest across the complete range of physiological responses, from slight variations in the resting **heart rate** through the apparently chaotic nature of firing neurons.

# BIOMECHATRONIC SYSTEMS

- A **chaotically healty heart** would be governed by a rule that maintains function while leading to changes in heart rate that cannot be predicted.
- The heart rate **does not change** very much and looks predictable when measured on an **hourly basis**. But when measurements made **every minute**, heart rate fluctates in **a nonlinear and unpredictable** way.
- **Body temperature** is a complex, non-linear variable, subject to many sources of endogenous and exogenous variation.
- The human subject adds the *bio to this mechatronic control and monitoring process. What* makes **biomechatronics** particularly **interesting** compared with other mechatronic systems is the **diversity and complexity of human physiology**. Unlike the usual engineering systems, the behavior of which can be more or less predicted, each human being is unique and ever changing.

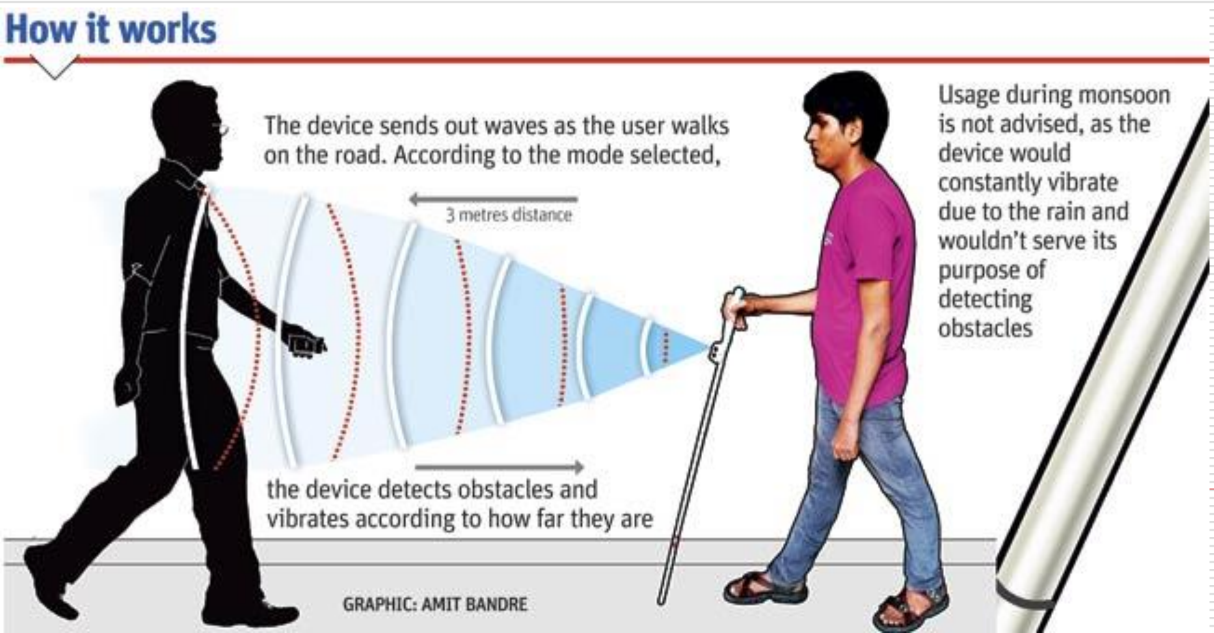
# BIOMECHATRONIC SYSTEMS

- In a typical biomechatronic system, a number of components can be identified. These include the following:
  - The human (or animal) subject
  - Stimulus or actuation
  - Transducers and sensors
  - Signal conditioning elements
  - Recording and display
  - Feedback elements



