C H A P T E R 1

Introduction to Control Systems

There are, in general, no unique solutions to the following exercises and problems. Other equally valid block diagrams may be submitted by the student.

Exercises

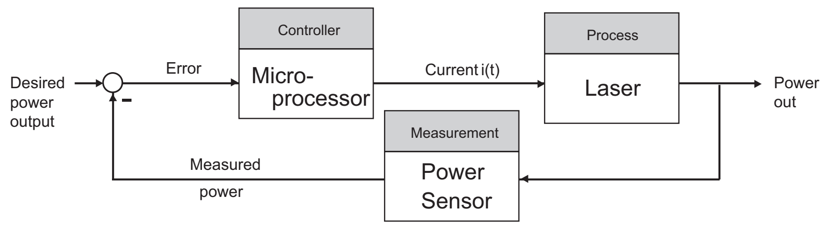
E1.1 Describe typical sensors that can measure each of the following:

a. Linear position $\rightarrow$ ultrasonic transducer
b. Velocity (or speed) $\rightarrow$ Doppler radar
c. Non-gravitational acceleration $\rightarrow$ inertial measurement unit
d. Rotational position (or angle) $\rightarrow$ rotary encoder
e. Rotational velocity $\rightarrow$ gyroscope
f. Temperature $\rightarrow$ thermocouple
g. Pressure $\rightarrow$ barometer
h. Liquid (or gas) flow rate $\rightarrow$ velocimeter
i. Torque $\rightarrow$ torquemeter
j. Force $\rightarrow$ load cell
k. Earth's magnetic field $\rightarrow$ magnetometer
l. Heart rate $\rightarrow$ electrocardiograph

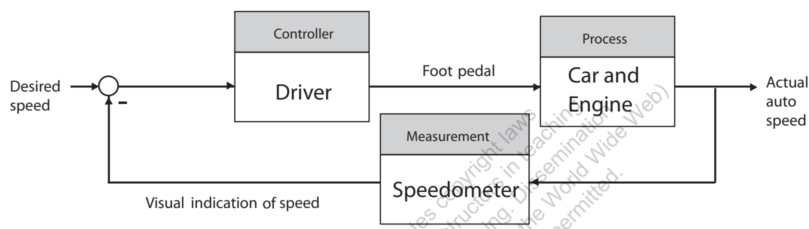
E1.2 Describe typical actuators that can convert the following:

a. Fluidic energy to mechanical energy $\rightarrow$ hydraulic cylinder
b. Electrical energy to mechanical energy $\rightarrow$ electric motor
c. Mechanical deformation to electrical energy $\rightarrow$ piezoelectric actuator
d. Chemical energy to kinetic energy $\rightarrow$ automobile engine
e. Heat to electrical energy $\rightarrow$ thermoelectric generator

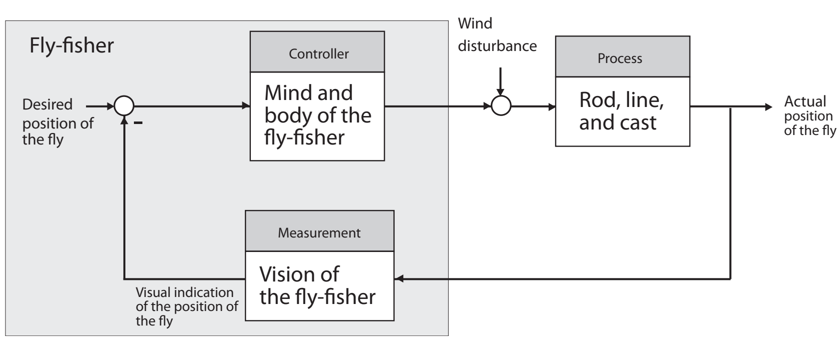
E1.3 A microprocessor controlled laser system:



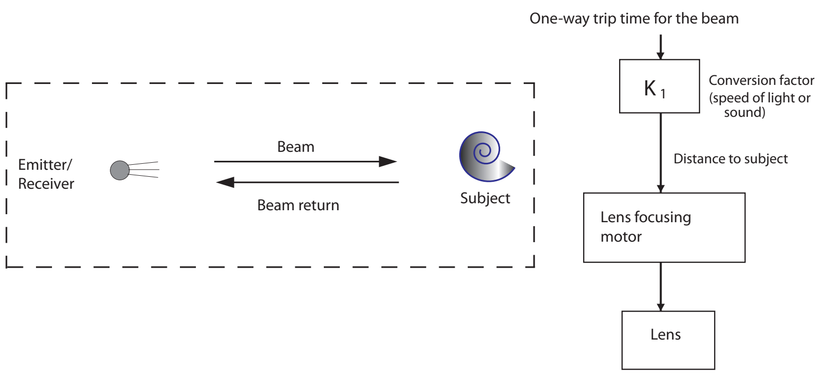
E1.4 A driver controlled cruise control system:



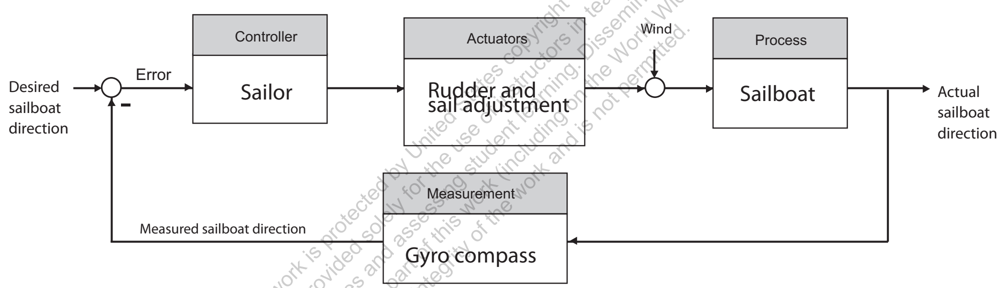
E1.5 Although the principle of conservation of momentum explains much of the process of fly-casting, there does not exist a comprehensive scientific explanation of how a fly-fisher uses the small backward and forward motion of the fly rod to cast an almost weightless fly lure long distances (the current world-record is 236 ft). The fly lure is attached to a short invisible leader about 15-ft long, which is in turn attached to a longer and thicker Dacron line. The objective is cast the fly lure to a distant spot with dead-eye accuracy so that the thicker part of the line touches the water first and then the fly gently settles on the water just as an insect might.



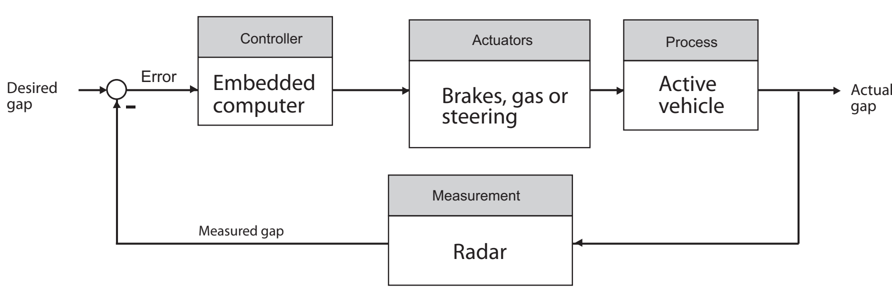
E1.6 An autofocus camera control system:



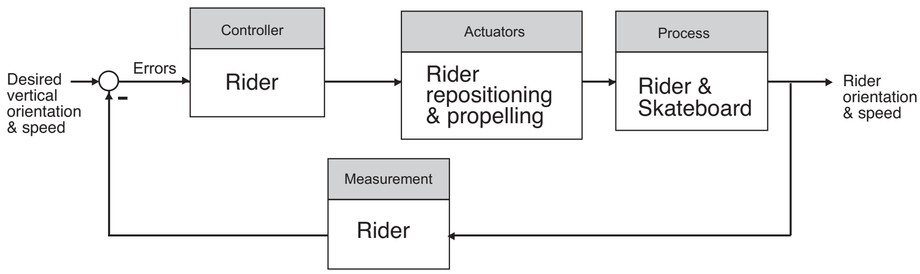
E1.7 Tacking a sailboat as the wind shifts:



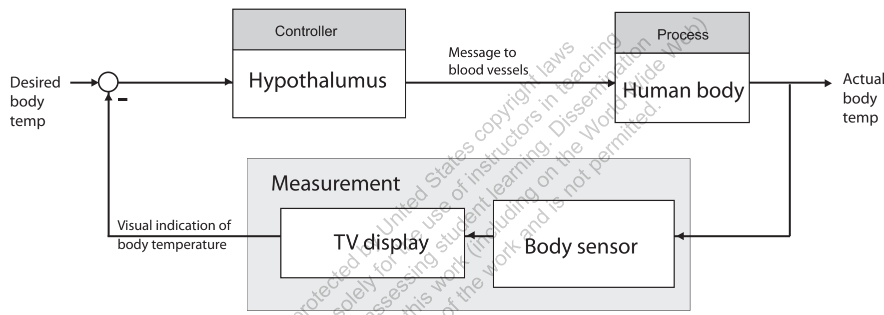
E1.8 An automated highway control system merging two lanes of traffic:



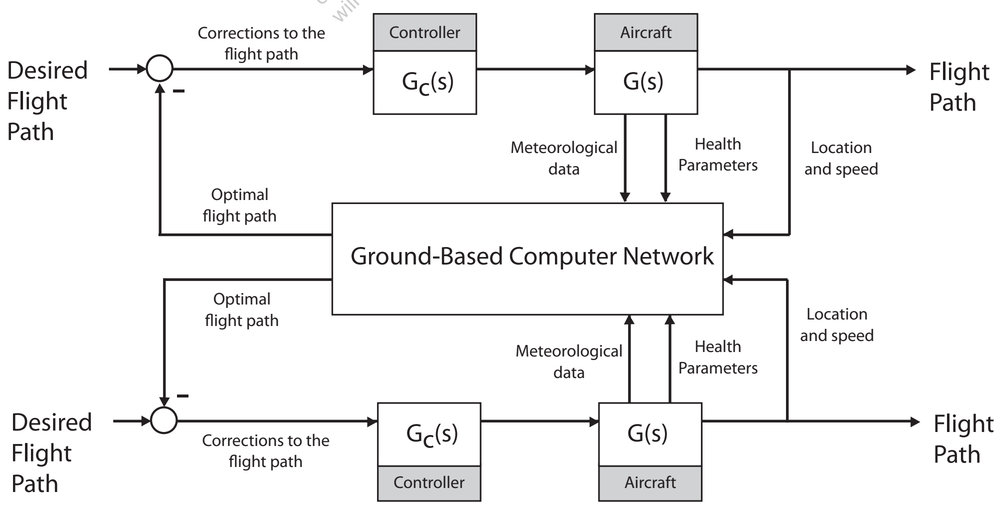
E1.9 A skateboard rider maintaining vertical orientation and desired speed:



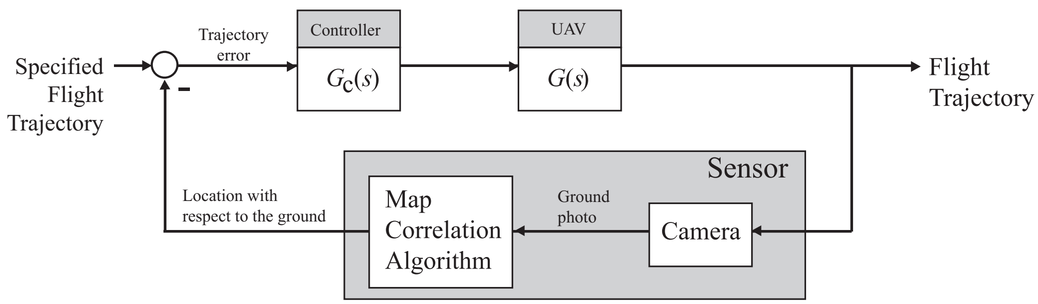
E1.10 Human biofeedback control system:



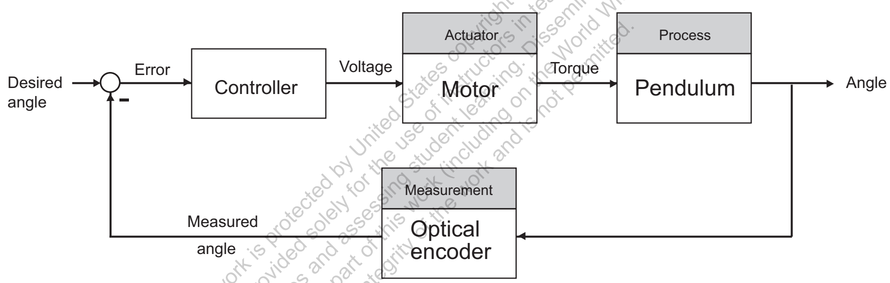
E1.11 E-enabled aircraft with ground-based flight path control:



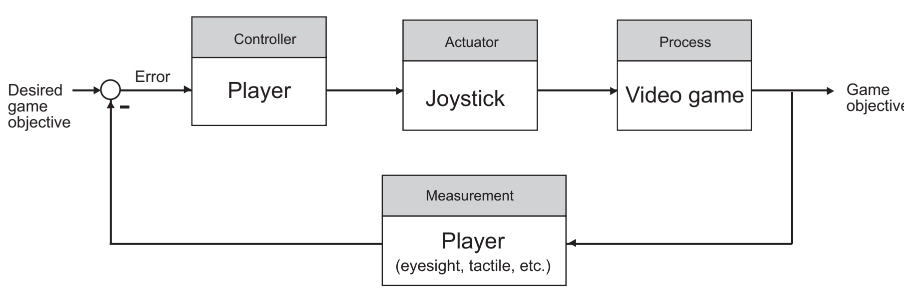
E1.12 Unmanned aerial vehicle used for crop monitoring in an autonomous mode:



E1.13 An inverted pendulum control system using an optical encoder to measure the angle of the pendulum and a motor producing a control torque:

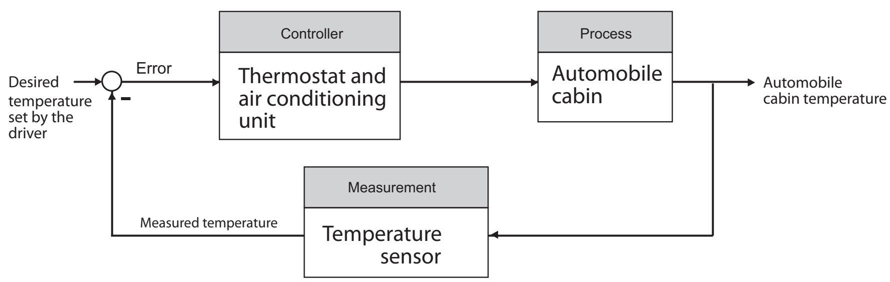


E1.14 In the video game, the player can serve as both the controller and the sensor. The objective of the game might be to drive a car along a prescribed path. The player controls the car trajectory using the joystick using the visual queues from the game displayed on the computer monitor.

