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Lab Groups ? ✓

Lab 1 starts today.

Wall follow

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Controller Design and Implementation

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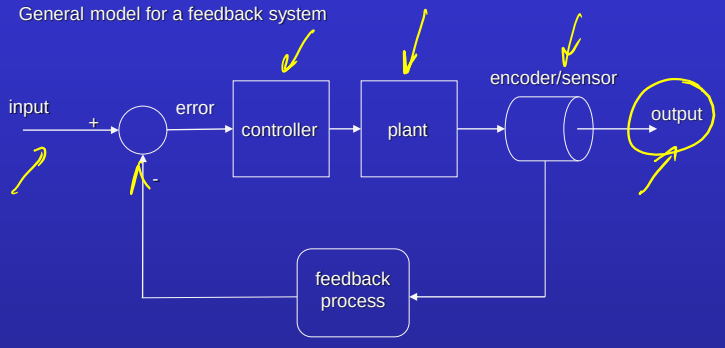
S&C - 1

General model for a feedback system



forward process

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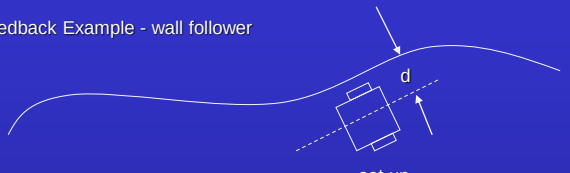
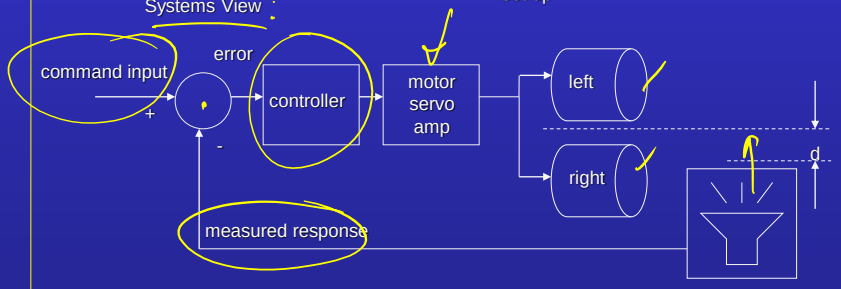
S&C - 2

Simple Feedback Example - wall follower



set up

Systems View



• Difference in motor speeds controls lateral distance - d

ultrasonic sensor

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S&C - 3

Designing the Controller

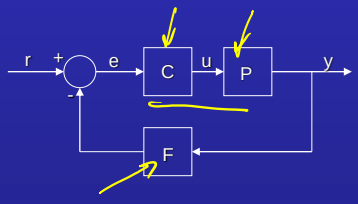
- An intuitive view (you will study formal methods in ECSE 404, Control Systems)

Known Entities

- The plant model can be measured and/or suitably approximated
- The range of inputs
- The desired response of the system to the inputs

Design Problem

- Figure out appropriate controller and feedback models to achieve the desired response



if CP large, then y ≈ r / F

$$y = CPe$$
$$e = r - Fy$$
$$y = CP(r - Fy) = CPr - CPFy$$
$$y(1+FCP) = CPr$$
$$y = \frac{CP}{(1+FCP)}r$$

$y \approx \frac{1}{F}$

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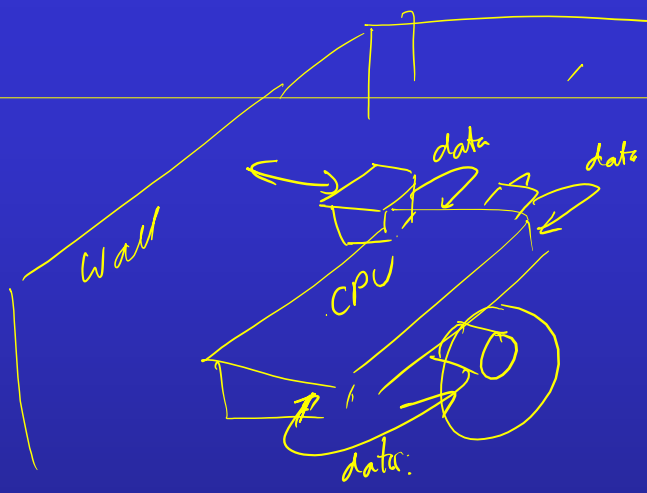

