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Solutions Manual: Chapter 1

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Feedback Control of Dynamic Systems

Gene F. Franklin

J. David Powell

Abbas Emami-Naeini

Assisted by:
H. K. Aghajan
H. Al-Rahmani
P. Coulot
P. Dankoski
S. Everett
R. Fuller
T. Iwata
V. Jones
F. Safai
L. Kobayashi
H-T. Lee
E. Thuriyasena
M. Matsuoka

Chapter 1

An Overview and Brief History of Feedback Control

1.1 Problems and Solutions

1. Describe the following feedback control systems in terms of simple block diagram.

   (a) Missile launching and guidance system

   (b) The temperature control system of the human body (perspiration process)

   (c) Photocell-based light switch system

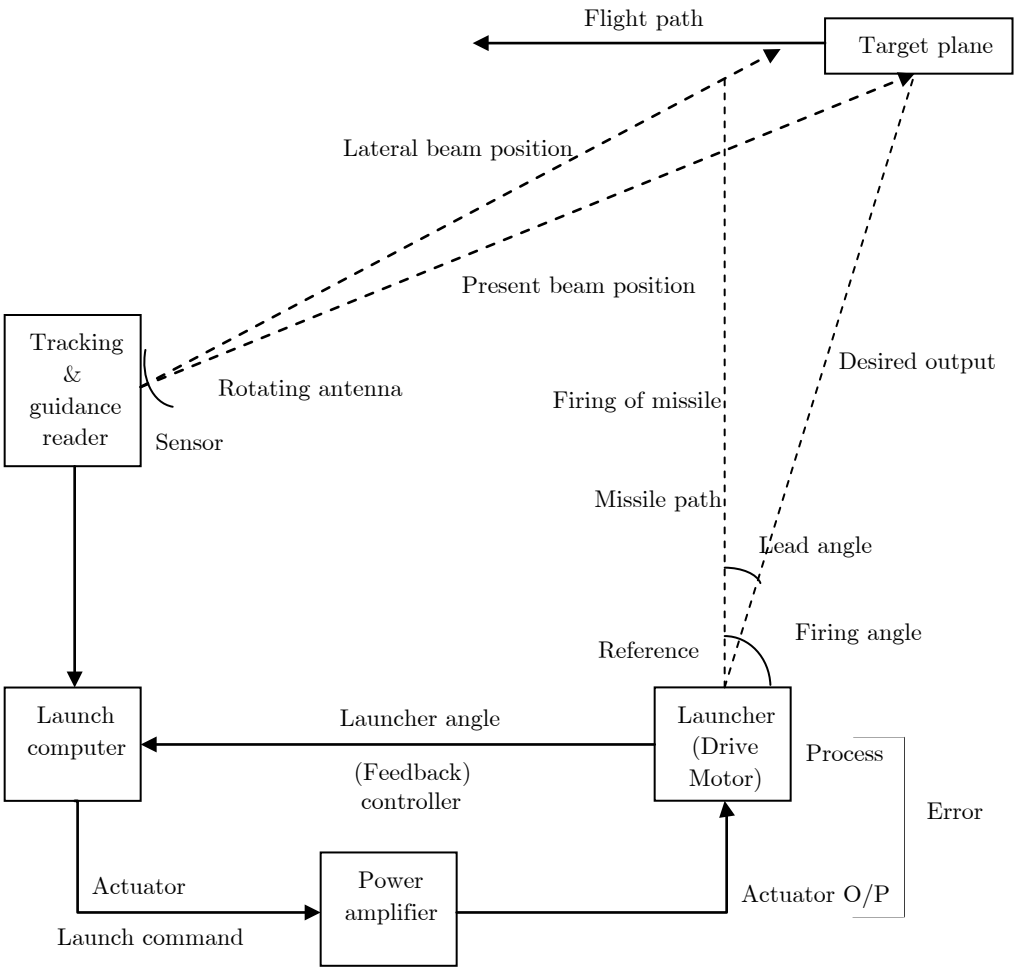
   (d) A person crossing a road in heavy traffic

   For each system, indicate the location of the following elements and mention the units associated with each parameter.

