Feedback Control of Dynamic Systems 9th edition Powell Solutions Manual

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Instructor's Solution Manual

Feedback Control of Dynamic Systems

9th Edition

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Chapter 1: An Overview and Brief History of Feedback Control

1.1 Draw a component block diagram for each of the following feedback control systems below. In each case, indicate the location of the elements below:

- the process
- the process desired output signal
- the sensor
- the actuator
- the actuator output signal
- the controller
- the controller output signal
- the reference signal
- the error signal

Notice that in a number of cases, the same physical device may perform more than one of these functions.

a. The manual steering system of an automobile.

b. A control system for staying in the required lane for an autonomous car.

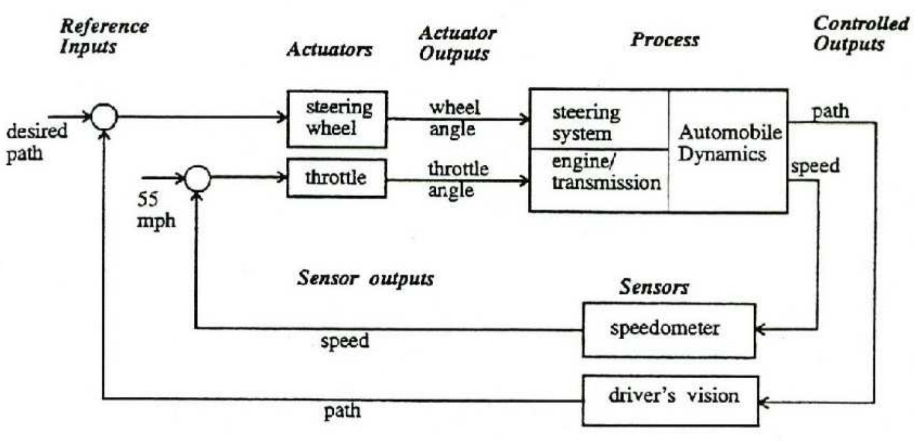
c. Altitude for a drone as it comes into land.

d. Watt's steam engine with fly-ball governor

e. An elevator control system.

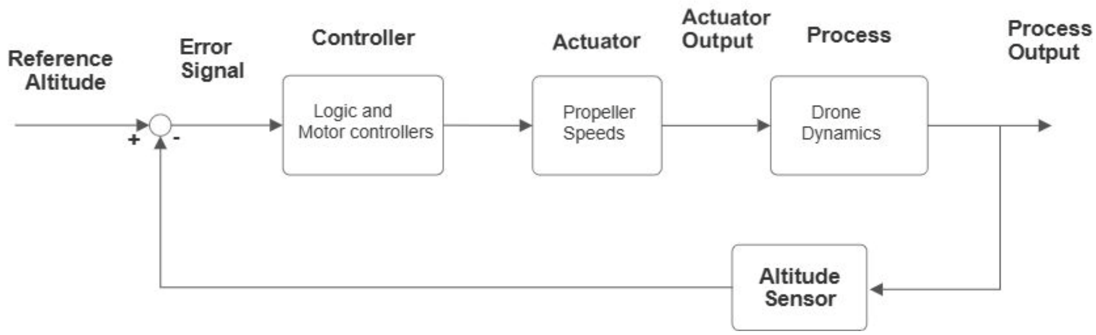
Solution:

a. A manual steering system for an automobile is in the outer loop below:

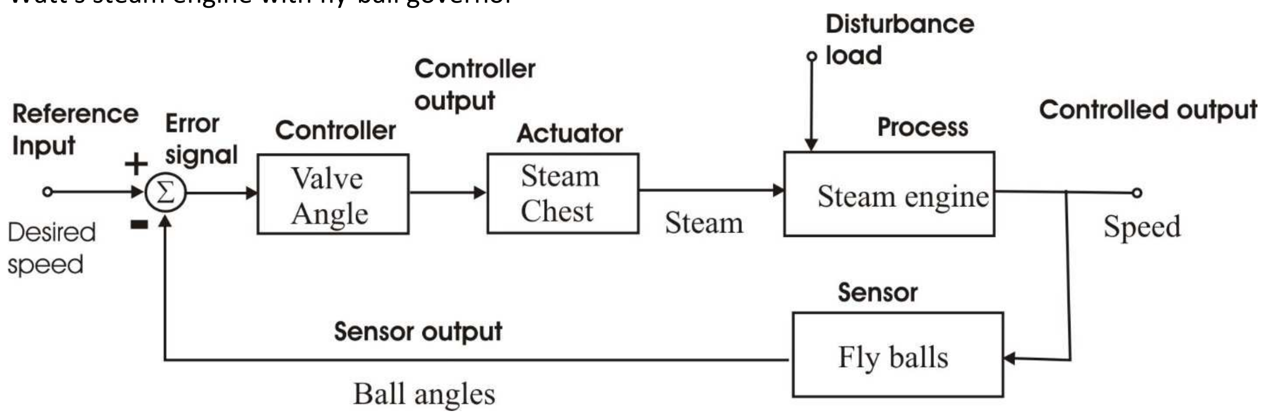


b. Control system for staying in the required lane for an autonomous car. See outer loop of the diagram above, but replace "driver's vision" with "lane position sensor".

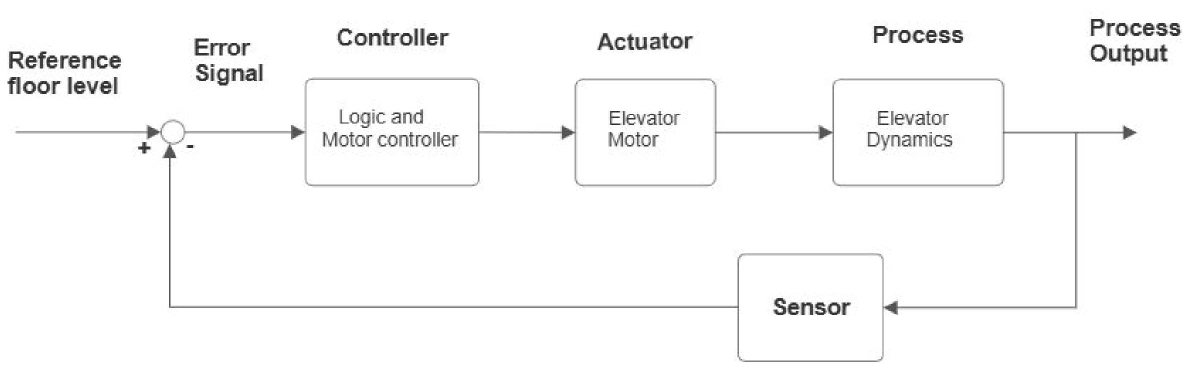
c. Altitude for a drone as it comes into land



d. Watt's steam engine with fly-ball governor



e. An elevator control system



1.2 Identify the physical principles and describe the operation of an automobile cruise control system (for speed only).

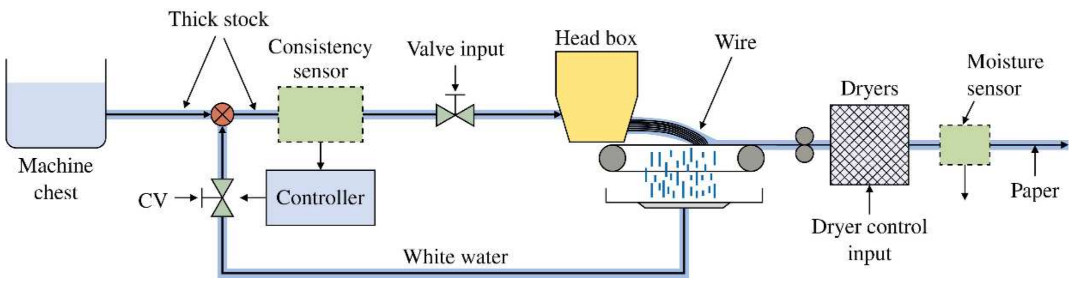
Solution:

The automobile speed is obtained by the vehicle's speedometer. That measurement is compared with the desired speed, as set by the driver. (See Figure above for Problem 1.1a) The difference (the error signal) is fed into a controller that determines the proper level for the throttle of the car (or the motor inputs for an EV). This signal is continuously adjusted as the vehicle speed changes and approaches the desired speed, i.e., until the error signal goes to zero.