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Back to the Wall Follower

Steering the cart:

- Error = reference control value - measured distance from the wall.
- If abs(Error) < Threshold, we consider the cart to be on a correct heading.
- if Error < 0, the cart is too far from the wall. Increase rotation of outside wheel; (decrease rotation of inside wheel).
- If Error > 0, the cart is too close to the wall. Decrease rotation of outside wheel; (increase rotation of inside wheel).
- Magnitude of change in rotation is proportional to the magnitude of the error.
- In our example, we follow the BANG BANG approach and define 2 speeds:
  - FWDSPEED – speed at which left and right wheel rotate to go straight.
  - DELTASPD – amount by which speed increased/decreased to effect motion towards/away from wall.
- A more elaborate approach would scale the correction, i.e., DELTASPD according to Error (this is called proportional control).

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S&C - 8

```
package wf1EV3;

import lejos.hardware.Button;                  // All references to classes in your code
import lejos.hardware.ev3.LocalEV3;            // need to be included here.  Eclipse
import lejos.hardware.lcd.TextLCD;             // can do this for you.
import lejos.hardware.motor.Motor;
import lejos.hardware.port.Port;
import lejos.hardware.sensor.EV3TouchSensor;
import lejos.hardware.sensor.EV3UltrasonicSensor;
import lejos.hardware.sensor.SensorModes;
import lejos.robotics.RegulatedMotor;
import lejos.robotics.SampleProvider;

// A direct, procedural implementation of the simple wall follower.
// Lab 1 introduces a more object-oriented approach.

public class SimpleWF {

// Class Constants

        public static final int WALLDIST = 20;      // Standoff distance to wall
        public static final int DEADBAND = 2;       // Error threshold
        public static final int FWDSPEED = 200;     // Default rotational speed of wheels
        public static final int DELTASPD = 100;     // Bang-bang constant
        public static final int SLEEPINT = 50;      // Sleep interval 50 mS = 20Hz
```

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```
// Class Variables

        public static int wallDist=0;        // Measured distance to wall
        public static int distError=0;       // Error

// Objects instantiated once in this class

        static TextLCD t = LocalEV3.get().getTextLCD();
        static RegulatedMotor leftMotor = Motor.A;
        static RegulatedMotor rightMotor = Motor.D;

// Sensor set-up

// 1. Allocate a port for each sensor

        static Port portUS = LocalEV3.get().getPort("S1");
        static Port portTouch = LocalEV3.get().getPort("S2");

// 2. Create an instance for each sensor

        static SensorModes myUS = new EV3UltrasonicSensor(portUS);
        static SensorModes myTouch = new EV3TouchSensor(portTouch);
```

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```
// 3. Create an instance of a sample provider for each sensor in the
//     desired measurement mode.

        static SampleProvider myDistance = myUS.getMode("Distance");
        static SampleProvider myTouchStatus = myTouch.getMode(0);

// 4. Sensors return real-valued data; need to allocate buffers for each

        static float[] sampleUS = new float[myDistance.sampleSize()];
        static float[] sampleTouch = new float[myTouchStatus.sampleSize()];
//
//   Main entry point - set display, start motors, enter polling loop.
//   (this is a very inefficient way to do things)

        public static void main(String[] args) throws InterruptedException {

            t.clear();                          // Clear display
            t.drawString("Simple Wall F", 0, 0);  // Print banner
            t.drawString("Distance: ", 0, 1);

            leftMotor.setSpeed(FWDSPEED);       // Start moving forward
            rightMotor.setSpeed(FWDSPEED);
            leftMotor.forward();
            rightMotor.forward();
```