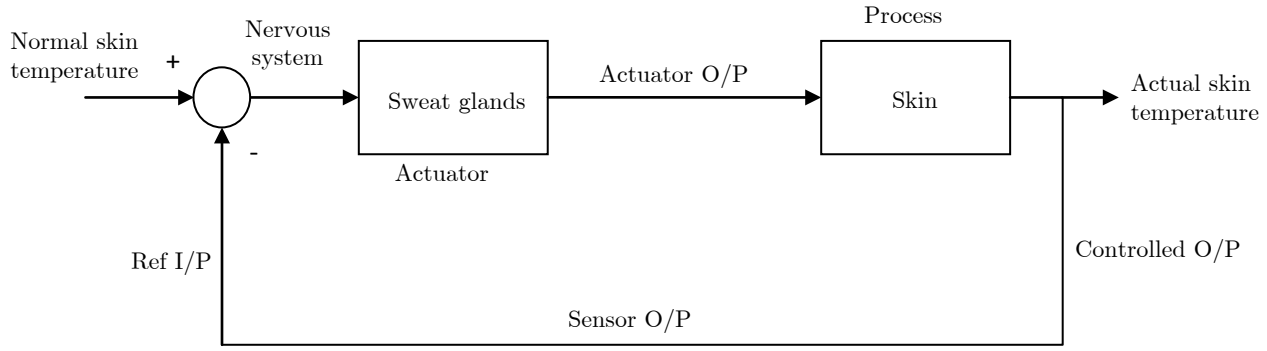
   - The process
   - Desired output signal
   - Sensor
   - Actuator
   - Actuator output
   - Controller
   - Controller output
   - Reference
   - Error

   Note that in certain cases, the same physical device may perform more than one of these functions.
   Solution:

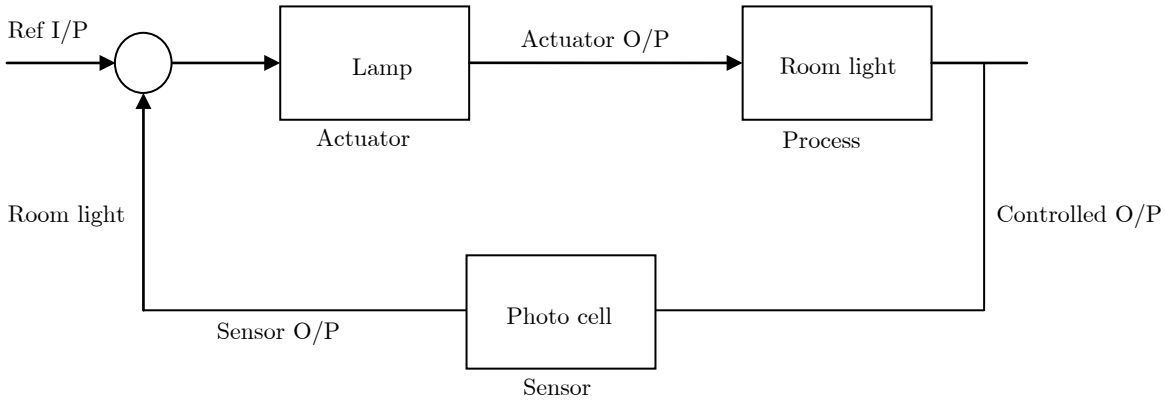
   (a) Missile launching and guidance system:



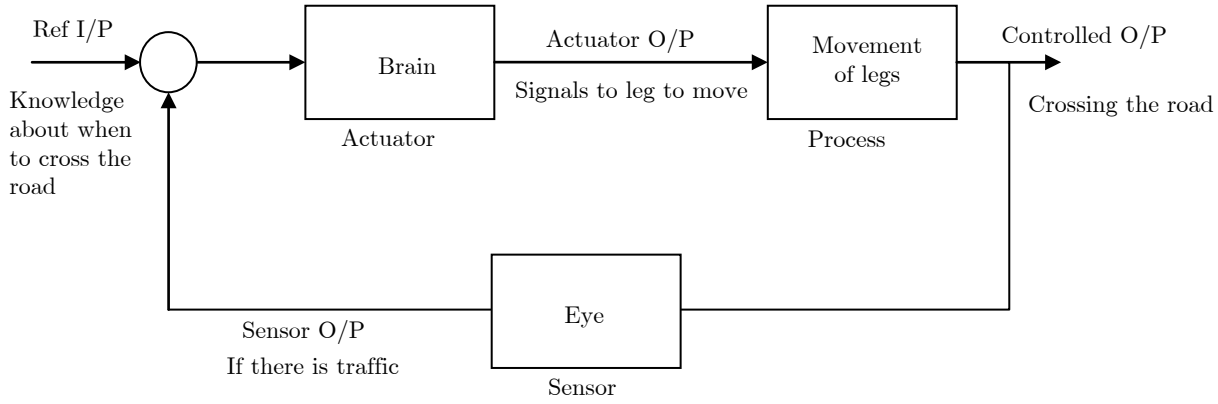
(b) Human body temperature control system (Perspiration Process)



(c) Photocell-based light switch system:



(d) A person crossing a road in heavy traffic:



2. Identify the concept involved and highlight the process of automatic aperture control in a camera.

Solution:

Modern cameras often have the feature of automatic aperture area control. The film used is similar to the retina of the eye. The aperture regulates the incident light. Since the film speed & exposure time are controllable, one can easily design this system. Due to the absence of negative feedback, this system becomes an open loop.