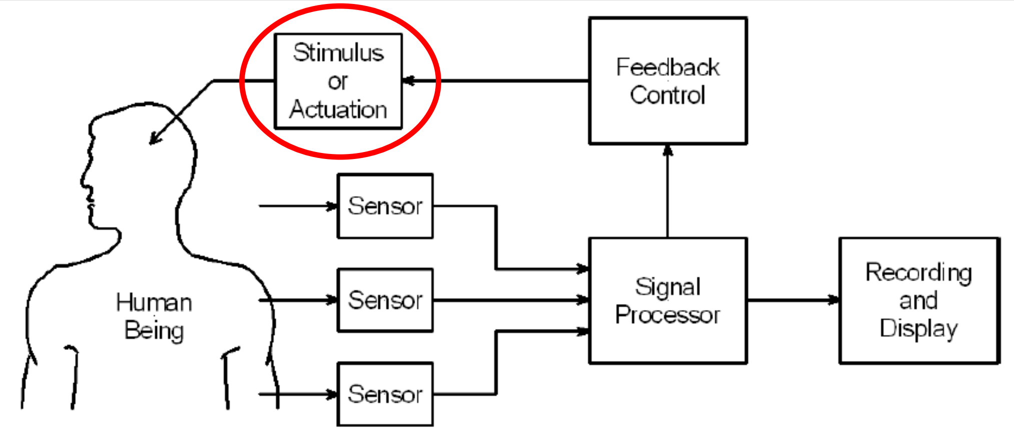
# An Example: SmartCane

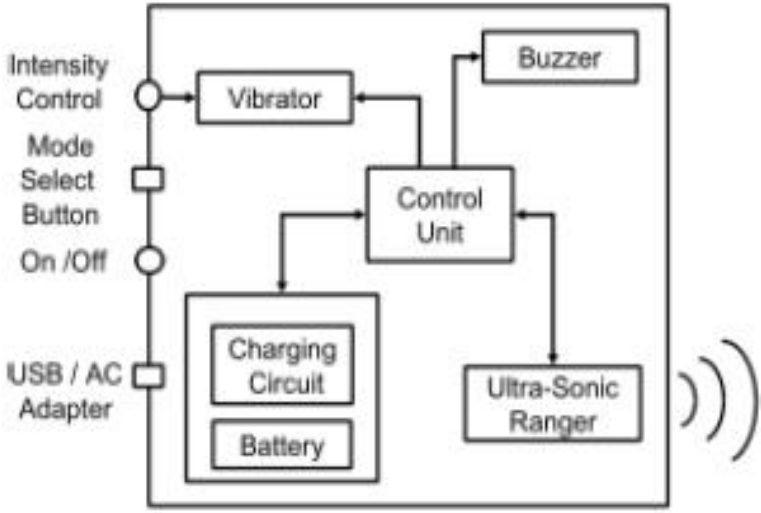
- An example of a biomechatronic system is a smart version of whitecane called smartcane.
- Smart cane produce stimulus that is triggered in response to obstacles around a blind person to prevent him or her from collision.




# Stimulus or Actuation

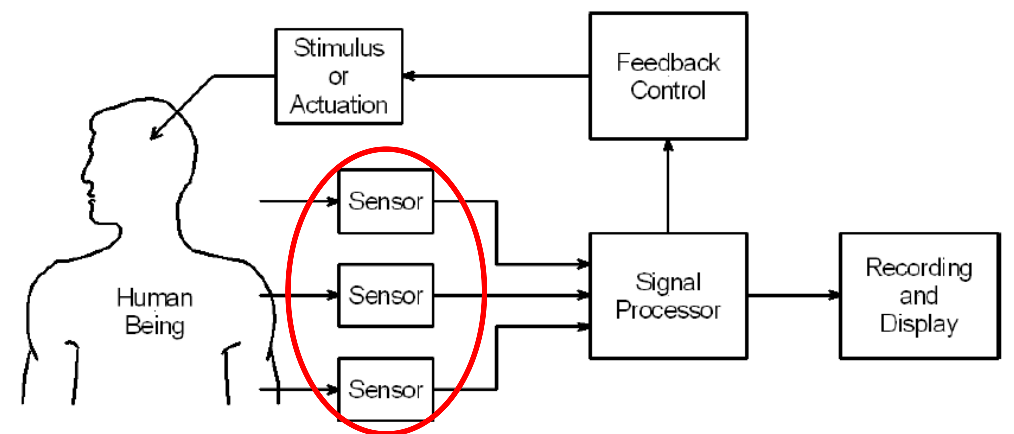
- The process of stimulation can be introduced as a feedback element, as shown in Figure 1-2, or as a naturally occurring input.
- Sources of stimuli can encompass any modality that has an effect on the human element. This can include electrical stimuli, an audio tone, control of air or blood flow, a source of light, a tactile stimulus, or even the physical actuation of a limb.