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```
//
//   Main control loop: read distance, determine error, adjust speed, and repeat

                        boolean traveling=true;
                        int status=0;

// Check for stop command or collisions

                        while(traveling){
                          status=Button.readButtons();                  // Check for abort
                          myTouchStatus.fetchSample(sampleTouch, 0);    // Check for collision
                          if ((status==Button.ID_ALL)||(sampleTouch[0]==1))  // Abort if keypad
pressed
                                  System.exit(0);                       // or touch sensor
                                                                        // tripped.
// Get sensor reading and update display

                          myDistance.fetchSample(sampleUS, 0);  // Get latest reading
                          wallDist=(int)(sampleUS[0]*100.0);    // Scale to integer
                          t.drawInt(wallDist,6,11,1);           // Print current
                                                                // sensor reading
```

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```
// Controller
                        distError=WALLDIST-wallDist;       // Compute error

                        if (Math.abs(distError) <= DEADBAND) {        // Within limits, same
speed
                                leftMotor.setSpeed(FWDSPEED);  // Start moving forward
                                rightMotor.setSpeed(FWDSPEED);
                                leftMotor.forward();
                                rightMotor.forward();
                                }
                        else if (distError > 0) {                     // Too close to the wall
                                leftMotor.setSpeed(FWDSPEED);
                                rightMotor.setSpeed(FWDSPEED-DELTASPD);
                                leftMotor.forward();
                                rightMotor.forward();
                                }
                        else if (distError < 0) {
                                leftMotor.setSpeed(FWDSPEED);
                                rightMotor.setSpeed(FWDSPEED+DELTASPD);
                                leftMotor.forward();
                                rightMotor.forward();
                                }
                        Thread.sleep(SLEEPINT);        //  Allow other threads to get CPU
                        }
                }
```

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Improving the Simple Wall Follower

1. Control both wheels, i.e., operate wheels differentially:

```
if (Math.abs(error) <= DEADBAND) {          /* Within tolerance */
leftMotor.setSpeed(FWDSPEED);               /* 0 bias           */
rightMotor.setSpeed(FWDSPEED);
}
else if (error > 0) {                       /* Too close        */
leftMotor.setSpeed(FWDSPEED+DELTA);          /* Speed up inner wheel */
rightMotor.setSpeed(FWDSPEED-DELTA);        /* Slow outer wheel */
}
else {                                      /* Too far          */
leftMotor.setSpeed(FWDSPEED-DELTA);         /* Exactly opposite to above  */
rightMotor.setSpeed(FWDSPEED+DELTA);
}
```

n.b. the leftMotor.forward() and rightMotor.forward() methods are not shown for brevity.

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2. Use a timer to control servo updates (also use touch to detect collisions)

```
package myPackage;

import lejos.hardware.Button;
import lejos.hardware.ev3.LocalEV3;
import lejos.hardware.lcd.TextLCD;
import lejos.hardware.motor.Motor;
import lejos.hardware.port.Port;
import lejos.hardware.sensor.EV3TouchSensor;
import lejos.hardware.sensor.EV3UltrasonicSensor;
import lejos.hardware.sensor.SensorModes;
import lejos.robotics.RegulatedMotor;
import lejos.robotics.SampleProvider;
import lejos.utility.Timer;
import lejos.utility.TimerListener;

//
// This is the Timed Wall Follower from the NXT updated to run on EV3 hardware.
// Differences between the two implementations are indicated in the comments.
//
```