The light metal is positioned in order to measure the intensity continuously & the correct aperture area is adjusted. If the exposure time is manually altered, the system must also alter the aperture accordingly. The light metal readings are made to control the aperture mechanism and the exposure time is controlled by the use of an electric circuit. Under an open loop setup, malfunctions, in last operation of photo-cells, battery power, etc cannot be rectified due to the absence of feedback.

But faulty parts can easily be repaired or replaced in an open-loop setup. So, feedbacks are to be used only when it is absolutely necessary.

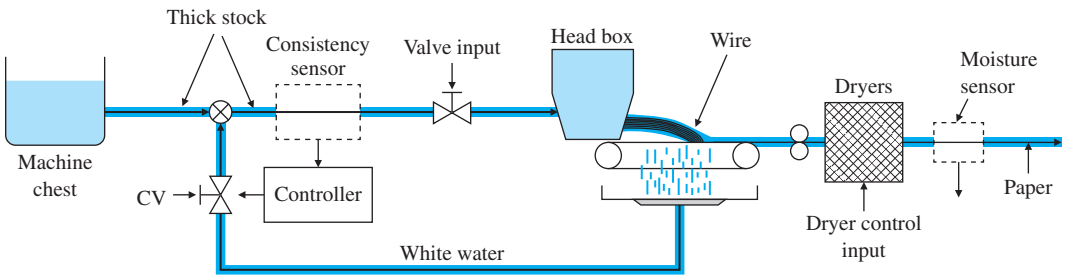


Fig 1.12 A Paper Making Machine

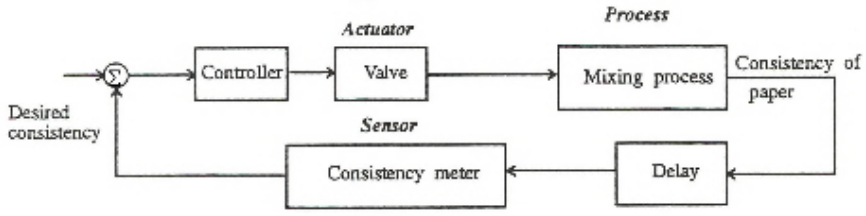
3. A machine for making paper is diagrammed in Fig. 1.12. There are two main parameters under feedback control: the density of fibers as controlled by the consistency of the thick stock that flows from the headbox onto the wire, and the moisture content of the final product that comes out of the dryers. Stock from the machine chest is diluted by white water returning from under the wire as controlled by a control valve (CV). A meter supplies a reading of the consistency. At the "dry end" of the machine, there is a moisture sensor. Draw a signal graph and identify the seven components listed in Problem 1 for

   (a) Control of consistency

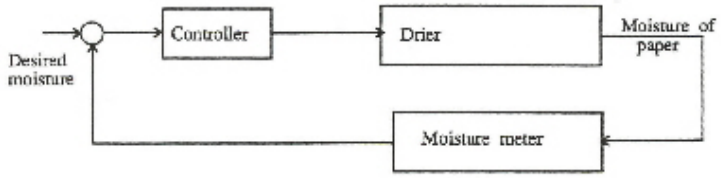
   (b) Control of moisture

   Solution:

   (a) Control of paper machine consistency:



   (b) Control of paper machine moisture:



4. Many variables in the human body are under feedback control. For each of the following controlled systems, draw a block diagram showing the process being controlled, the sensor that measures the variable, the actuator that causes it to increase and/or decrease, the information path that completes the feedback path, and the disturbances that upset the variable. You may need to consult an encyclopedia or textbook on human physiology for information on this problem.

