Control in Biological Systems

Lec # 03

Introduction

- The field of control and systems has been connected to biological systems and biotechnology for many decades, going back to the work of Norbert Wiener on cybernetics in 1965, the work of Walter Cannon on homeostasis in 1929.
- *Nonetheless, the impact of control and systems on devices and applications in the field of biology has only emerged in recent years.*

Successful Applications of Control:

- As noted above, the field of biomedical control systems is relatively young compared to aerospace, automotive, and the chemical process fields.
- Nevertheless, some noteworthy recent developments have emerged in two key application areas: cardiovascular systems and endocrinology.

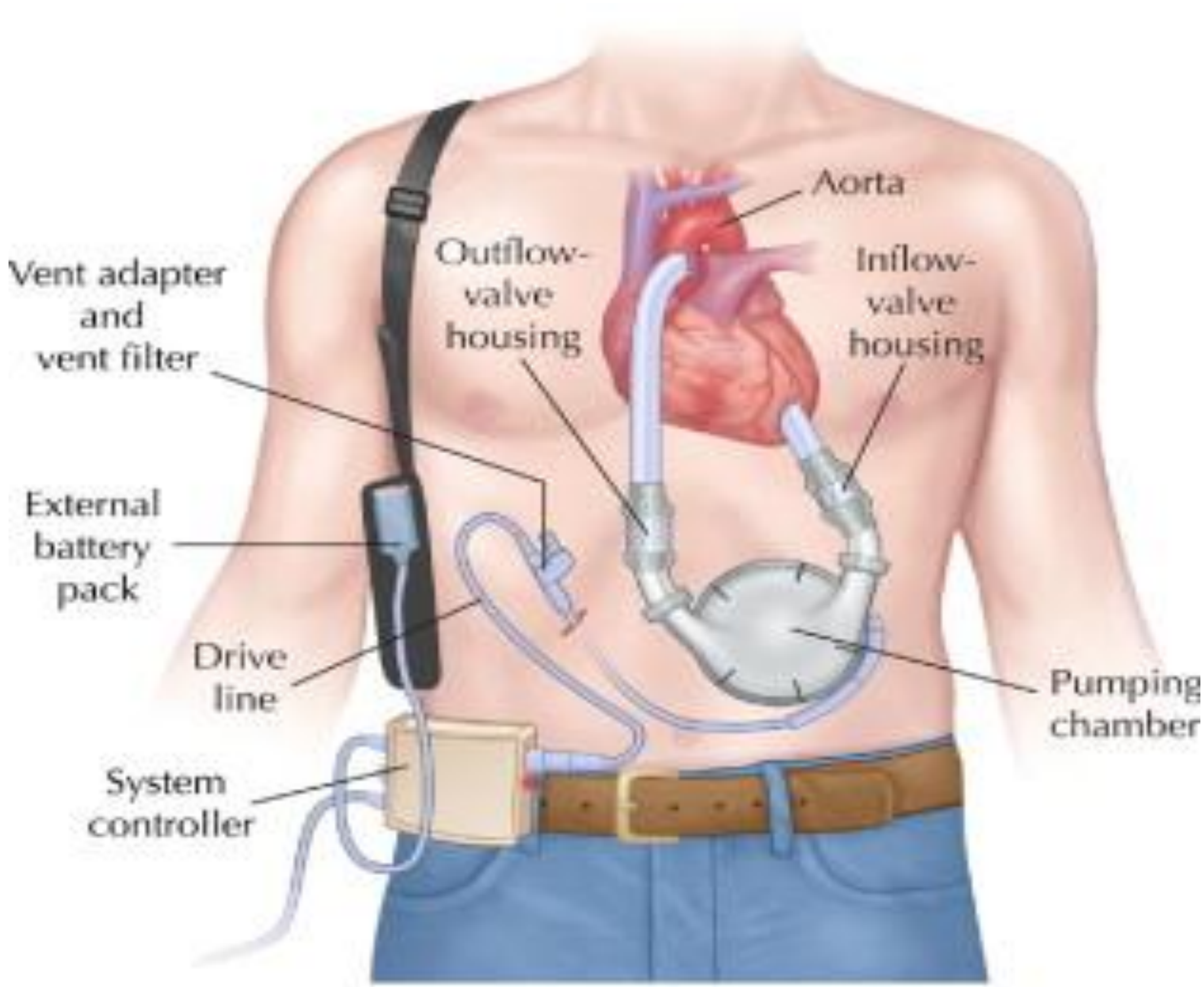
Cardiac Assist Devices

- The area of cardiac assist devices has had a relatively long history of development, although advanced control theory and process modeling have only recently been applied to these devices.
- Cardiac assist devices are mechanical pumps that supplement endogenous cardiac output at an appropriate pressure to allow normal circulation through the patient's body.