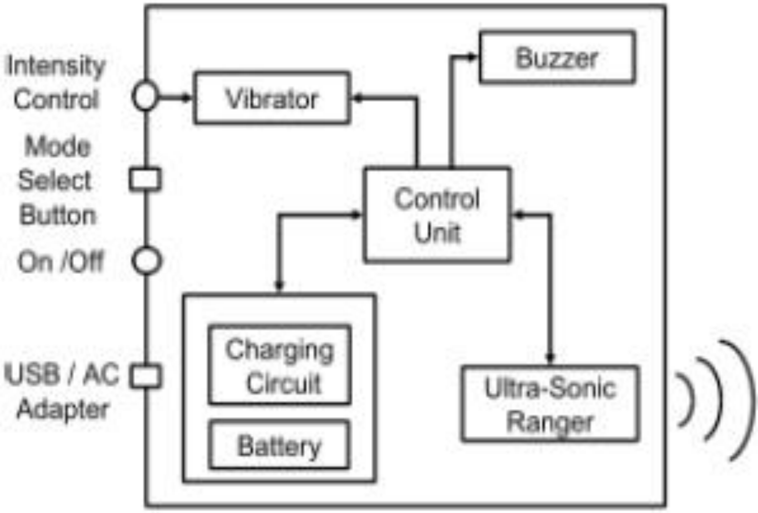


# Transducers and Sensors

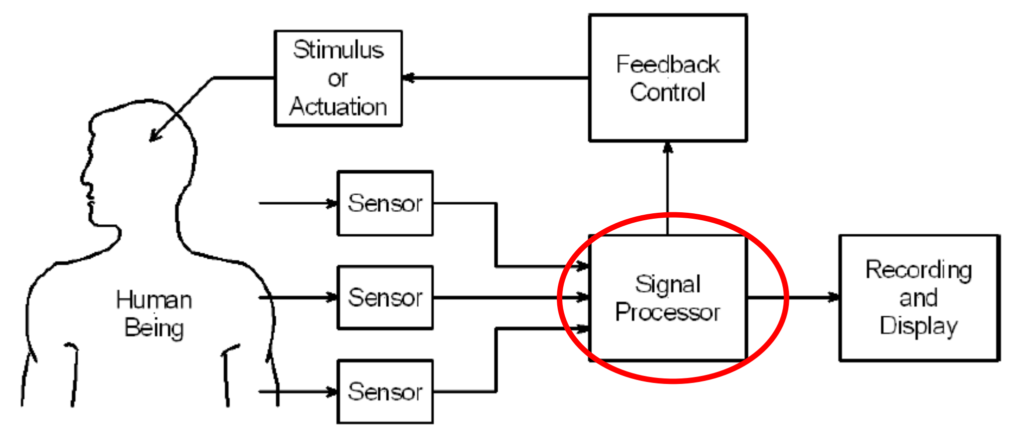
- Transducers and sensors are the devices that convert physiological outputs into signals that can be used. In most cases, these are sensors that amplify electrical signals or convert them from chemical concentration, temperature, pressure, or flow into electrical signals that can be further processed.
- Interfacing to the human body is not a trivial task, as embedded sensors must be biocompatible, flexible, and extremely robust to survive in the aggressive internal environment, while surface sensors, particularly electrodes, must be able to form a compatible and relatively stable conductive interface across the skin.

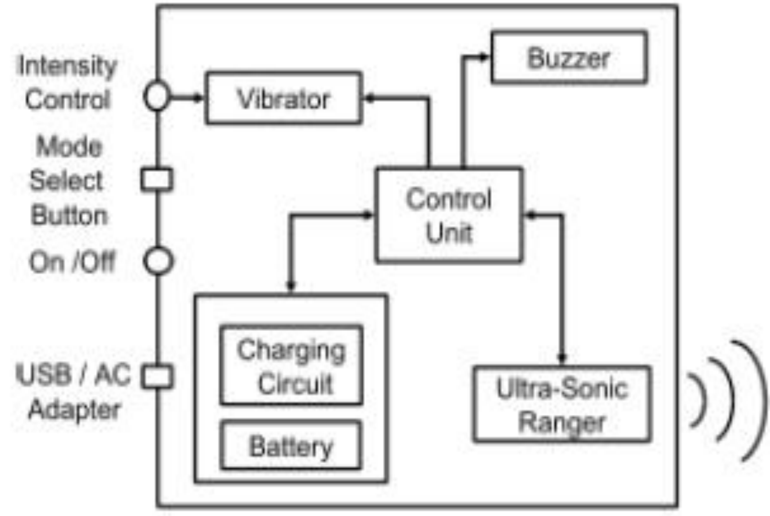


# Signal Processing Elements

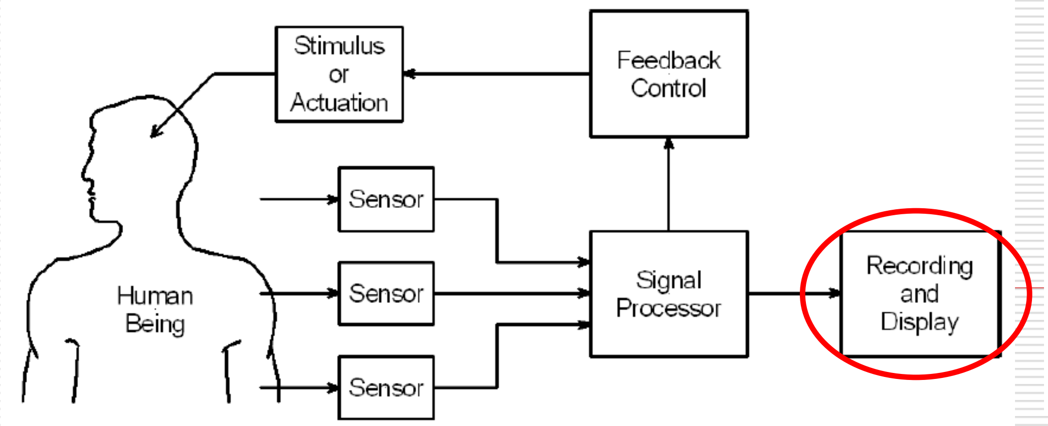
- Signal processing involves modification of the electrical signal to some form that is more useful. This generally involves **amplification** and **filtering** to extract salient features. However, it often involves the conversion of the analog signal to a digital equivalent that allows for the application of complex algorithms to obtain subtler characteristics.