   (a) Muscle stretch reflex

   (b) Cardiac output regulation

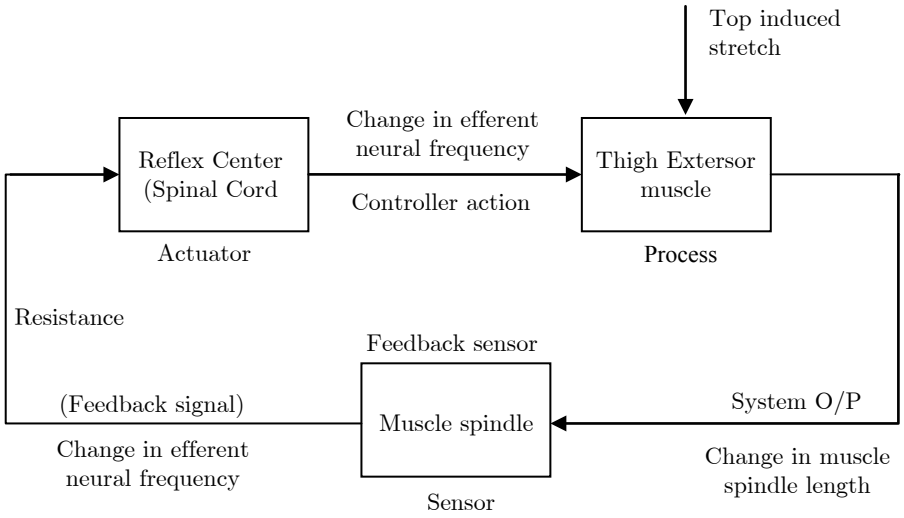
   (c) Pupillary light reflex

   (d) Chemoreflex control of ventilation

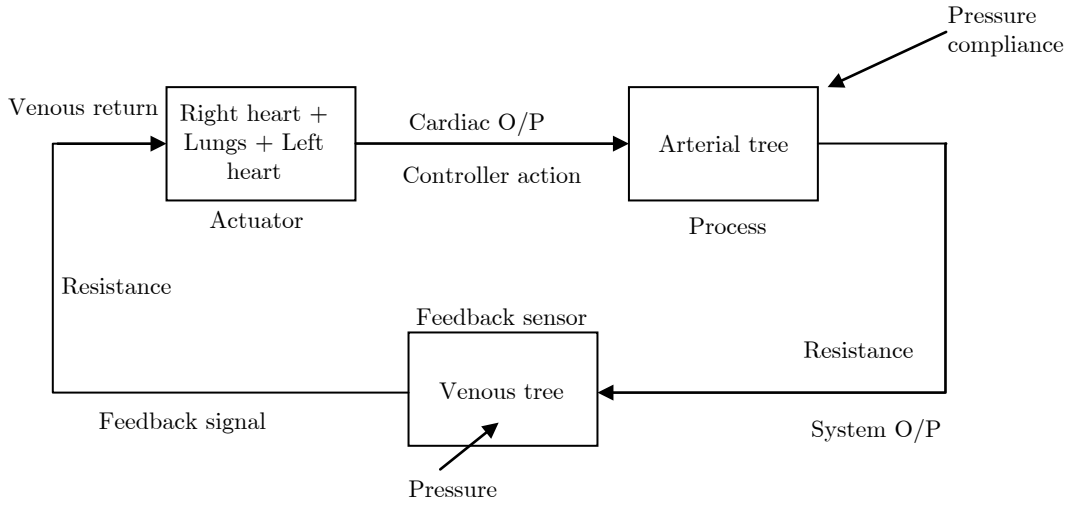
   (e) Respiratory control during re-breathing

   Solution:

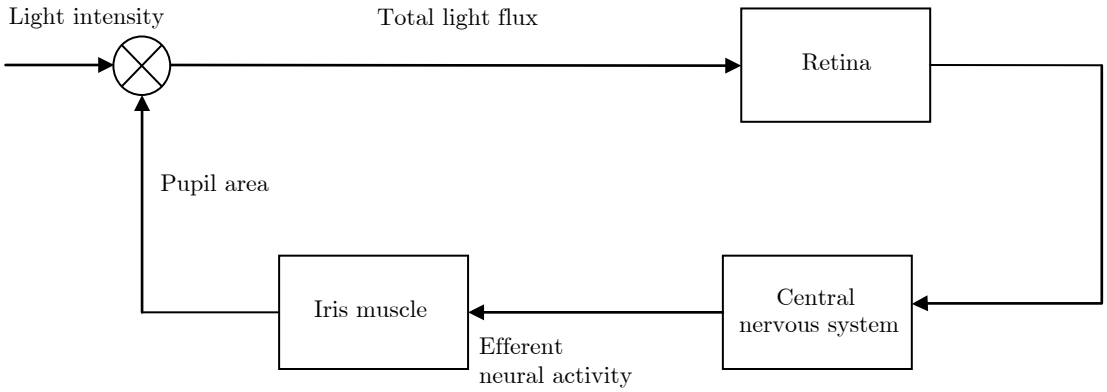
   (a) Muscle stretch reflex



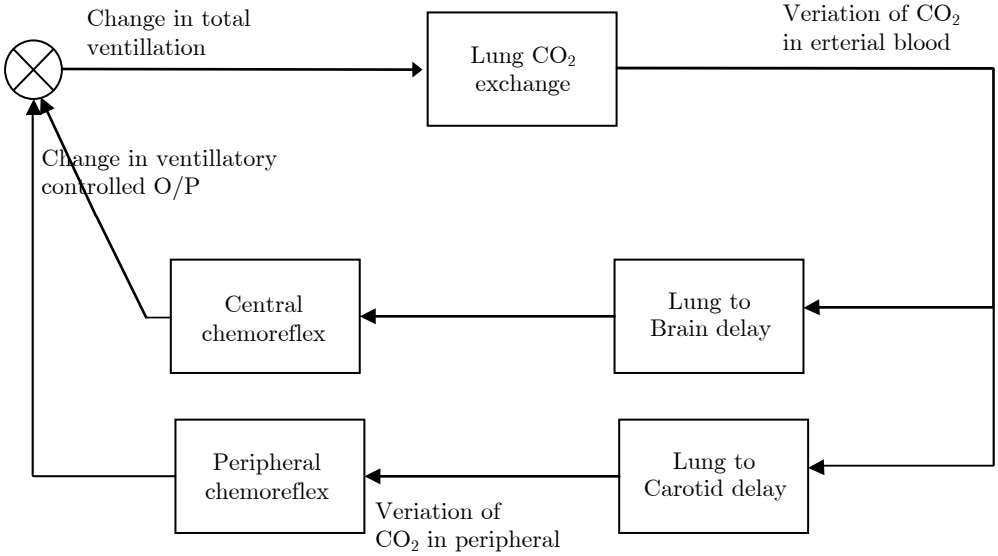
(b) Cardiac output regulation



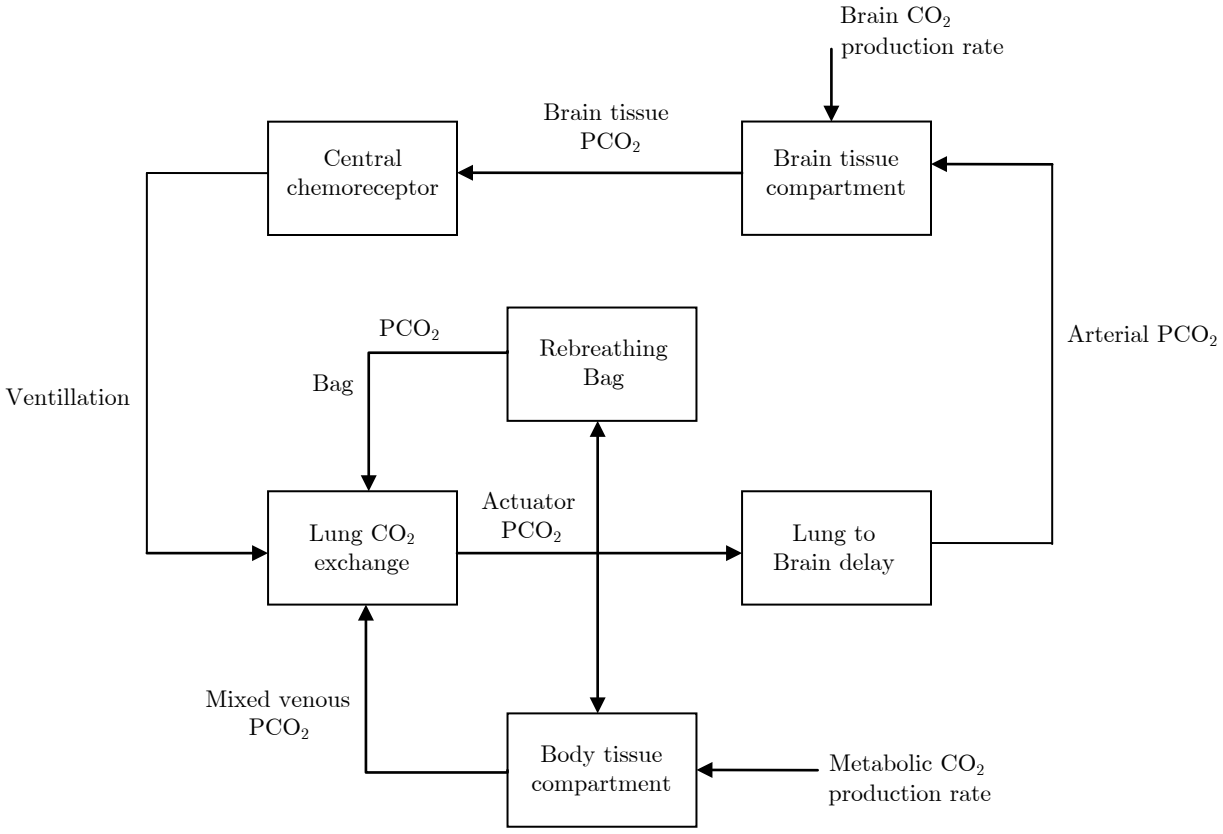
(c) Pupillary light reflex



(d) Chemoreflex control of ventilation

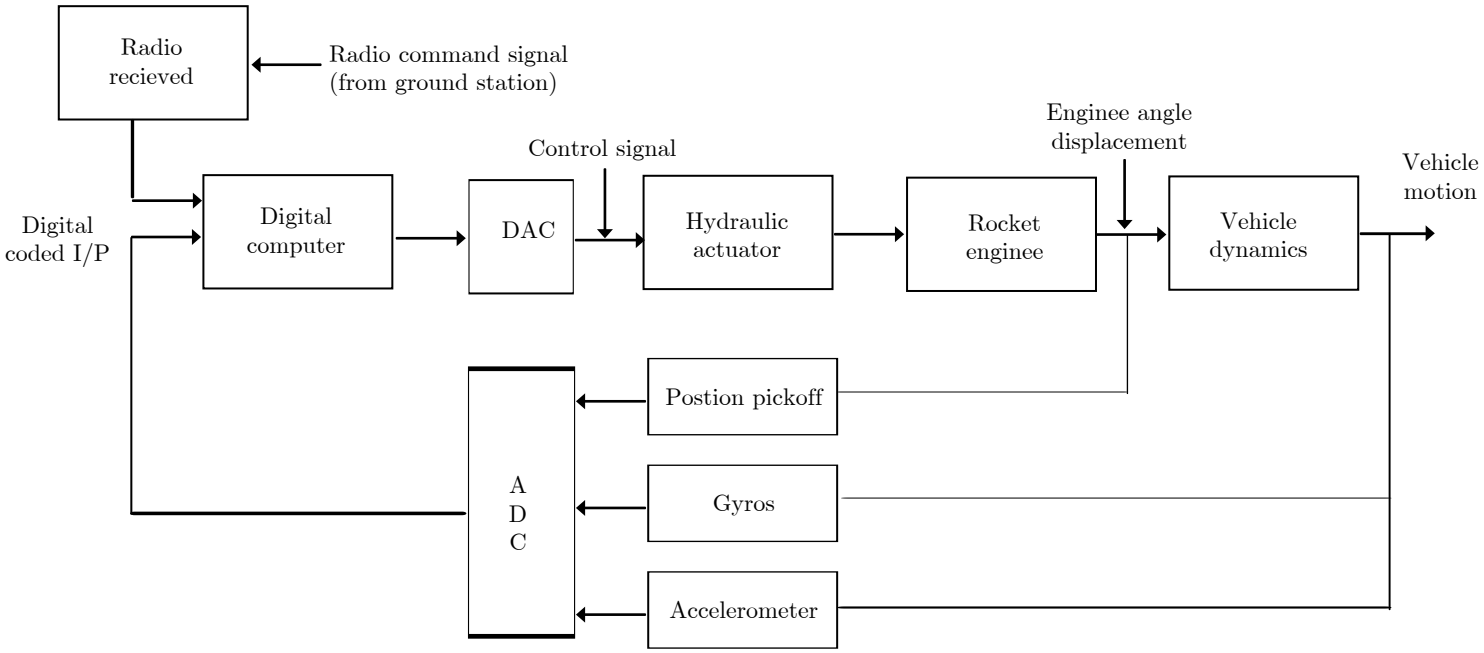


(e) Respiratory control during re-breathing



Note: P_{CO2} = Pertial pressure of CO_2

5. Draw a block diagram showing how a typical autopilot system in a rocket functions.
Solution:



6. (a) Describe in a simplified way, the components and variables of the physiological system involved in walking in a specific direction.
(b) Why is walking considered a closed-loop operation?
(c) Under what conditions would the walking process become an open-loop system? (Assume the subject has normal vision.)

Solution:

(a) Components involved – Brain, Eyes, Legs, Feet.
I/P – Desired walk direction
O/P – Actual walk Direction
Control – Eyes sense the difference between input and output & send this information to brain.
Brain – Commands legs & feet to walk as specified.

(b) Walking is a closed loop operation because the control action is a function of the output.

c) If eyes are closed the feedback loop is broken & system becomes open loop. If eyes are open & closed periodically, the system becomes a sampled-data type & walking then is more accurately controlled than with the eyes closed.