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```
// Class Constants

        public static final int SINTERVAL=50;          // A 20Hz sampling rate
        public static final int WALLDIST=20;           // Distance to wall * 1.4 (cm)
        public static final int FWDSPEED=200;          // Forward speed (deg/sec)
        public static final int GAIN=100;              //  Constaint gain (BANG-BANG)
        public static final long SLEEPINT=500;         // Display update 2Hz
        public static final int DEADBAND =2;           // Dead band(cm)
        public static final int MAXDIST=200;           // Max value of valid distance
        public static final int ID_ESCAPE=32;          // Value returned when ESCAPE
key pressed

// Class Variables
        public static int wallDist=0;                  // Measured distance to wall
        public static int distError=0;                 // Error
        public static int leftSpeed=FWDSPEED;          // Vehicle speed
        public static int rightSpeed=FWDSPEED;

// Objects instanced once by this class

        static TextLCD t = LocalEV3.get().getTextLCD();
        static RegulatedMotor leftMotor = Motor.A;
        static RegulatedMotor rightMotor = Motor.D;
```

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```
Using a timer cont.
// leJOS EV3 uses a new scheme for doing sensor I/O

// 1. Get a port instance for each sensor used

        static Port portUS = LocalEV3.get().getPort("S1");
        static Port portTouch = LocalEV3.get().getPort("S2");

// 2. Get an instance for each sensor

        static SensorModes myUS = new EV3UltrasonicSensor(portUS);
        static SensorModes myTouch = new EV3TouchSensor(portTouch);

// 3. Get an instance of each sensor in measurement mode

        static SampleProvider myDistance = myUS.getMode("Distance");
        static SampleProvider myTouchStatus = myTouch.getMode(0);

// 4. Allocate buffers for data return

        static float[] sampleUS = new float[myDistance.sampleSize()];
        static float[] sampleTouch = new float[myTouchStatus.sampleSize()];
```

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Using a timer cont.

```
public static void main(String[] args) throws InterruptedException {
        boolean noexit;
        int status;

// Set up the display area
        t.clear();
        t.drawString("Wall Follower", 0, 0);
        t.drawString("Distance:", 0, 4);
        t.drawString("L Speed:", 0, 5);
        t.drawString("R Speed:", 0, 6);
        t.drawString("Error:", 0, 7);

// Set up timer interrupts
        Timer myTimer = new Timer(SINTERVAL, new TimedWF());

// Start the cart rolling forward at nominal speed
        leftMotor.setSpeed(leftSpeed);
        rightMotor.setSpeed(rightSpeed);
        leftMotor.forward();
        rightMotor.forward();
        distError=0;
```

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Using a timer cont.

```
// Enable the exception handler
        myTimer.start();

// There are two threads in operation, Main and the timer exception
// handler.  Main continuously updates the display and checks for
// an abort from the user.
        noexit=true;

        while(noexit) {
          status=Button.readButtons();        // Check for press on console
          myTouchStatus.fetchSample(sampleTouch,0);
          if ((status==32)||(sampleTouch[0]==1)) {
                System.exit(0);
           }
// Update status on LCD
        t.drawInt(wallDist,5,11,4);             // Display key parameters on LCD
        t.drawInt(leftSpeed,4,11,5);
        t.drawInt(rightSpeed,4,11,6);
        t.drawInt(distError,4,11,7);

        Thread.sleep(SLEEPINT);
// Have a short nap
        }
}
```

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S&C - 19

```
//
// The servo (control) loop is implemented in the timer handler (listener).  Version 0.90 of
// leJOS EV3 has a bug in the servo code.  A motion command has to follow setSpeed in
// order for the new set point to register.  Hopefully this will get fixed in later versions.
//
                public void timedOut() {
                  int diff;
                  myDistance.fetchSample(sampleUS,0);       // Read latest sample in buffer
                  wallDist=(int)(sampleUS[0]*100.0);          // Convert from MKS to CGS;
truncate to int
                  if (wallDist <= MAXDIST)
                    distError = WALLDIST-wallDist;            // Compute error term

// Controller Actions

                  if (Math.abs(distError) <= DEADBAND) {      // Case 1: Error in bounds, no
correction
                    leftSpeed=FWDSPEED;
                    rightSpeed=FWDSPEED;
                    leftMotor.setSpeed(leftSpeed);              // If correction was being applied on
last
                    rightMotor.setSpeed(rightSpeed);          // update, clear it
                    leftMotor.forward();                       // Hack - leJOS bug
                    rightMotor.forward();
                  }
```