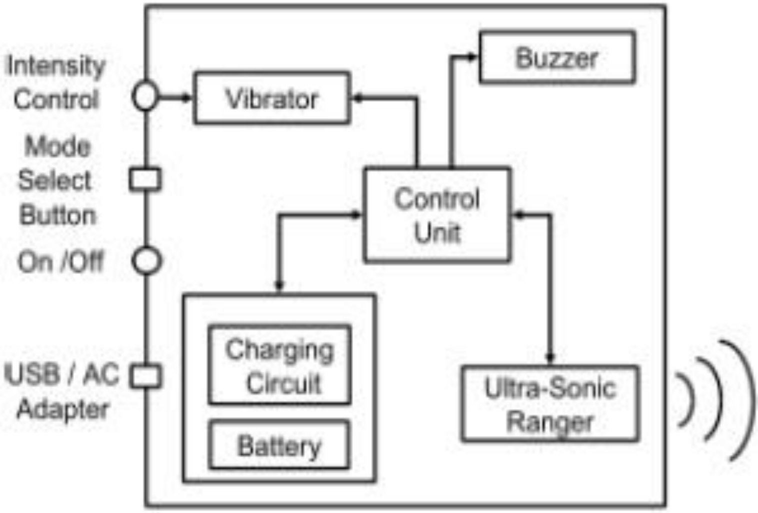


# Recording and Display

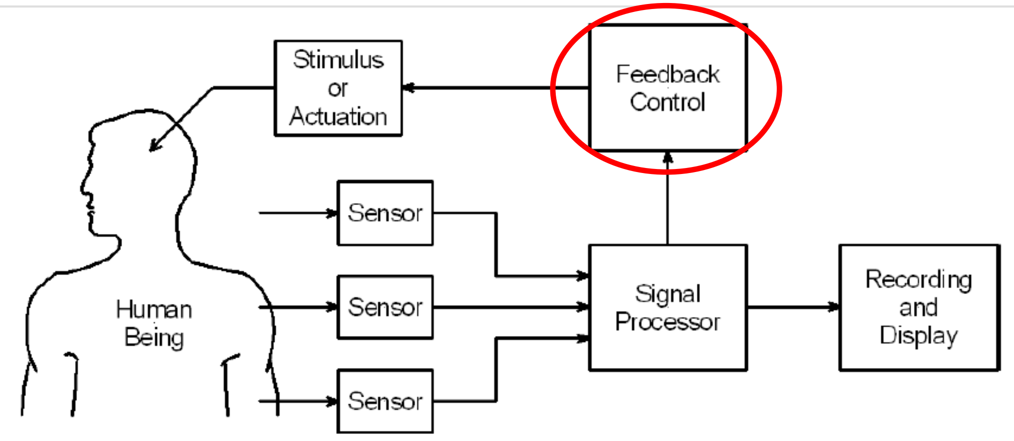
- In many cases, the biomechatronic device functions to monitor a physiological process or response. In these cases it may be important to display the information in a form that is easy to interpret, or to store it for later analysis. Common examples of such devices are the now ubiquitous 12-lead electrocardiograph, pneumotachographs and sphygmomanometers. In the past many of these devices were mechanical and outputs were recorded onto paper tape or photographic film, but with the advent of modern electronics, most have been replaced by their electronic equivalents—random access memory (RAM) and liquid crystal displays.