1.3 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 1.1 for

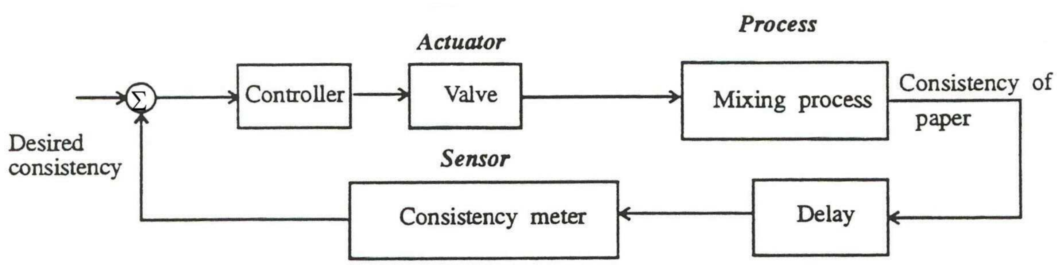
a. control of consistency
b. control of moisture

Figure 1.12 A papermaking machine

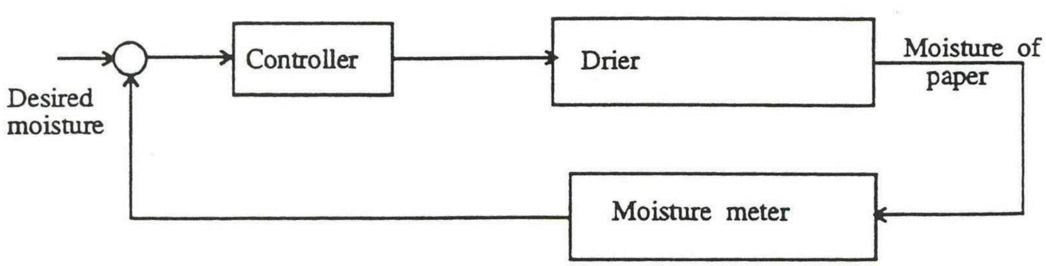


Solution:

(a) Control of paper machine consistency



(b) Control of paper machine moisture



1.4 Many variables in the human body are under feedback control. For each of the following controlled variables, draw a graph 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) blood pressure
(b) blood sugar concentration
(c) heart rate
(d) eye-pointing angle
(e) eye-pupil diameter

Solution:

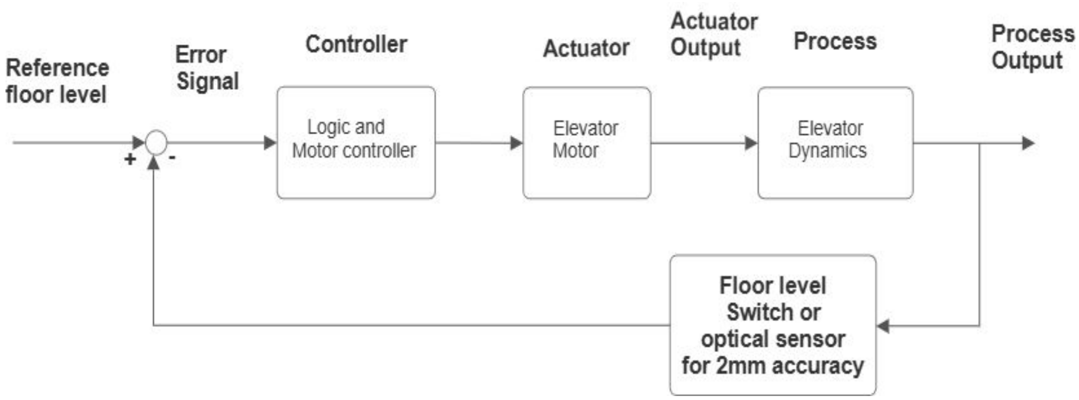
Feedback control in human body:

Variable	Sensor	Actuator	Information path	Disturbances
a) Blood pressure	Arterial baroreceptors	Cardiac output Arteriolar/venous dilation	Afferent nerve fibers	Bleeding Drugs Stress, Pain
b) Blood sugar concentration (Glucose)	Pancreas	Pancreas secreting insulin	Blood flow to pancreas	Diet Exercise
c) Heart rate	Diastolic volume sensors Cardiac sympathetic nerves	Electrical stimulation of sino-atrial node and cardiac muscle	Mechanical draw of blood from heart. Circulating epinephrine	Hormone release. Exercise
d) Eye pointing angle	Optic nerve. Image detection	Extraocular muscles	Cranial innervation	Head movement. Muscle twitch
e) Pupil diameter	Rods	Pupillary sphincter muscles	Autonomous system	Ambient light. Drugs
f) Blood calcium level	Parathyroid gland detectors	Ca from bones to blood. Gastrointestinal absorption	Parathormone hormone affecting effector sites	Ca need in bones. Drugs

1.5 Draw a graph of the components for an elevator-position control. Indicate how you would measure the position of the elevator car. Consider a combined coarse and fine measurement system. What accuracies do you suggest for each sensor? Your system should be able to correct for the fact that in elevators for tall buildings there is significant cable stretch as a function of cab load.

Solution:

A coarse measurement can be obtained by an electro switch located before the desired floor level. When touched, the controller reduces the motor speed. A "fine" sensor can then be used to bring the elevator precisely to the floor level. With a sensor such as the one depicted in the figure below, a linear control loop can be created (as opposed to the on-off type of the coarse control). Accuracy required for the course switch is around 5 cm; for the fine floor alignment, an accuracy of about 2 mm is desirable to eliminate any noticeable step for those entering or exiting the elevator.



1.6 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 the following:

a. temperature

b. pressure

c. liquid level

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

e. position on a map

f. angular position

g. speed along a road

h. 3-dimensional velocity

i. distance of a car in front of your position

j. angular velocity

k. acceleration of a car in the direction of travel

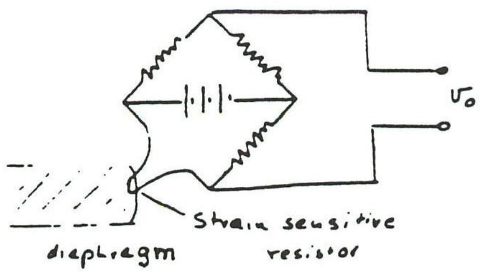
l. distance from a drone to the ground below

Solution:

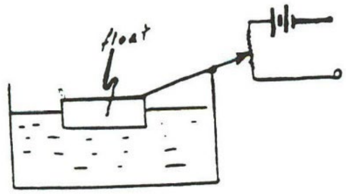
Sensors for feedback control systems with electrical output. Examples

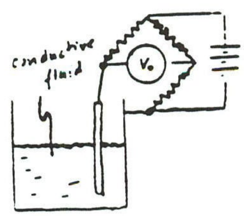
a. Temperature: Thermistor- temperature sensitive resistor with resistance change proportional to temperature; Thermocouple; Thyristor. Modern thermostats are computer controlled and programmable.

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

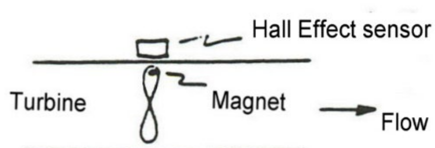


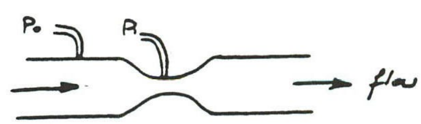
c. Liquid level: Float connected to potentiometer. If liquid is conductive the impedance change of a rod immersed in the liquid may indicate the liquid level.





d. Flow of liquid along a pipe (or blood along an artery): 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.



