



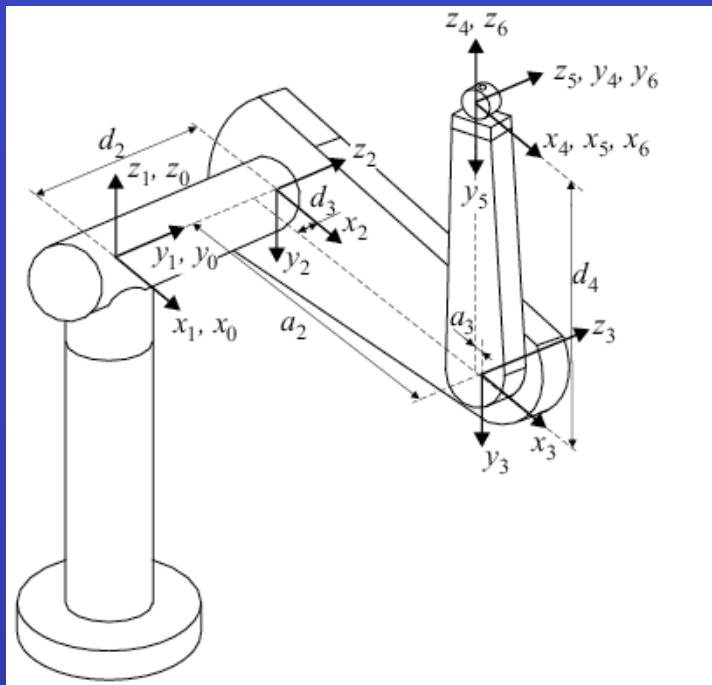
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Research Week 2

Open Loop Control & Odometry



- Kinematic model
 - Relates the configuration of a robot in a local coordinate frame, e.g., (x,y) to motor shaft positions, e.g., (Ω_1, Ω_2) .
 - A kinematic model is robot-specific.



- A robot with N degrees of freedom needs at least N motors/actuators
- The kinematic model describes the static behavior of a robot and does not include the effects of internal and external forces.
- Have to take into account the dynamic behavior as well.



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Odo-2

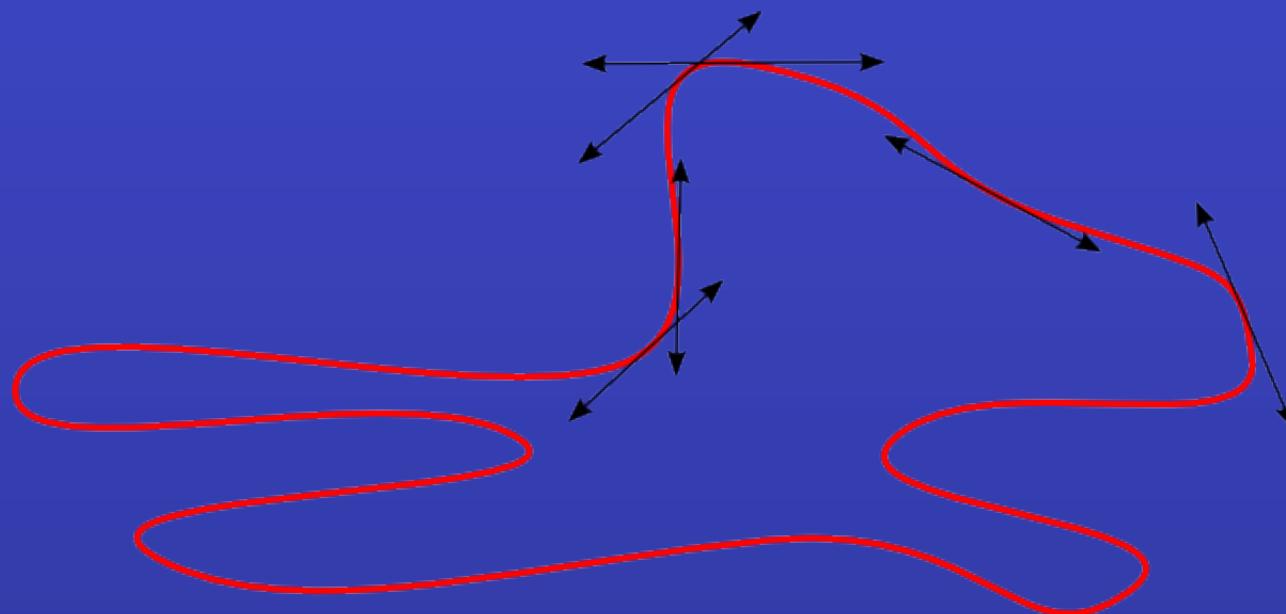
- Odometry
 - Determining the position of a robot in an external coordinate system based on counting motor rotations (change in actuator position).
 - The kinematic model is used to determine the instantaneous displacement.
 - The integral of the displacement determines current position.
 - Odometry (sometimes referred to as dead reckoning) provides only an *estimate* of the robot's actual position.
 - Odometry errors can be corrected by the use of sensors which measure the robot's true position with respect to landmarks in the environment (think of GPS).
 - In general, determining position involves simultaneous estimation over different sources of information, e.g., odometry, GPS, radar, etc.)