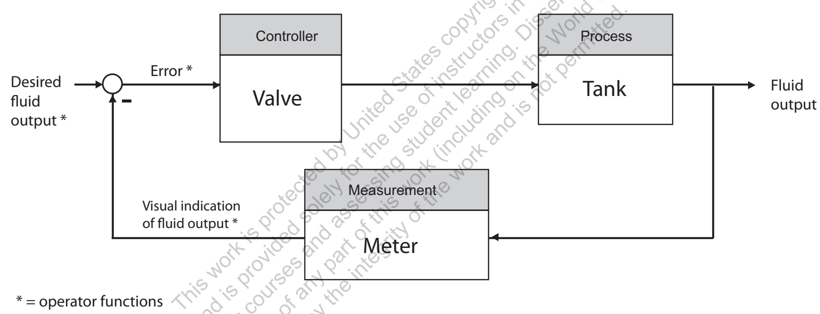


Problems

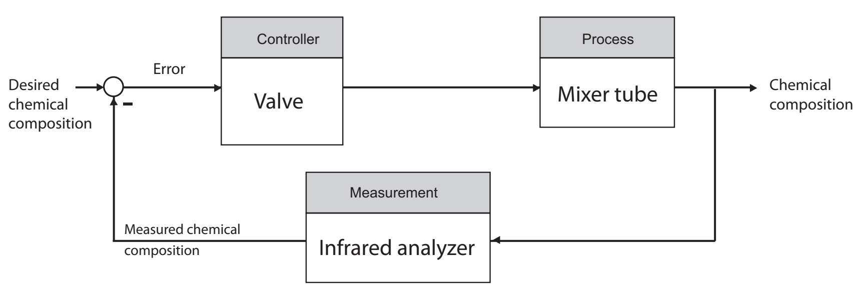
P1.1 An automobile interior cabin temperature control system block diagram:



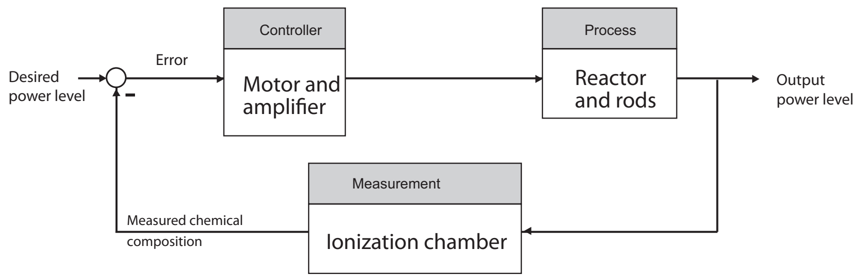
P1.2 A human operator controlled valve system:



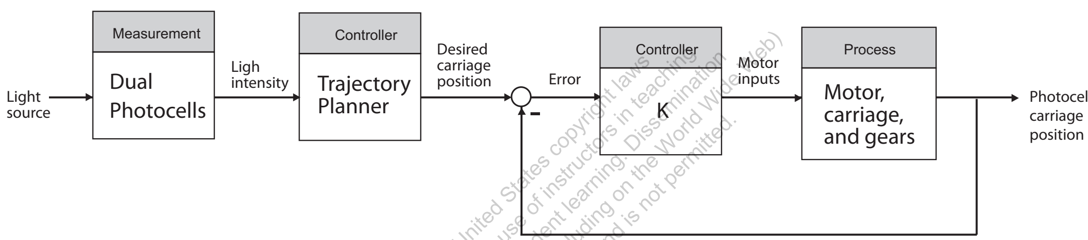
P1.3 A chemical composition control block diagram:



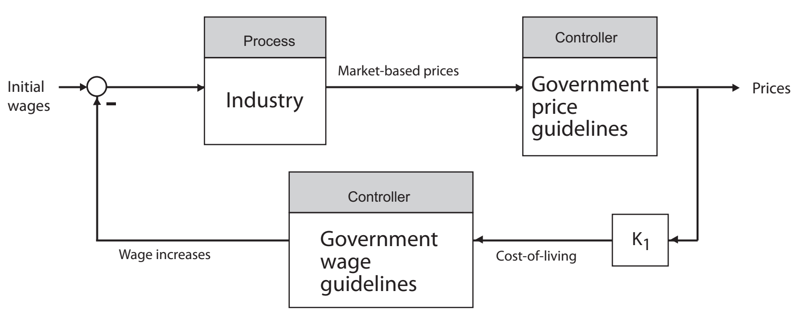
P1.4 A nuclear reactor control block diagram:



P1.5 A light seeking control system to track the sun:



P1.6 If you assume that increasing worker's wages results in increased prices, then by delaying or falsifying cost-of-living data you could reduce or eliminate the pressure to increase worker's wages, thus stabilizing prices. This would work only if there were no other factors forcing the cost-of-living up. Government price and wage economic guidelines would take the place of additional "controllers" in the block diagram, as shown in the block diagram.



P1.7 Assume that the cannon fires initially at exactly 5:00 p.m.. We have a positive feedback system. Denote by Δt the time lost per day, and the net time error by E_T. Then the follwoing relationships hold:

$$\Delta t = 4/3 \text{ min.} + 3 \text{ min.} = 13/3 \text{ min.}$$

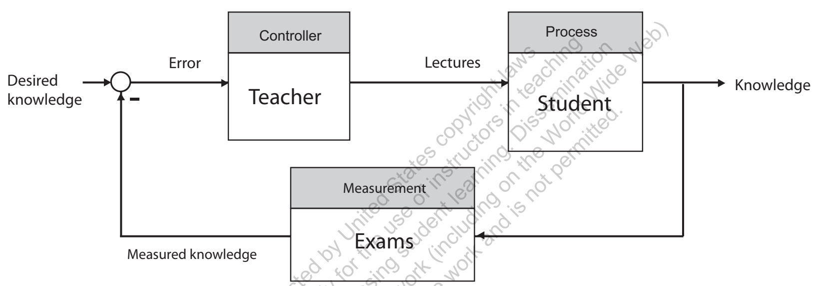
and

$$E_T = 12 \text{ days} \times 13/3 \text{ min./day} .$$

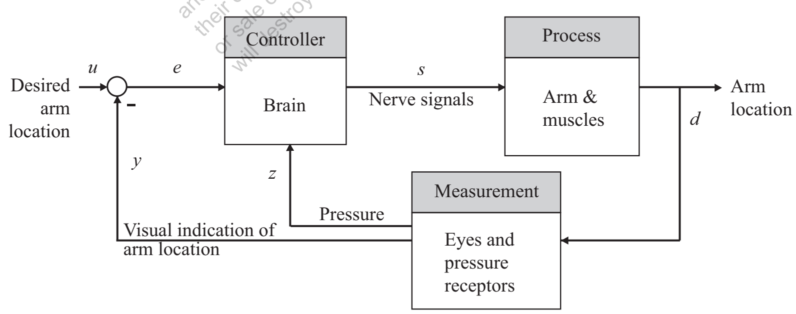
Therefore, the net time error after 15 days is

$$E_T = 52 \text{ min.}$$

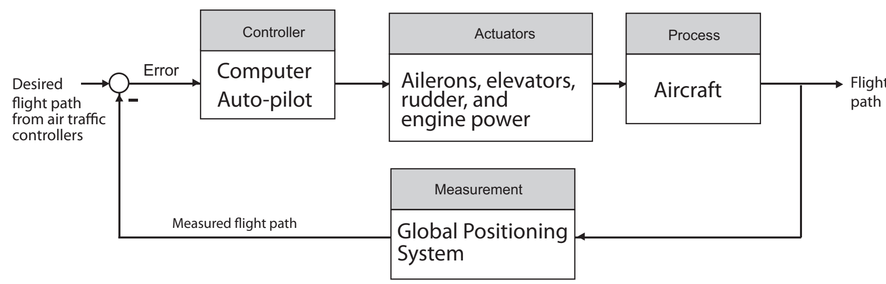
P1.8 The student-teacher learning process:



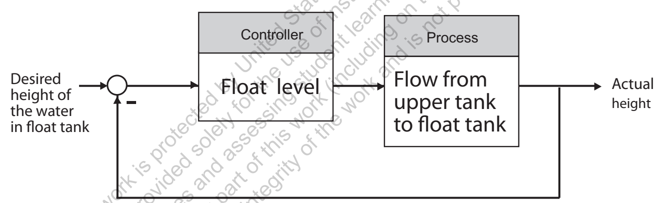
P1.9 A human arm control system:



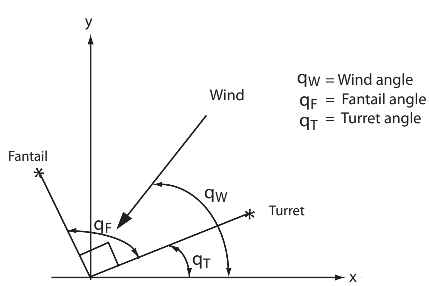
P1.10 An aircraft flight path control system using GPS:

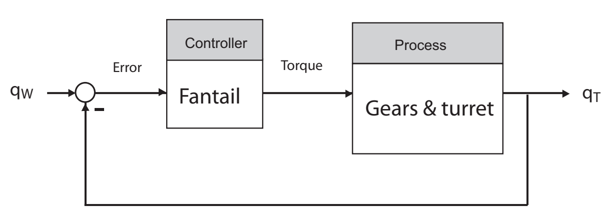


P1.11 The accuracy of the clock is dependent upon a constant flow from the orifice; the flow is dependent upon the height of the water in the float tank. The height of the water is controlled by the float. The control system controls only the height of the water. Any errors due to enlargement of the orifice or evaporation of the water in the lower tank is not accounted for. The control system can be seen as:

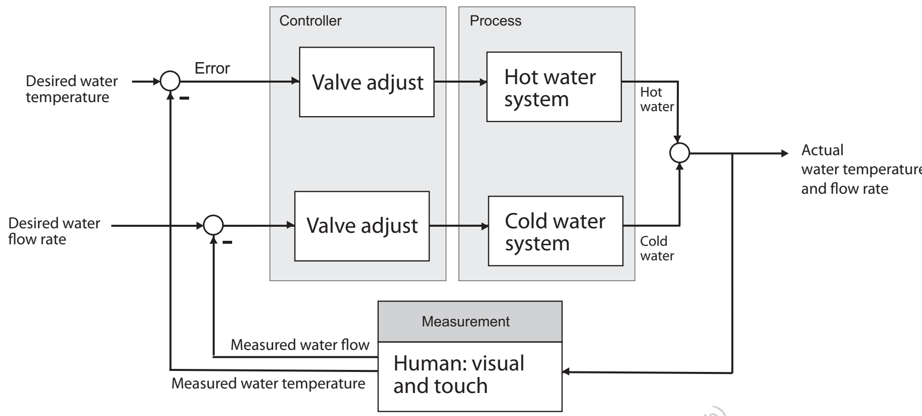


P1.12 Assume that the turret and fantail are at 90°, if $\theta_w \neq \theta_F$-90°. The fantail operates on the error signal θ_w - θ_T, and as the fantail turns, it drives the turret to turn.





P1.13 This scheme assumes the person adjusts the hot water for temperature control, and then adjusts the cold water for flow rate control.

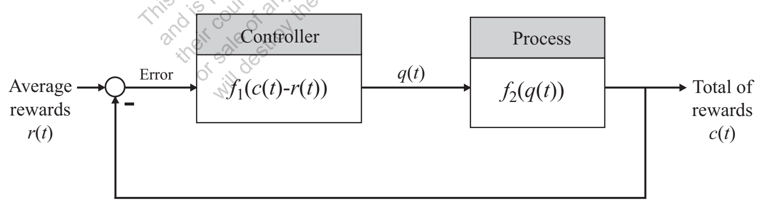


P1.14 If the rewards in a specific trade is greater than the average reward, there is a positive influx of workers, since

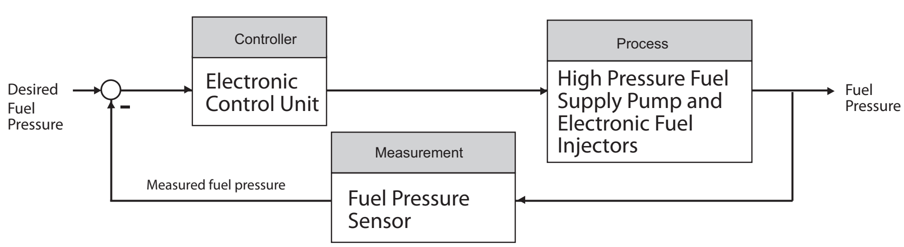
$$q(t) = f_1(c(t) - r(t)).$$

If an influx of workers occurs, then reward in specific trade decreases, since

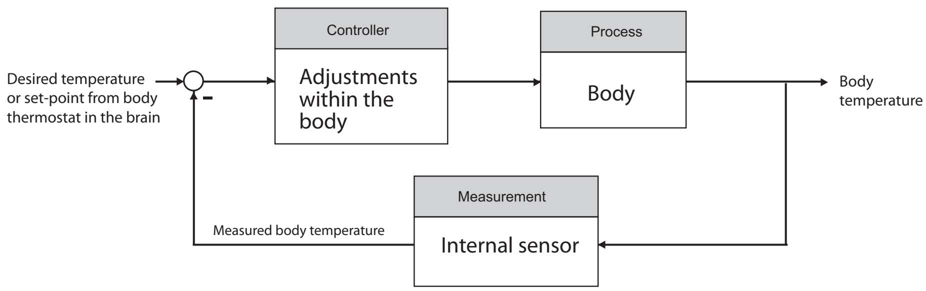
$$c(t) = -f_2(q(t)).$$



P1.15 A computer controlled fuel injection system:

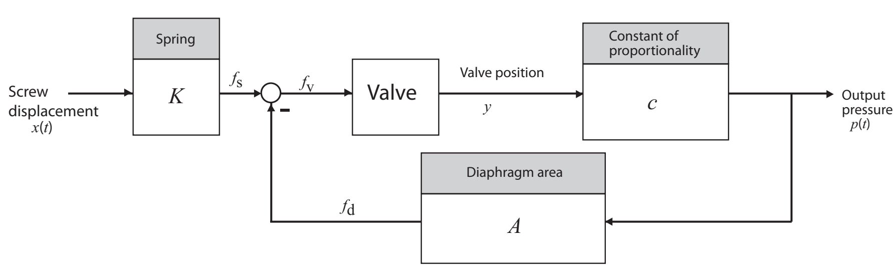


P1.16 With the onset of a fever, the body thermostat is turned up. The body adjusts by shivering and less blood flows to the skin surface. Aspirin acts to lowers the thermal set-point in the brain.