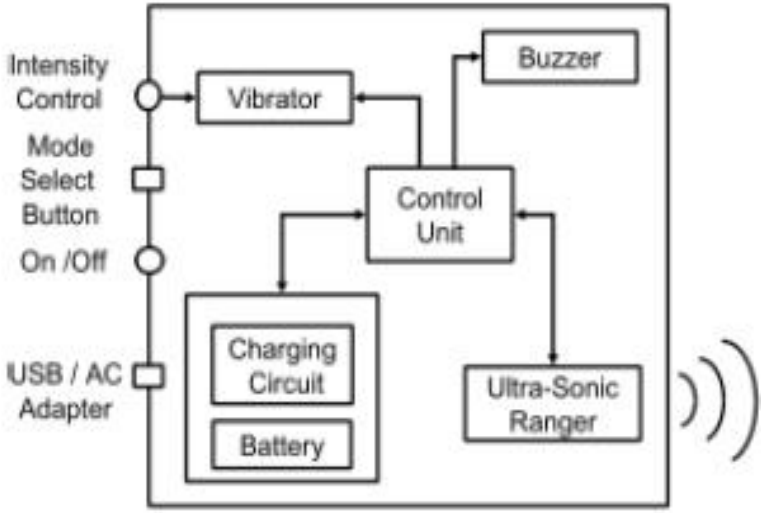


# Feedback Elements

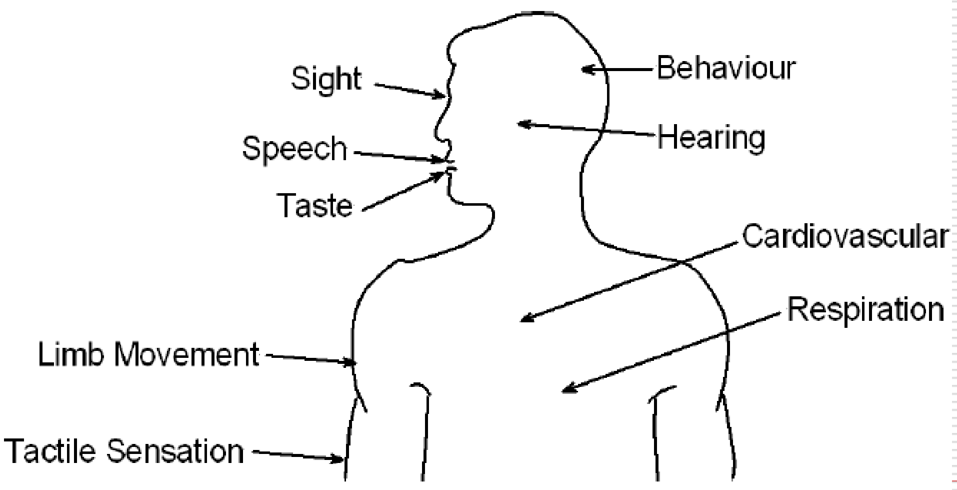
- In a closed-loop control application, any stimulus or excitation signal is conditioned by the processed outputs of one or a number of sensors monitoring the physiological process. The link that connects the sensing output back to the stimulus includes further processing through control elements. This feedback can be used to close an external loop or one that operates through the human being.



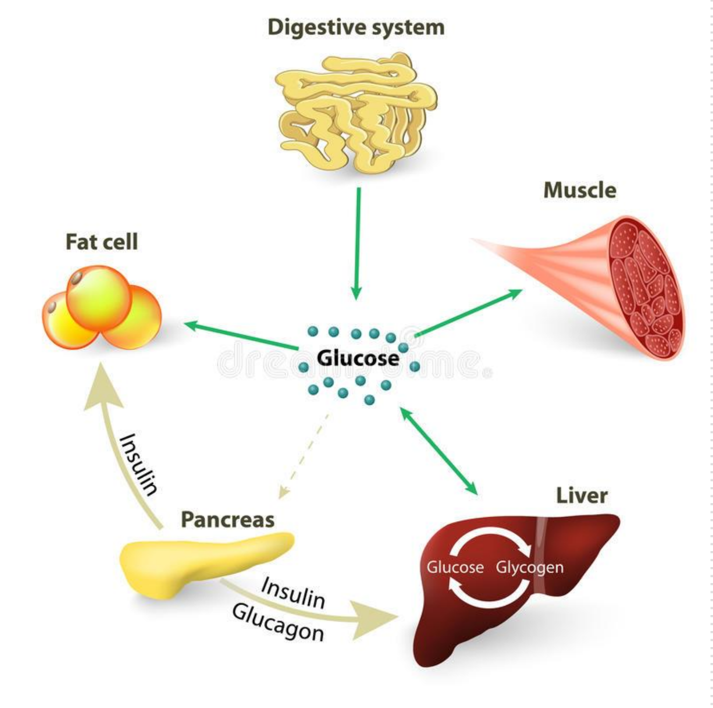
# PHYSIOLOGICAL SYSTEMS

- To interact effectively with the human part of the structure shown in Figure 1-2, it is essential to have some understanding of the subject on which the measurements are being made or to which the stimulus is applied. The major functional systems of the body include the cardiovascular, respiratory, and musculoskeletal systems along with those that interpret of taste, sight, hearing, and touch.



