Tishk International University
Mechatronics Engineering Department
MEDICAL MECHATRONICS
Lecture 2: PHYSIOLOGICAL SYSTEMS
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MEDICAL MECHATRONICS

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Outline

- Physiological systems
- Human physiology
- Biochemical system
- Anatomy, Cell and Cell structure
- Nervous system
- Cardiovascular system
- Respiratory system
- Musculoskeletal system
- The future of Biomechatronic systems
Physiological systems

To interact effectively with the human part of the structure we discussed previously in Biomechatronics system, 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 human body include the nervous system, cardiovascular, respiratory, and musculoskeletal systems along with those that interpret of taste, sight, hearing, and touch.

FIGURE:
Major physiological components that can be incorporated into biomechatronic systems.

Human Physiology

Functional study of:

1. Nervous system
2. Musculoskeletal system
3. Visual System
4. Auditory System
5. Cardiovascular system
6. Respiratory system
7. Digestive system
8. Urinary system
9. Reproductive system (genital system)

Ref: Google pictures
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.
Biochemical System

METABOLISM

CHEMICAL ENERGY
- Carbohydrates
- Fats
- Proteins
- Others

Body's Energy Currency
ATP

CHEMICAL WASTE
- Carbon Dioxide
- Water

HEAT

Ref: Google pictures
Biochemical System

Digestive system

Fat cell

Muscle

Pancreas

Liver

Glucose

Insulin

Glucagon

Ref: Google pictures
Biochemical System

Ref: Google pictures
Human Physiology and Anatomy

- **Physiology**: is the study of how the human body works. It describes the chemistry and physics behind basic body functions, from how molecules behave in cells to how systems of organs work together.

- **Anatomy**: a field in the biological sciences concerned with the identification and description of the body structures of living things.

- **Anatomy and Physiology** are studied together to give students a full appreciation and understanding of human body.
Anatomy

The study of anatomy includes many sub specialties, there are:

1. Gross anatomy
2. Microscopic anatomy
3. Development anatomy and Embryology

- **Gross anatomy** studied body structure with out microscope.
  - **Systematic anatomy** studied functional relationships of organs within a system.
  - **Regional anatomy** studied body part regionally.

Both **systematic** and **regional anatomy** approaches may be used to study across anatomy.

Ref: Google pictures
Anatomy

- **Microscopic anatomy (Histology)** requires the use of a microscope to study tissues that form the various organs of the body.

Ref: Google pictures
Anatomy

- **Embryology** is the discipline concerned with the study of **embryogenesis**, the development of the embryo from a fertilized egg cell.
Cell

• “A cell is defined as the smallest, basic unit of life that is responsible for all of life’s processes.”

• Cells are the structural, functional, and biological units of all living beings.

• The cell can replicate itself independently. Hence, they are known as the building blocks of life.

• Cells are the fundamental unit of life. They range in size from 0.0001 mm to nearly 150 mm across.
The cell consists of three main parts: the cell membrane, the nucleus, and, between the two, the cytoplasm. ... Within the cytoplasm lie intricate arrangements of fine fibers and hundreds or even thousands of minuscule but distinct structures called organelles.
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.
- The nervous system is a complex network of nerves and cells that carry messages to and from the brain and spinal cord to various parts of the body.
- The nervous system has two main parts: The central nervous system CNS is made up of the brain and spinal cord. The peripheral nervous system PNS is made up of nerves that branch off from the spinal cord and extend to all parts of the body.
Nervous System

- At the nervous system center is the brain, which performs the processing and memory storage tasks, and to it are connected myriad input/output nerve channels.

- The 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.
The nervous system has three primary functions, they are:

- **Sensing**: sensory, or afferent, nerves, nervous system gathers information of body & environment.
- **Integration**: this information goes to brain for processing.
- **Response**: brain sends out appropriate motor response through the efferent (motor) nerves based on information.
Nervous System Mechanism

Ref: What are neurons and how do they work? - YouTube
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.
Cardiovascular System

cardiovascular system, also known as circulatory system is made up of heart and blood vessels.

- It works to transport oxygen and other nutrients to all the organs and tissues in your body.
- It also works to remove carbon dioxide and other waste products.
The Cardiac Cycle

Ref: The cardiac cycle - YouTube
3D bioprinted heart

Ref: Google pictures
3D bioprinted heart

Ref: Carnegie Mellon University / 3D-Printed, Lifelike Heart Models Could Help Train Tomorrow’s Surgeons | Headline Science - YouTube
Heart robot mimics healthy cardiac muscles

Ref: Harvard University
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 closed 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.
Respiratory System

Ref: Google pictures
Surgical procedure, (A) A picture of the partially resected trachea. The ventral part of the resected trachea is a semi-circular shape. (B) The artificial trachea is cut into semi-circular shapes and placed with interrupted sutures. Scale bars indicate 1 cm

❖ From: Experimental Tracheal Replacement Using 3-dimensional Bioprinted Artificial Trachea with Autologous Epithelial Cells and Chondrocytes
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 protects 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.
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.

Ref: First-ever targeted sensory reinnervation surgery in the US gives Melissa Loomis the ability to feel touch, pressure, and cold — Quartz (qz.com)
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.

Ref: Monkey operating a robotic arm with brain–computer interfacing (Schwartz lab, University of Pittsburgh)
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.
Next Lecture

• Acquiring Biological Signal
• Biological Signal Processing