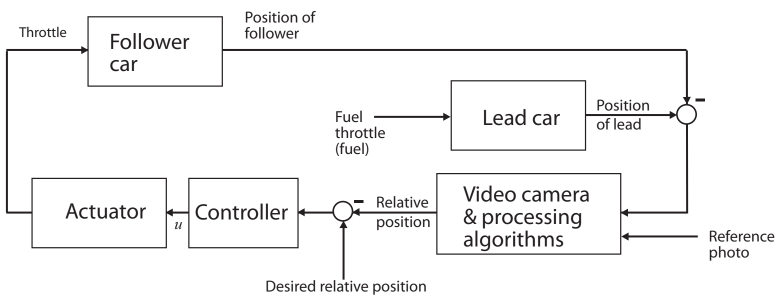


P1.17 Hitting a baseball is arguably one of the most difficult feats in all of sports. Given that pitchers may throw the ball at speeds of 90 mph (or higher!), batters have only about 0.1 second to make the decision to swing—with bat speeds aproaching 90 mph. The key to hitting a baseball a long distance is to make contact with the ball with a high bat velocity. This is more important than the bat's weight, which is usually around 33 ounces. Since the pitcher can throw a variety of pitches (fast ball, curve ball, slider, etc.), a batter must decide if the ball is going to enter the strike zone and if possible, decide the type of pitch. The batter uses his/her vision as the sensor in the feedback loop. A high degree of eye-hand coordination is key to success—that is, an accurate feedback control system.

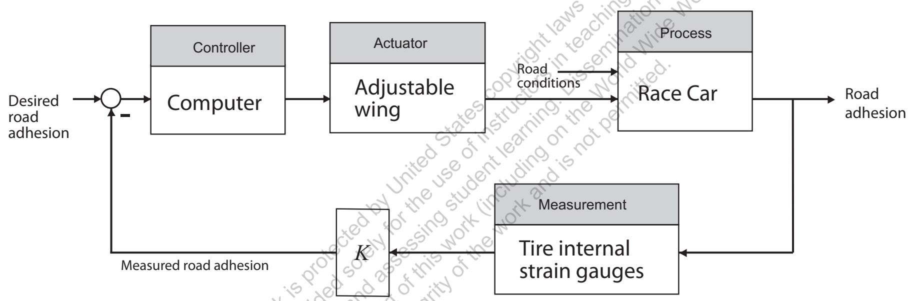
P1.18 Define the following variables: p = output pressure, f_s = spring force $= Kx$, f_d = diaphragm force $= Ap$, and f_v = valve force $= f_s - f_d$. The motion of the valve is described by $\ddot{y} = f_v/m$ where m is the valve mass. The output pressure is proportional to the valve displacement, thus $p = cy$, where c is the constant of proportionality.



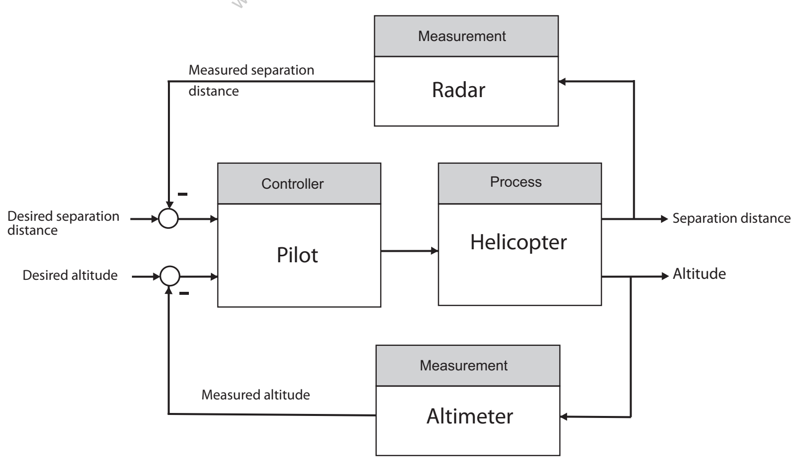
P1.19 A control system to keep a car at a given relative position offset from a lead car:



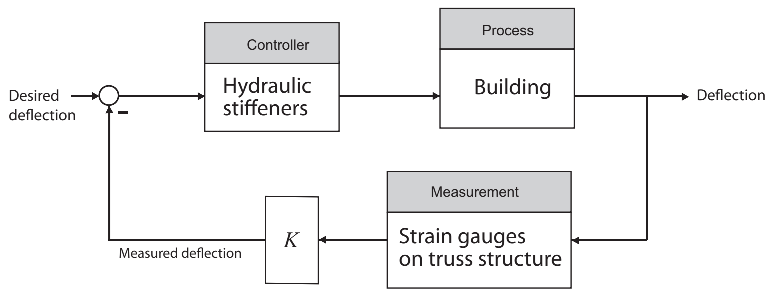
P1.20 A control system for a high-performance car with an adjustable wing:



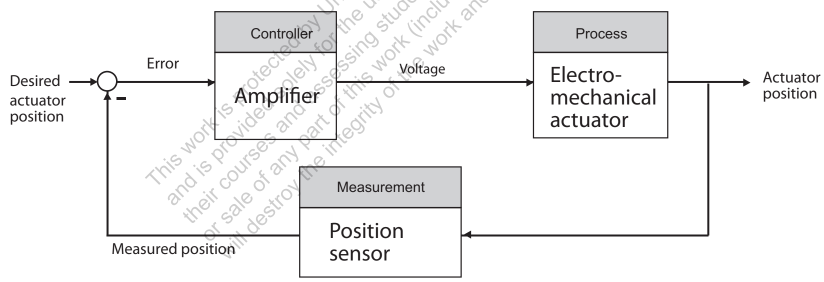
P1.21 A control system for a twin-lift helicopter system:



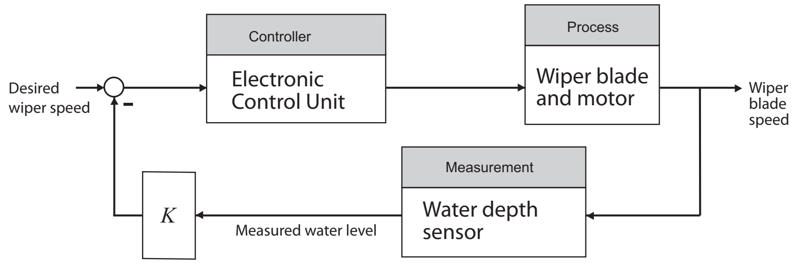
P1.22 The desired building deflection would not necessarily be zero. Rather it would be prescribed so that the building is allowed moderate movement up to a point, and then active control is applied if the movement is larger than some predetermined amount.



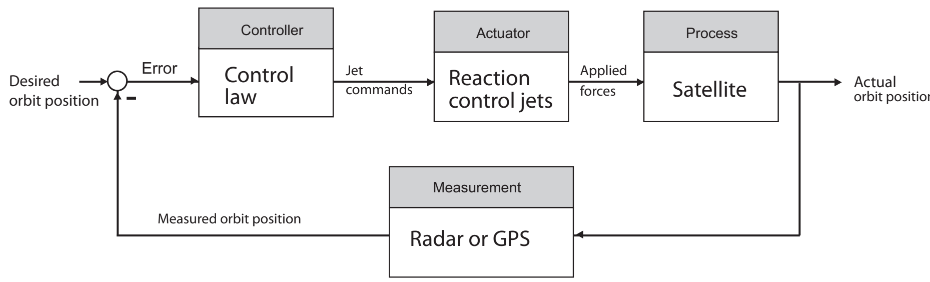
P1.23 The human-like face of the robot might have micro-actuators placed at strategic points on the interior of the malleable facial structure. Cooperative control of the micro-actuators would then enable the robot to achieve various facial expressions.