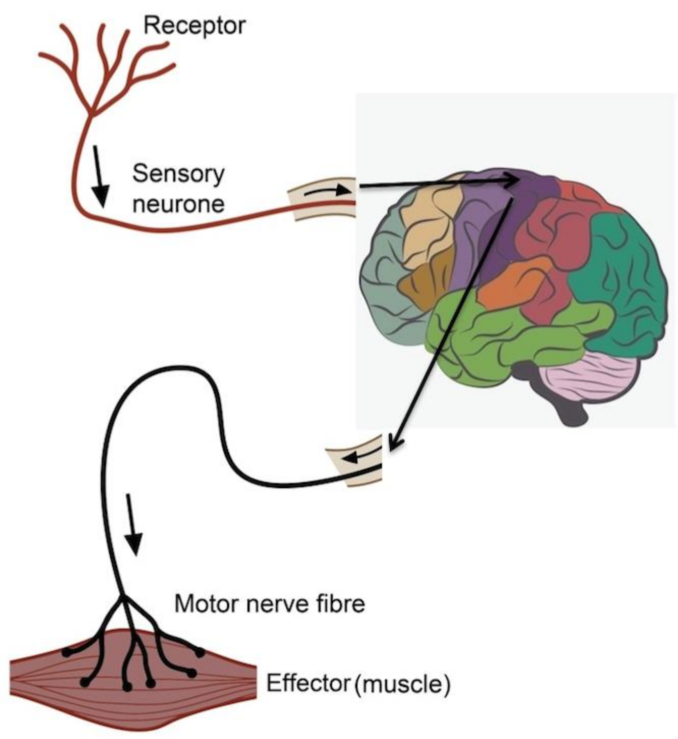
# Biochemical System

- The human body is controlled and powered by a complex system of chemical processes. Biochemical processes convert the food we eat into amino acids that are used for building and repair; they break down sugars and fats and store them for later use as sources of energy.
- In addition, our blood and tissues are awash with hormones and other organic molecules that control, signal, and regulate the amazingly interconnected functions that keep the system alive and healthy.
- We will examine some of the sensors and actuators that interact with these biochemical processes for monitoring and control purposes.



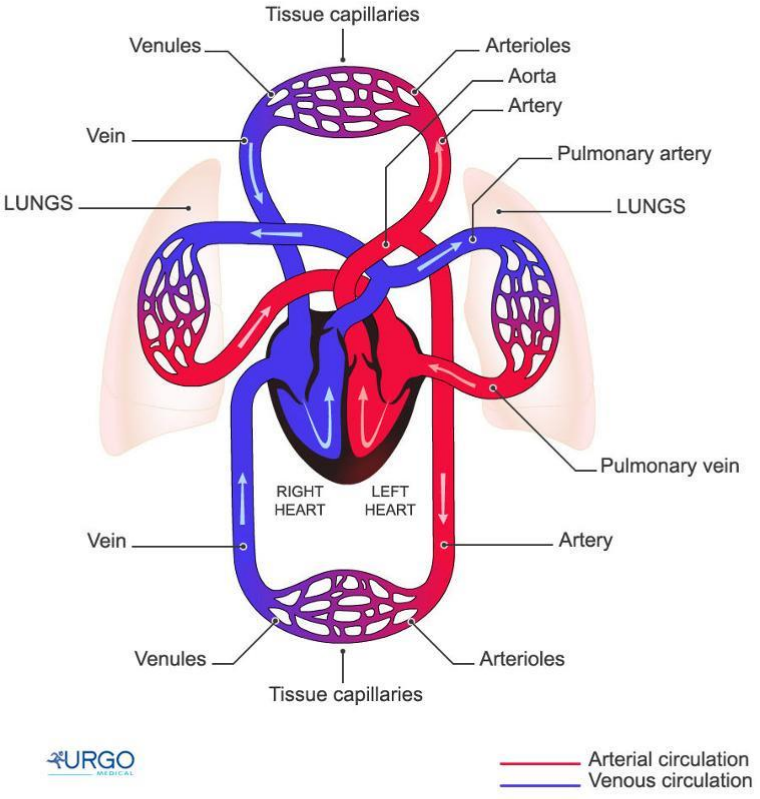
# Nervous System

- Whereas the biochemical system is concerned mostly with long-term signaling and control, the nervous system is the high-speed communications network for the body. At its center is the brain, which performs the processing and memory storage tasks, and to it are connected myriad input/output nerve channels. These nerves convey sensory and status information to the brain from specialized sensory organs like the eyes, ears, and skin and from the various internal organs. Nerve outputs from the brain provide feedback to control some of the internal processes and to adjust the tension in the hundreds of muscles in the body that allow us to interact with the environment. We will discuss some of these interactions in more detail, particularly in regard to biomechatronic prostheses and interfaces that can restore function when sensory organs have been damaged.