7. Feedback control requires being able to sense the variable being controlled. Because electrical signals can be transmitted, amplified, and processed easily, often we want to have a sensor whose output is a voltage or current proportional to the variable being measured. Describe a sensor that would give an electrical output proportional to:

   (a) temperature

   (b) pressure

   (c) liquid level

   (d) flow of liquid along a pipe (or blood along an artery) force

   (e) linear position

   (f) rotational position

   (g) linear velocity

   (h) rotational speed

   (i) translational acceleration

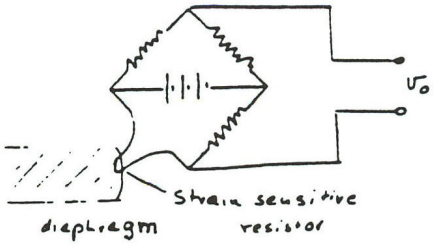
   (j) torque

   Solution:

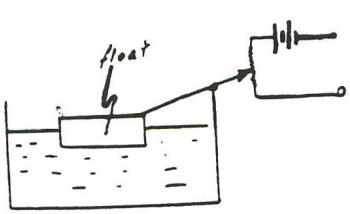
   Sensors for feedback control systems with electrical output. Examples

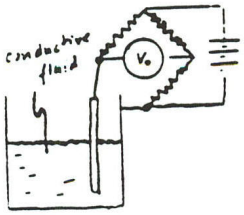
   (a) Temperature: Thermistor- temperature sensitive resistor with resistance change proportional to temperature; Thermocouple; Thyristor. Modern thermostats are computer controlled and programmable.

   (b) Pressure: Strain sensitive resistor mounted on a diaphragm which bends due to changing pressure



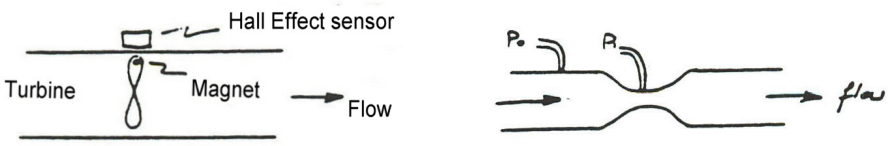
   (c) Liquid level: Float connected to potentiometer. If liquid is conductive the impedance change of a rod immersed in the liquid may indicate the liquid level.





   (d) Flow of liquid along a pipe: A turbine actuated by the flow with a magnet to trigger an external counting circuit. Hall effect produces an electronic output in response to magnetic field changes. Another

way: Measure pressure difference from venturi into pressure sensor as in figure; Flowmeter. For blood flow, an ultrasound device like a SONAR can be used.



(e) Position.

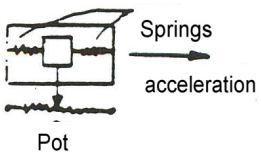
When direct mechanical interaction is possible and for "small" displacements, the same ideas may be used. For example a potentiometer may be used to measure position of a mass in an accelerator (h). However in many cases such as the position of an aircraft, the task is much more complicated and measurement cannot be made directly. Calculation must be carried out based on other measurements, for example optical or electromagnetic direction measurements to several known references (stars,transmitting antennas ...); LVDT for linear, RVDT for rotational.

(f) Rotational position. The most common traditional device is a potentiometer. Also common are magnetic machines in which a rotating magnet produces a variable output based on its angle.

(g) Linear velocity. For a vehicle, a RADAR can measure linear velocity. In other cases, a rack-and-pinion can be used to translate linear to rotational motion and an electric motor(tachometer) used to measure the speed.

(h) Speed: Any toothed wheel or gear on a rotating part may be used to trigger a magnetic field change which can be used to trigger an electrical counting circuit by use of a Hall effect (magnetic to electrical) sensor. The pulses can then be counted over a set time interval to produce angular velocity: Rate gyro; Tachometer

(i) Acceleration: A mass movement restrained by a spring measured by a potentiometer. A piezoelectric material may be used instead (a material that produces electrical current with intensity proportional to acceleration). In modern airbags, an integrated circuit chip contains a tiny lever and 'proof mass' whose motion is measured generating a voltage proportional to acceleration.