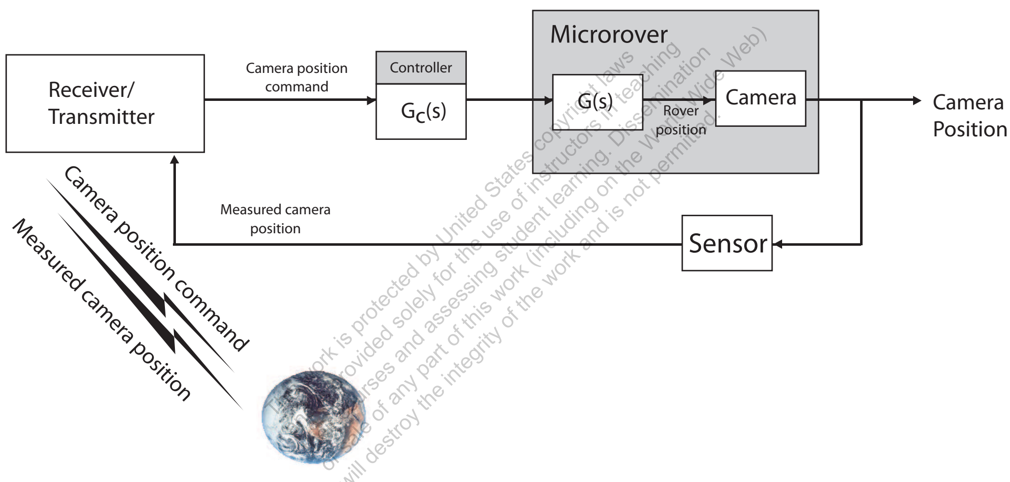
P1.24 We might envision a sensor embedded in a "gutter" at the base of the windshield which measures water levels—higher water levels corresponds to higher intensity rain. This information would be used to modulate the wiper blade speed.



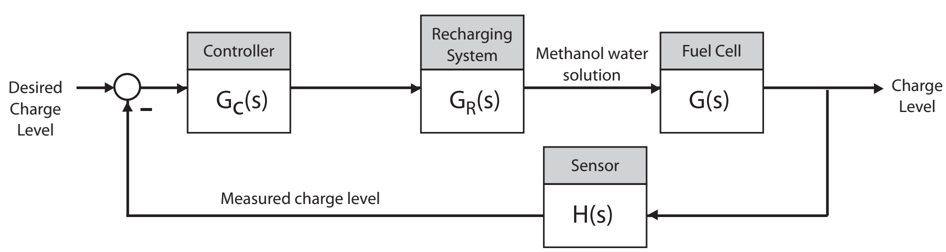
P1.25 A feedback control system for the space traffic control:



P1.26 Earth-based control of a microrover to point the camera:

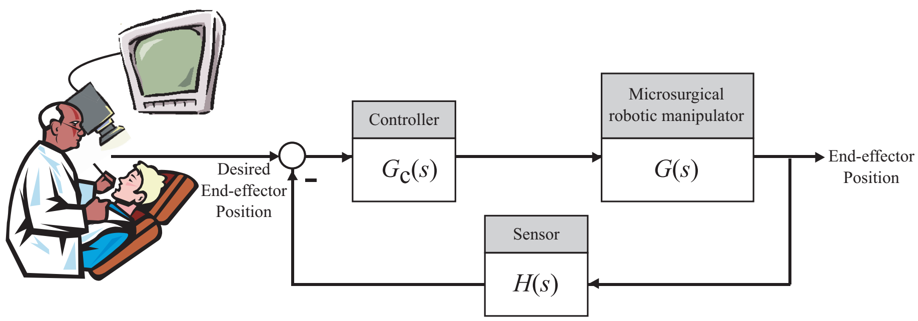


P1.27 Control of a methanol fuel cell:

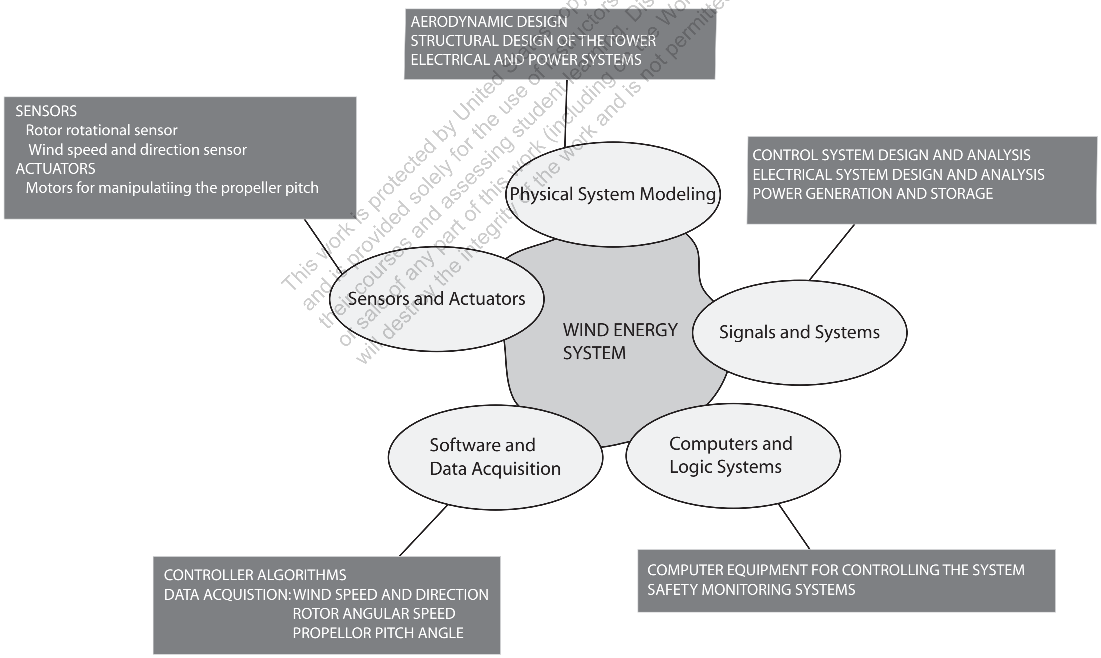


Advanced Problems

AP1.1 Control of a robotic microsurgical device:

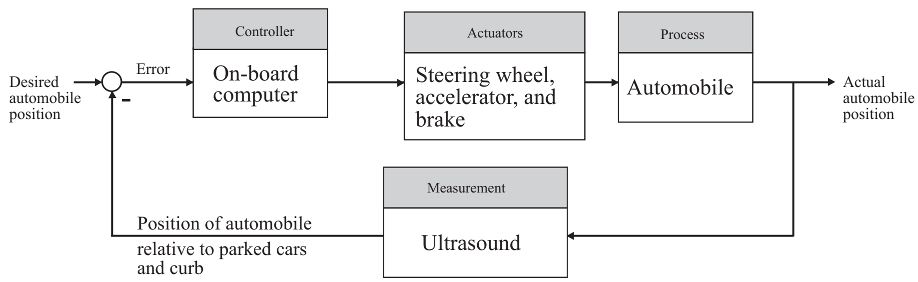


AP1.2 An advanced wind energy system viewed as a mechatronic system:

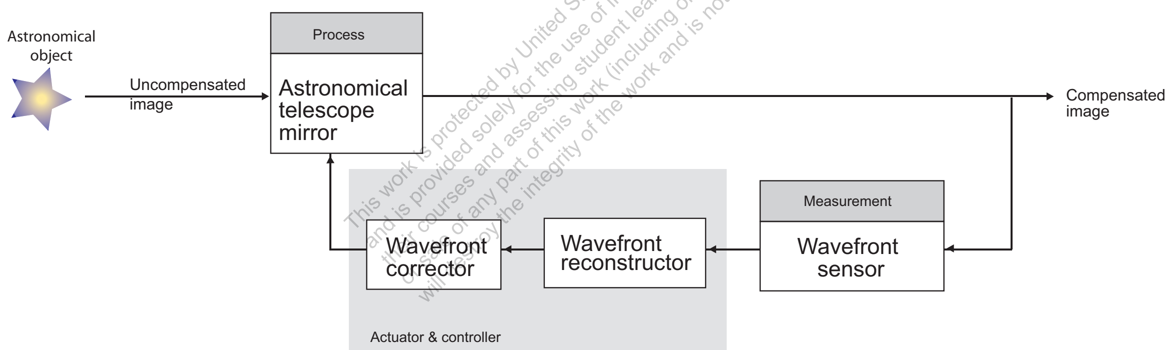


AP1.3 The automatic parallel parking system might use multiple ultrasound sensors to measure distances to the parked automobiles and the curb. The sensor measurements would be processed by an on-board computer to determine the steering wheel, accelerator, and brake inputs to avoid collision and to properly align the vehicle in the desired space.

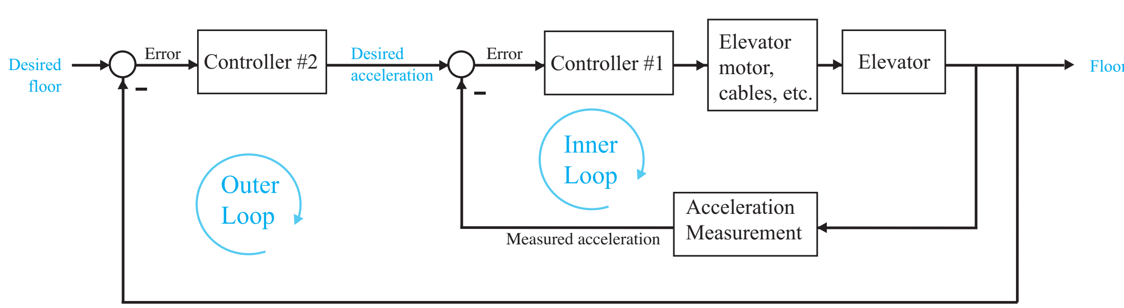
Even though the sensors may accurately measure the distance between the two parked vehicles, there will be a problem if the available space is not big enough to accommodate the parking car.



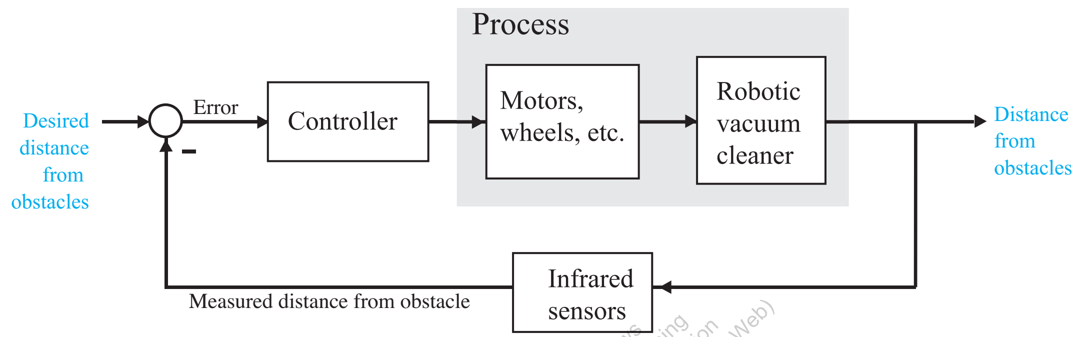
AP1.4 There are various control methods that can be considered, including placing the controller in the feedforward loop (as in Figure 1.3). The adaptive optics block diagram below shows the controller in the feedback loop, as an alternative control system architecture.



AP1.5 The control system might have an inner loop for controlling the acceleration and an outer loop to reach the desired floor level precisely.

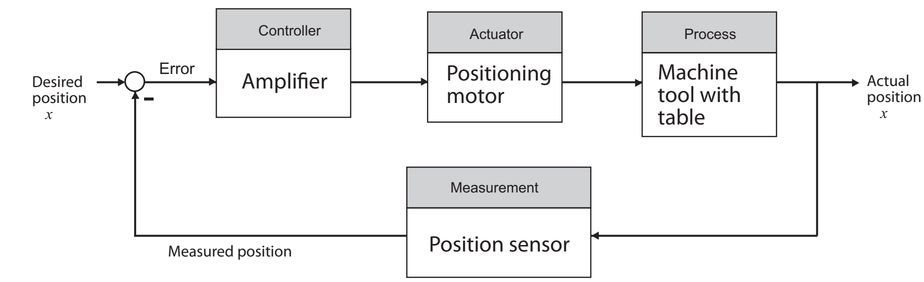


AP1.6 An obstacle avoidance control system would keep the robotic vacuum cleaner from colliding with furniture but it would not necessarily put the vacuum cleaner on an optimal path to reach the entire floor. This would require another sensor to measure position in the room, a digital map of the room layout, and a control system in the outer loop.

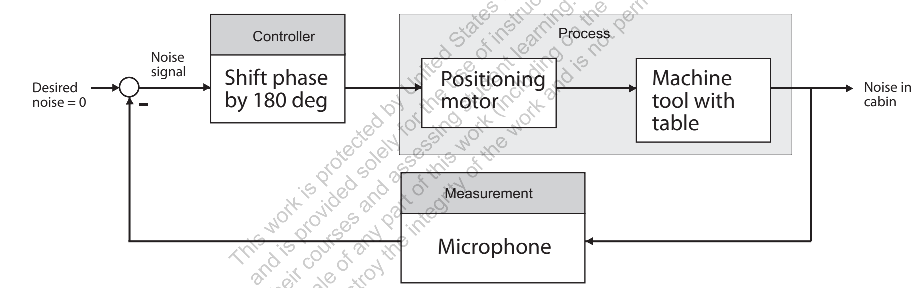


Design Problems

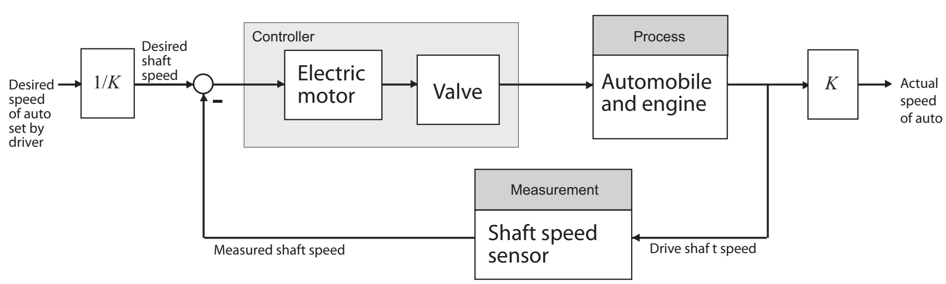
CDP1.1 The machine tool with the movable table in a feedback control configuration:



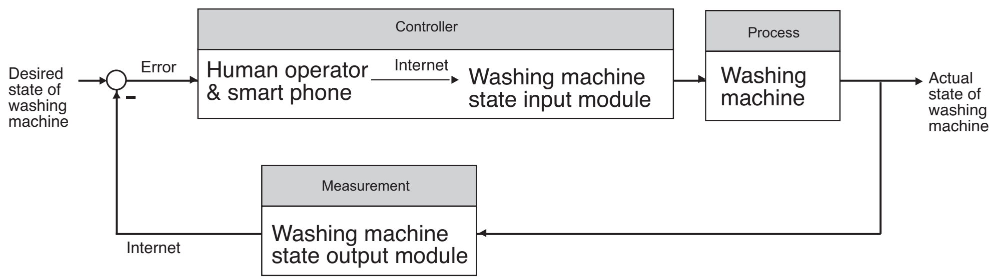
DP1.1 Use the stereo system and amplifiers to cancel out the noise by emitting signals 180° out of phase with the noise.



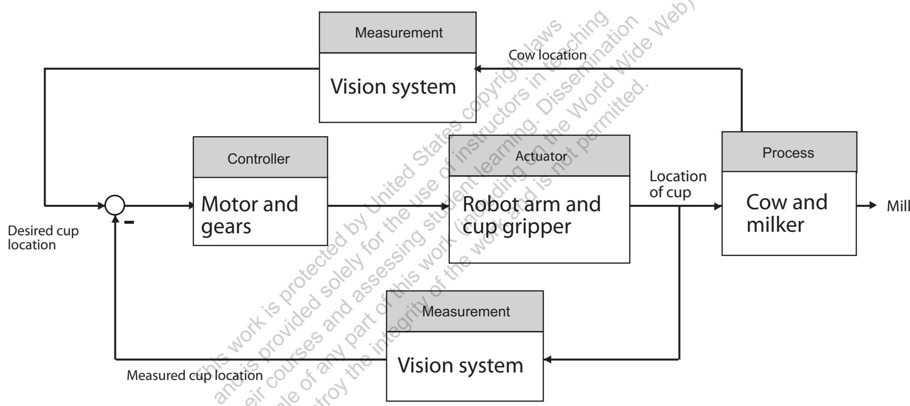
DP1.2 An automobile cruise control system:



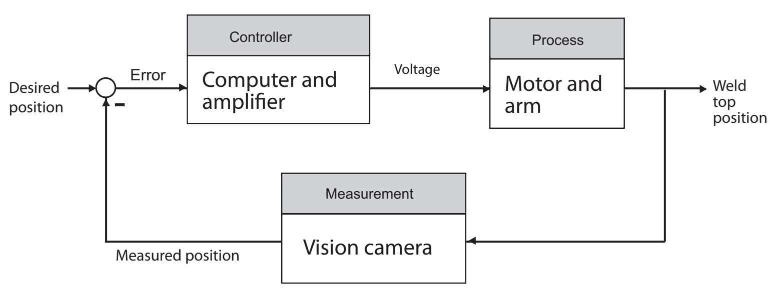
DP1.3 Utilizing a smart phone to remotely monitor and control a washing machine:



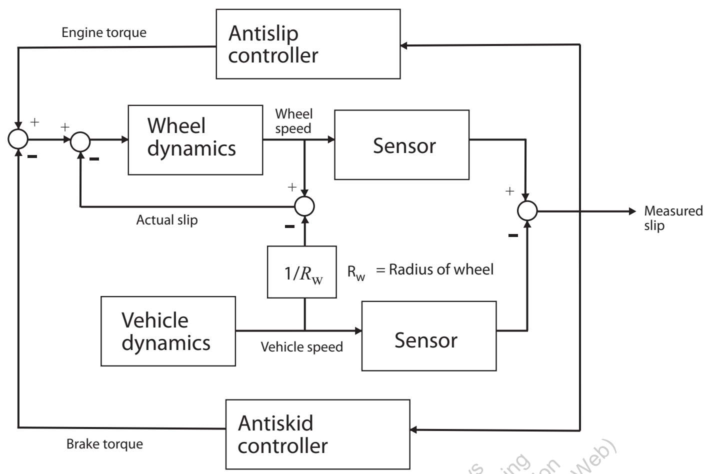
DP1.4 An automated cow milking system:



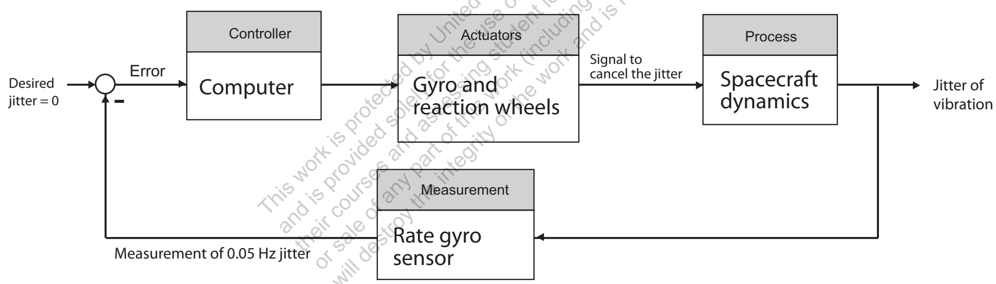
DP1.5 A feedback control system for a robot welder:



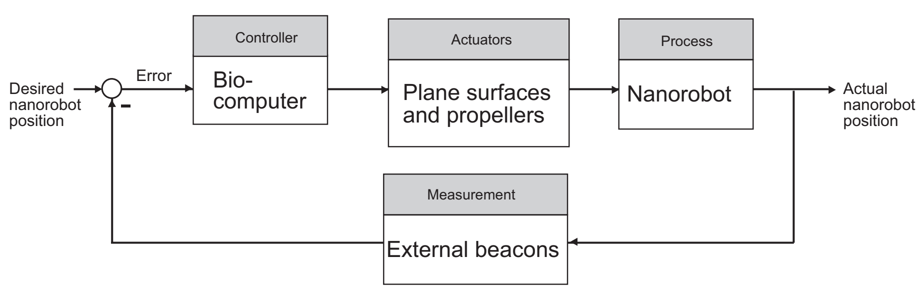
DP1.6 A control system for one wheel of a traction control system:



DP1.7 A vibration damping system for the Hubble Space Telescope:



DP1.8 A control system for a nanorobot:



Many concepts from underwater robotics can be applied to nanorobotics within the bloodstream. For example, plane surfaces and propellers can provide the required actuation with screw drives providing the propulsion. The nanorobots can use signals from beacons located outside the skin as sensors to determine their position. The nanorobots use energy from the chemical reaction of oxygen and glucose available in the human body. The control system requires a bio-computer–an innovation that is not yet available.

For further reading, see A. Cavalcanti, L. Rosen, L. C. Kretly, M. Rosenfeld, and S. Einav, "Nanorobotic Challenges n Biomedical Application, Design, and Control," *IEEE ICECS Intl Conf. on Electronics, Circuits and Systems*, Tel-Aviv, Israel, December 2004.

DP1.9 The feedback control system might use gyros and/or accelerometers to measure angle change and assuming the HTV was originally in the vertical position, the feedback would retain the vertical position using commands to motors and other actuators that produced torques and could move the HTV forward and backward.