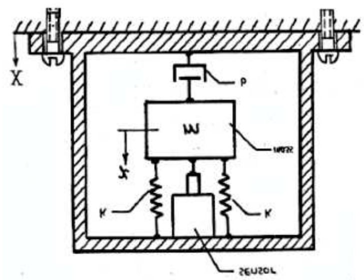


e. Position on a map.
GPS, Galileo, or any of the satellite-based navigation systems. I.e., look at the map in your iPhone. Aircraft also use land-based nav systems based on the angular position from a VOR antenna, and distance measured from a DME antenna. Autonomous cars use radar/lidar-based measurements from buildings in urban areas.

f. Angular 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. Aircraft use gyros, aided by a pendulum to sense pitch and roll.

g. Speed along a road. For cars when the wheels aren't skidding, simply measuring wheel speed gives the car speed.

h. 3-dimensional velocity: Inertial Navigation System (INS). Basically contains 3 accelerometers whose outputs are integrated over time. Their orientation is obtained from 3 rate gyros who's angular rates in 3 axes are integrated over time. So given the initial 3-D velocity, the time history of an object's velocity in 3 axes is obtained. A simplified version of an accelerometer is shown below:



i. Distance of a car in front of your position. Radar or lidar bounces a signal off the car in front of you thus giving a continuous signal proportional to the distance of the car in front.
j. Angular velocity. Rate gyros, which have a spinning wheel which deflects a spring when its axis direction is being changed. The deflection of the spring is measured, e.g., with a potentiometer, thus giving an electrical signal proportional to the angular velocity.
k. Acceleration of a car in the direction of travel. Easiest is to differentiate the speedometer output, which is based on wheel speed. In case of wheel slippage, it can be backed up by a GPS-based velocity.
l. Distance from a drone to the ground. For accurate altitude above a landing spot, lidar or ultrasonic sensors that actually measure the distance in that exact location is required. For higher altitudes and less accuracy, GPS along with a terrain elevation map will suffice.

1.7 Each of the variables listed in Problem 1.6 can be brought under feedback control. Describe an actuator that could accept an electrical input and be used to control the variables listed. Give the units of the actuator output signal.

Solution:

a. Resistor with voltage applied to it or mercury arc lamp to generate heat for small devices. a furnace for a building. (Units are Joules/sec).

b. Pump: Pumping air in or out of a chamber to generate pressure. (kg/sec)

c. Pump: Pumping liquid in or out of a container. (m^2/sec)

d. A valve is normally used to change an orifice size in the flow stream. (m^2)

e. For a car on a road, the steering wheel electrically operated. (front tire angle, Deg)

f. Electric motor (deg)

g. IC engine or Electric motor to generate torque on wheels (kg-m)

h. For an airplane, several flaps for pitch, roll, and yaw, plus engine speed for axial acceleration (multiple units)

i. Same as g.

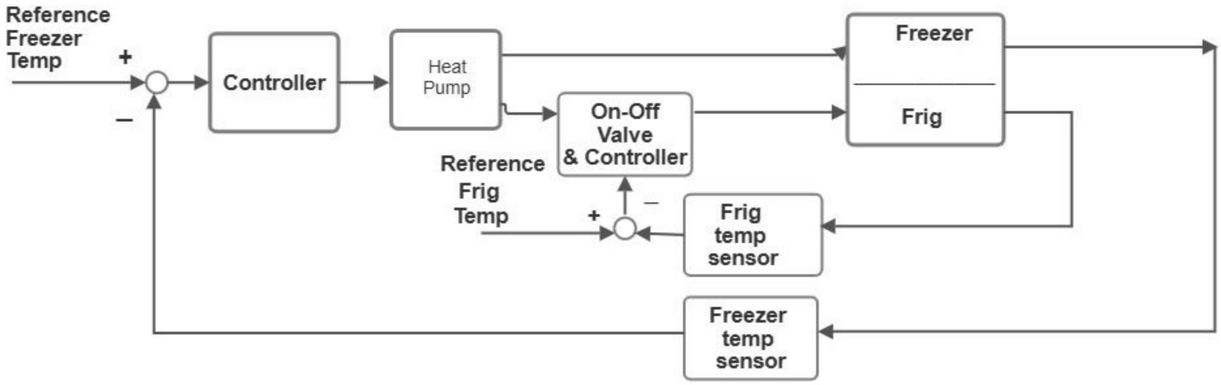
j. Torque motor. (kg-m)

k. Same as g. or i.