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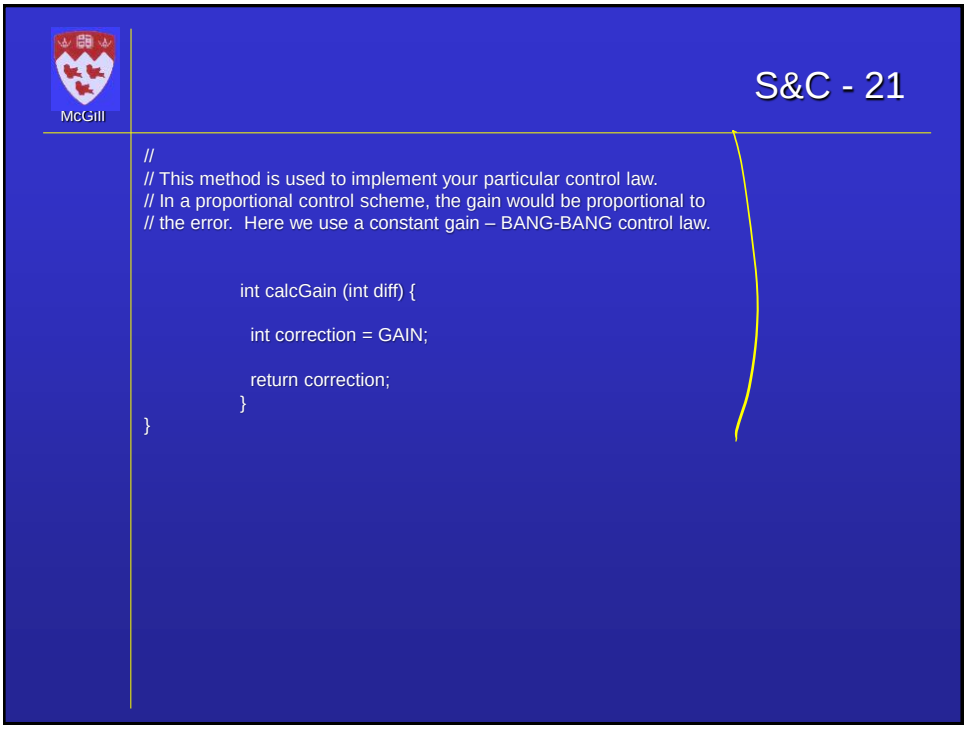
```
                else if (distError > 0) {                          // Case 2: positive error, move away
from wall
                  diff=calcGain(distError);                    // Get correction value and apply
                  leftSpeed=FWDSPEED+diff;
                  rightSpeed=FWDSPEED-diff;
                  leftMotor.setSpeed(leftSpeed);
                  rightMotor.setSpeed(rightSpeed);
                  leftMotor.forward();                         // Hack - leJOS bug
                  rightMotor.forward();
                }

                else if (distError < 0) {                          // Case 3: negative error, move towards
wall
                  diff=calcGain(distError);                    // Get correction value and apply
                  leftSpeed=FWDSPEED-diff;
                  rightSpeed=FWDSPEED+diff;
                  leftMotor.setSpeed(leftSpeed);
                  rightMotor.setSpeed(rightSpeed);
                  leftMotor.forward();                       // Hack - leJOS bug
                  rightMotor.forward();
                }
              }
```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S&C - 21
//
// This method is used to implement your particular control law.
// In a proportional control scheme, the gain would be proportional to
// the error. Here we use a constant gain – BANG-BANG control law.
int calcGain (int diff) {
int correction = GAIN;
return correction;
}
}