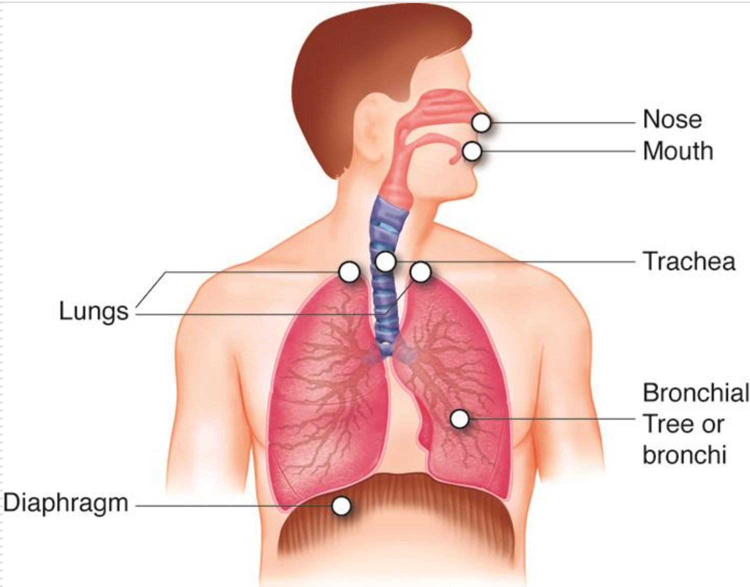
# Cardiovascular System

- From an engineering perspective, the cardiovascular system is a closed-circuit hydraulic system comprising a dual-action multichambered electrically controlled pump (the heart) interconnected through hundreds of kilometers of flexible tubing (arteries, veins, and capillaries). Pressure and flow regulation are achieved by changing the pump stroke and rate as well as altering the diameters of the arteries. The hydraulic fluid (blood plasma) contains organic molecules for regulation as well as larger particles to aid with puncture repair (blood platelets), defense against intruders (white cells), and the transport of oxygen to the tissues and waste products back to the lungs (red cells). We will analyze the performance of the heart and its mechatronic replacement.



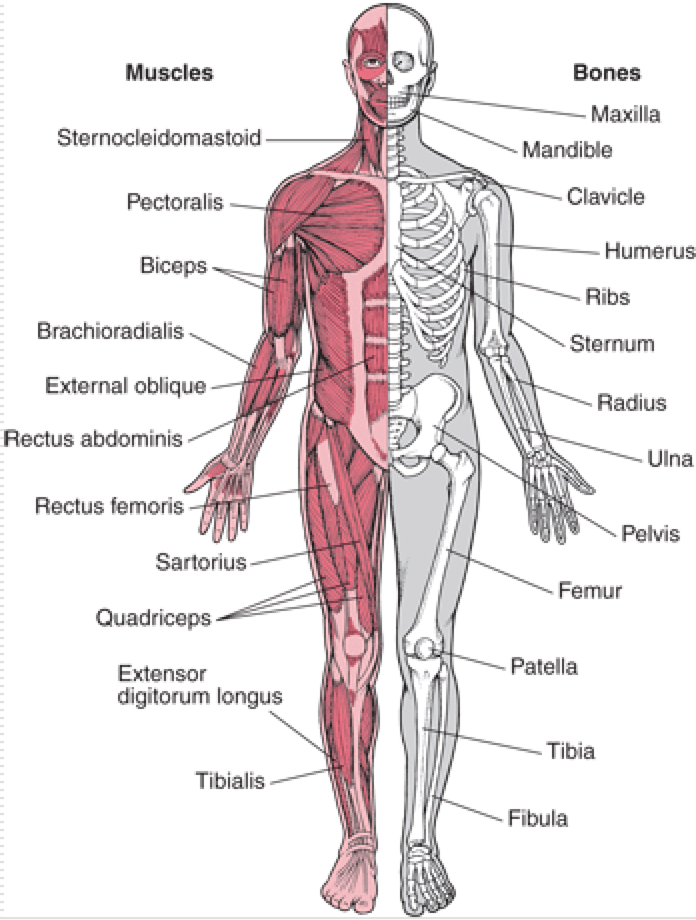
# Respiratory System

- The respiratory system is pneumatic and consists of an air pump (the diaphragm and ribcage) that alternately produces negative and positive pressures in a sealed chamber (the thoracic cavity) drawing air into and then expelling it from a pair of balloon-like organs (the lungs) linked to the atmosphere. The lungs are designed to provide hundreds of square meters of highly vascularized membranes (the alveoli) that allow for the free exchange of gas between the regularly replenished air and the blood to ensure that essential oxygen levels remain high and that waste carbon dioxide is flushed from the system. The pump regulatory mechanism is automatic, but it is provided with a conscious override that can be used to accelerate or inhibit flow as the circumstances dictate. We will analyze the biomechatronic mechanisms that can augment or replace the regulatory process should its performance become degraded or even if it fails altogether.



# Musculoskeletal System

- The musculoskeletal system performs two major functions. First, it maintains the integrity of the body by providing a firm structure to both support and protect the internal organs. Second, it provides a means for the organism to interact with the outside world by means of locomotion and manipulation. For human beings, locomotion is primarily provided by the legs and feet, and our capability for manipulation by the arms and the hands, and particularly the fingers. We will be concerned with replacing lost limbs and the augmentation of limb function in cases of diminished performance.



# Components Of Biomechatonic Systems

- Most biomechatronic systems operate by sensing some particular aspect of the environment or the human body, processing the information, and then responding in some way. It is therefore important that we are aware of
  - sensor technology,
  - processing methods,
  - and actuation systems.