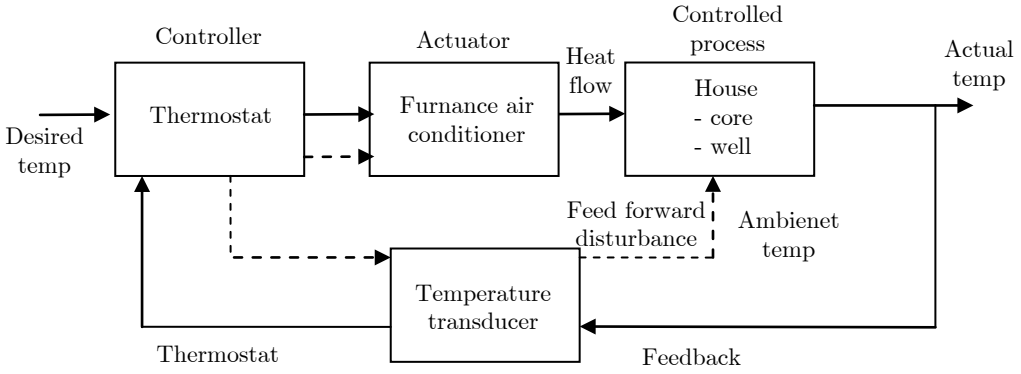


(j) Force, torque: A dynamometer based on spring or beam deflections, which may be measured by a potentiometer or a strain-gauge.

8. Describe the process of thermoregulation in a house as a control system. Indicate the controller, actuator, and controlled process feedback in a block diagram representation of this system.

Solution:

House Thermoregulation



In house thermoregulation, a thermostat is the reference input. The transducer is a bimetallic strip which bends with change in temperature. The feedback of the temperature transducer, due to the thermostat, helps in achieving the desired temperature, and the ambient air feedback helps in increasing the accuracy. This helps in a quicker response for external temperature changes and reduces the oscillations in the system

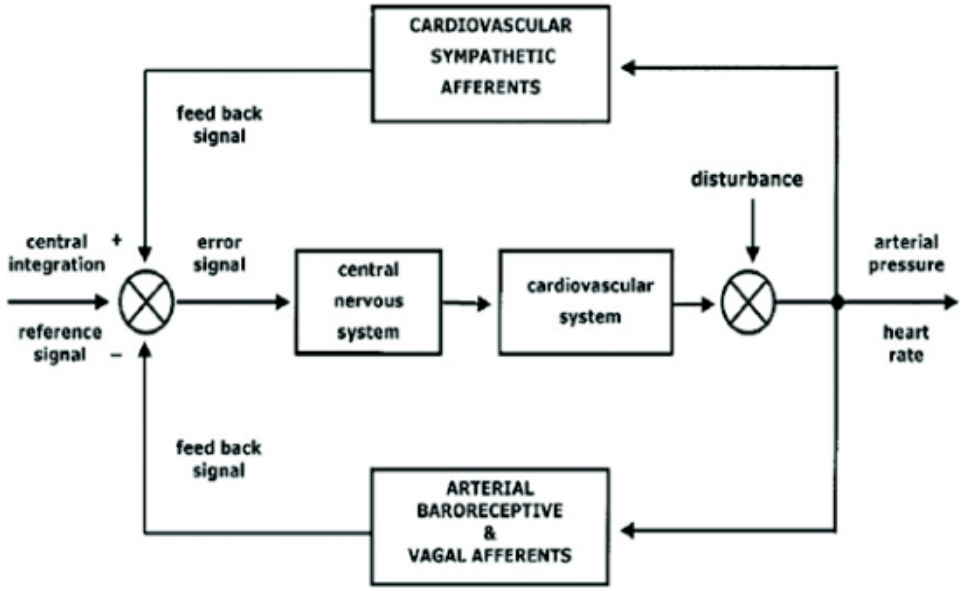
9. *Feedback in Biology*

(a) *The cardiovascular system in human beings*: In order to represent the human cardiovascular system in terms of a general feedback control system, one needs to divide the system into the controlling and the controlled system. The controlling system would then be the medullary cardiac centers and the vasomotor centers in the brain, the endocrine glands, and the blood vessels. On similar lines, the controlled centers will be the mechanical gas exchanger elements. Considering one or more outputs of the controlled system is fed back to the controlling system, illustrate the working of the cardiovascular system as a feedback control system.

(b) *Skeletal muscle servomechanism*: The muscle has contractile fibers which are organized into motor units and each of these units is fired by a motoneu-ron from the spinal cord. These fibers are attached to their relevant bone and are embedded in Golgi tendon organs. The Golgi tendon organs are sensitive to muscle tension. They provide the feedback to the motoneurons. But this feedback is not very satisfactory. However, the main feedback is given by the neuro-muscular spindle fibers. The primary afferents have a faster conduction velocity and the secondary afferents have a slower conduction rate. Draw an information flow diagram of this servomechanism.

Solution:

(a) The cardiovascular system in human beings



(b) Skeletal muscle servomechanism