l. Motors that control the drone propellors, usually torque command to the motors control the desired propellor speeds, thus controlling vertical thrust. (prop rpm)

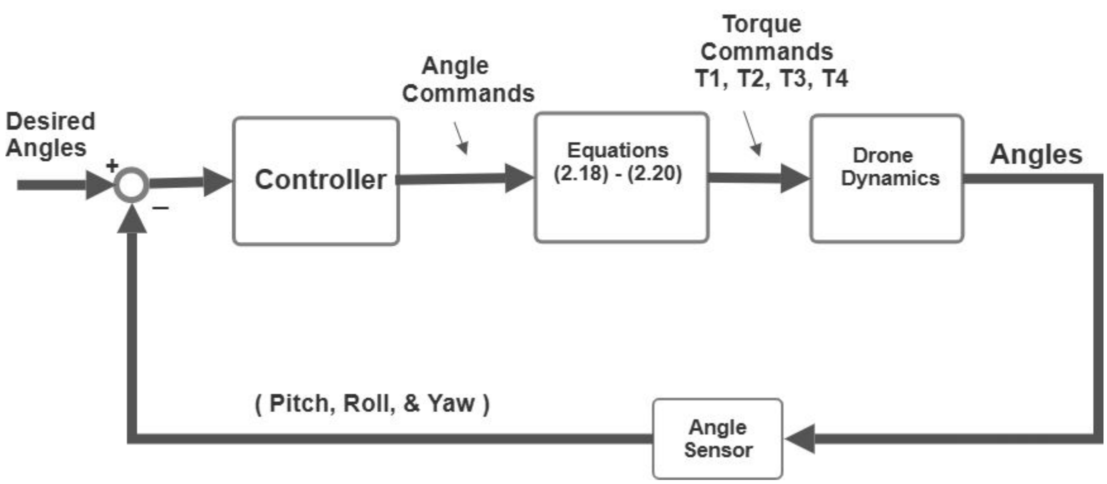
1.8 Draw the block diagram for temperature control in a refrigerator that includes a separate freezer compartment.

Solution:



1.9 Draw a block diagram for the control system of a quadrotor drone system that is described in Chapter 2, Example 2.5. They are also described in Chapters 5, 6, and 8.

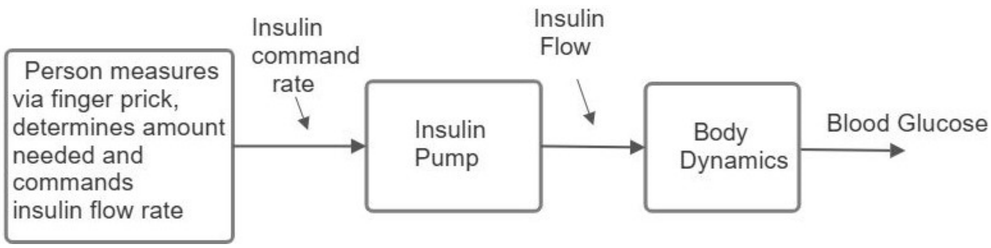
Solution:



1.10 Type I Diabetes occurs when the pancreas cannot produce sufficient insulin to maintain blood glucose levels in the body. In the recent past, patients with Type I diabetes were required to prick their finger multiple times a day to measure glucose levels and inject insulin into a vein to maintain blood glucose within the healthy range. Insulin pumps are now widely available to automatically monitor blood glucose and pump insulin to the bloodstream at a manually adjusted rate calculated and input by the user. Artificial pancreases are also being developed to measure blood glucose continuously and automatically provide insulin via feedback control to maintain blood glucose at a desired reference point. Draw two block diagrams illustrating the a) open-loop insulin pump and b) closed-loop artificial pancreas.

Solution:

a) Open loop Glucose Control



b) Closed Loop Artificial Pancreas