# Components Of Biomechatonic Systems

- The concept of biometrics, the science of measuring physiological signals, and myriad **sensors** that can be used to measure these.
- Such measurements include bioelectric signals in the form of the
  - electrocardiogram,
  - electroencephalogram,
  - and electromyogram.
- Microphones can be used to measure heart sounds, while pressure and flow sensors measure the characteristics of the cardiovascular and respiratory systems.
- Other sensors measure the position and rates of limb elements, real and prosthetic.

# Components Of Biomechatonic Systems

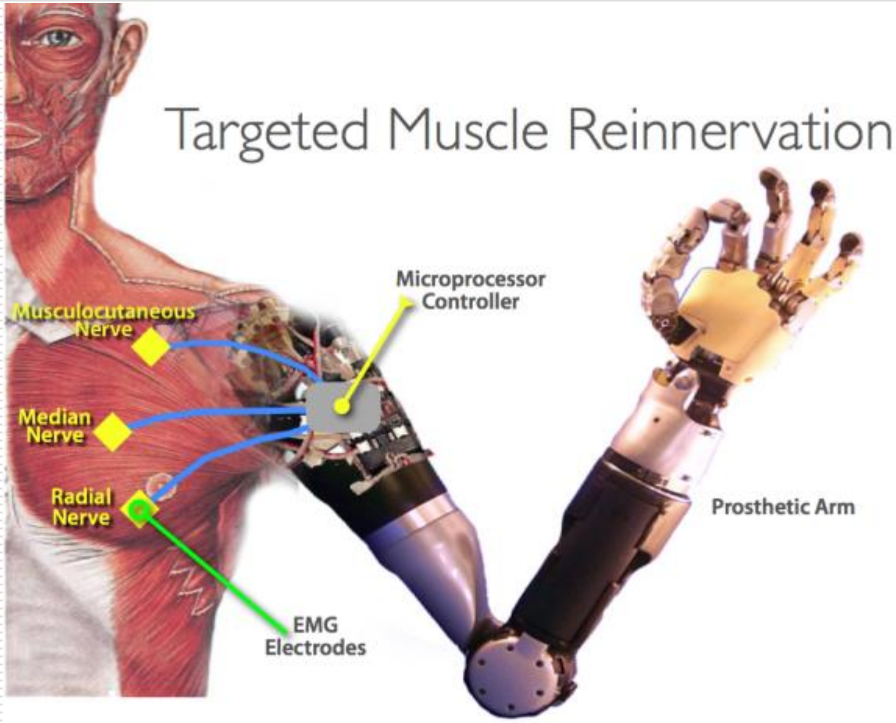
- Various forms of **actuation** is considered
  - electrics,
  - hydraulics,
  - or pneumatics.
- Loop around the measurement and actuation process is closed by examining various **feedback** types and methods of analysis.
- Concepts of both analog and digital **signal processing** that are applicable to biomechatronic systems are introduced. These include filtering in the analog and digital domains, rectification and detection of signals, and sampling and digitization. It also introduces the reader to machine learning algorithms, which are becoming important in improving our ability to interpret complex physiological processes.

# THE FUTURE OF BIOMECHATRONIC SYSTEMS

- This course provides some insight into the technology and applications that have been developed over the last 60 years or so.
- Some amazing new biomechatronic devices will become available within the next decade.
- Improvements in our ability to interface directly to the human neural system will provide the greatest advances in a range of applications.

# Targeted Muscle Reinnervation

- Already, neural reinnervation that offers both actuation and feedback is providing better interfaces to prosthetic limbs.
- The goal of a TMR fitting is to enable arm amputees to use their prosthesis intuitively, using just their minds. For this purpose, nerves that transmitted signals to the natural arm are connected to other muscles. This surgical intervention is called Targeted Muscle Reinnervation, or TMR for short.



# Targeted Sensory Reinnervation

- Targeted sensory reinnervation (TSR), which is much more experimental, potentially allows the prosthetic to transmit sensations like touch, cold or heat back to the brain.

# Targeted Sensory Reinnervation

- A literal map of the hand on the patient's upper arm is created. If you pressed the "thumb" she would feel pressure on her thumb.
- Each dot shows one fingertip in Loomis's newly mapped "hand" — red is the thumb, black is the middle finger, green is the index finger, blue is the ring finger, and purple is the pinky.

# Brain Machine Interface

- Schwartz’s team extracted even more complicated information from the brains of two rhesus macaques by reading the electrical pulses of about 100 brain cells.
- To train the monkeys, the researchers first recorded their brain activity as they controlled the robotic arm with a joystick. Once the monkeys had learned to feed themselves in this way, Schwartz’s team secured their arms and made them rely on controlling the robot with their brain.
- In tests where a monkey had to grab marshmallows or grapes and feed himself, one monkey succeeded 61% of the time

# Exoskeleton

- Where the body is intact but is dysfunctional, new lightweight materials, improved batteries, and small but powerful actuators will be used to provide full-body powered exoskeletons that will allow the wheelchair bound to walk again.

# Text Book

- Graham M. Brooker, Introduction to Biomechatronics,