Components

There are 3 major components of the VAD:

- the inflow cannula- The inflow cannula is a large tube that drains blood from the heart into the pump;
- the outflow cannula- the outflow cannula returns blood to either the aorta (in a left ventricular assist device or LVAD) or pulmonary artery (in a right ventricular assist device), and
- the pump itself.



HeartMate XVE LVAD

Why VADS' are used?

- The main purpose of a VAD is to unload the failing heart and help maintain blood flow to vital organs.
- VADs were originally developed to serve as a temporary bridge to heart recovery, and then as a bridge to transplant.
- Bridge to transplant or destination therapy VADs are typically placed through a chest incision after the patient has been placed on a heart-lung bypass machine.

VAD types

- First-generation pumps were pulsatile, contained artificial heart valves, and ejected blood at rates typically between 80 and 100 times per minute with the use of either forced air or electricity.
- Second-generation pumps circulate blood in a continuous fashion by use of an internal rotor that spins up to 15 000 times per minute (typical range, 8000–10 000 rpm). The major advantages of continuous-flow pumps are that they are smaller, quieter, easier to implant, and last longer than the older, pulsatile pumps.

- Currently approved VADs are implanted just below the diaphragm in the abdomen, or can sit outside of the body on top of the abdomen.
- Smaller pumps that can be implanted adjacent to the heart in the chest cavity or provide only partial heart support are under development.
- A driveline that contains the power wires exits the skin, usually on the right side of the abdomen, and connects to a controller that is worn on a belt.
- This controller is then connected to either a power-based unit that plugs into the wall or large batteries that can be worn in a vest for portable use.
- The controller is the brain of the pump, and provides important information to the patient, caregivers, and medical team about VAD function and battery life.

Blood Pressure Control

- The IVAC Titrator was developed to regulate mean arterial pressure in hypertensive intensive care unit (ICU) patients by infusing sodium nitroprusside.
- The device received FDA approval in 1987 and was marketed for a short time, but was discontinued after a few years.
- The reasons for its failure in the marketplace include the following:

(1) no consistent communication standards existed at the time, so the device had its own blood pressure sensor that was not particularly easy to set up;

(2) the computer interface technology was not advanced;

(3) the units were overpriced and

(4) although studies showed less variability in blood pressure than with manual control, the effect of the reduced variability on patient outcomes was unclear .

- Some studies suggested that patients were able to reduce hospital stays by a day. With new communication standards and advances in microprocessor-based pump technology, a closed-loop blood pressure system could probably succeed in the marketplace today.

Anesthesia Delivery

- The effect of the intravenous anesthetic propofol is directly related to its concentration in the blood.
- Target-controlled infusion (TCI) is a model-based open-loop strategy designed to regulate the concentration of a drug in the blood by giving an initial intravenous bolus (shot), followed by time-dependent infusion.
- A commercial device, the Diprifusor has been available throughout much of the world since 1996, with millions of successful propofol infusions administered.
- For a variety of reasons, no TCI device has received FDA approval in the United States .
- Approval may be more likely if the infusion system incorporates a depth of anesthesia monitor, to form a fully closed-loop system.

Other Applications

- Beyond those highlighted here, a number of biomedical devices that have been successfully translated into commercial products using closed-loop technology include:
  - the implantable cardioverter defibrillator (ICD),
  - the intracardiac electrogram (IEGM), and
  - the oxygen saturation monitor.
- In other biomedical device areas, sensors are used to provide feedback to control and deliver electric signals that stimulate the brain to ease the tremors of Parkinson's disease and epilepsy by determining the extent and timing of stimulation.
- Additionally, closed-loop biomedical devices are used to treat peripheral vascular disease by using sensors to measure blood flow in a patient's limbs and determine the level of spinal cord or peripheral nerve stimulation required to improve blood flow, thereby reducing ischemic pain in the limbs.

Assignment

- Search for a new application of control system in Biomedical.
- Submit the report in group & explain your topic in class.

- Red biotechnology
- Blue biotechnology

System Representation

- Multiple subsystems are represented in two ways:
  - as block diagrams and
  - as signal-flow graphs.

Block Diagram v/s Signal flow graph

Block Diagram	Signal Flow Graph
• Block diagrams are usually used for frequency-domain analysis and design. • Systems represented by a block with its input and output & a transfer function. • Block diagram algebra will be used to reduce block diagrams	• Signal-flow graphs for state-space analysis. • Signal-flow graphs represent transfer functions as lines, and signals as small circular nodes. • Mason's rule to reduce signal-flow graphs.