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Odo-3

- Open loop control - using odometry to generate a path in space
- Method
 - Decompose path into tangent segments
 - Incrementally move along each segment (trajectory generator)

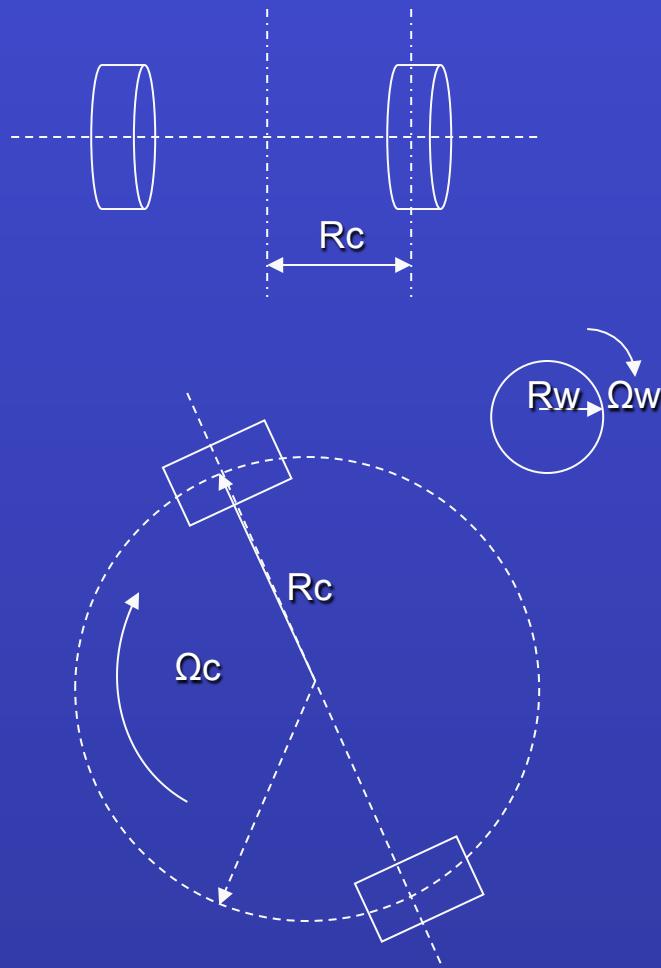




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Odo-4

Odometry of the Tribot



Linear Motion:

- both wheels rotating
- distance = $2 \pi \times \text{wheel radius} \times \Omega_w / 360$
- accuracy depends on degree of slip

Rotation in place (no displacement):

- Ω_w defined as wheel rotation
- Ω_c defined as rotation about cart center point
- R_w and R_c are radii of wheel and turning circle respectively (see diagrams at left)

$$\text{arc length} = \text{radius} \times \text{angle (radians)}$$

$$R_w \times \Omega_w = R_c \times \Omega_c$$

$$\Omega_w = \Omega_c \times (R_c / R_w)$$



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Odo-5

Open Loop Control - Odometry, cont. 1

- For the Tribot, $R_w = 2.8 \text{ cm}$, $R_c = 6.61 \text{ cm}$, $R_c/R_w = 2.35$
- Putting this all together

$$\text{distance} = 2 \pi R_w \times \Omega_w / 360$$

- assuming wheel rotation Ω_w in degrees
- units for distance are the units of R_w

$$\Omega_w = (360 D) / (2\pi R_w) = 20.46 D \quad \text{where } D \text{ is in cm}$$

- Practical problem – what if your computer does not support real numbers?

Example: Assume we want to move by 5 cm

Then $\Omega_w = 20 \times 5 = 100$ (should be 102.3). This adds up over a long path.

- Integer scaling

Multiply 20.46 by 100 to keep all 4 digits so scale factor is 2046

Multiply $2046 \times 5 = 10230$, and then divide by 100, $10230 / 100 = 102$

Observe that the answer is equivalent to determining the exact answer and then converting to integer.

- General rule

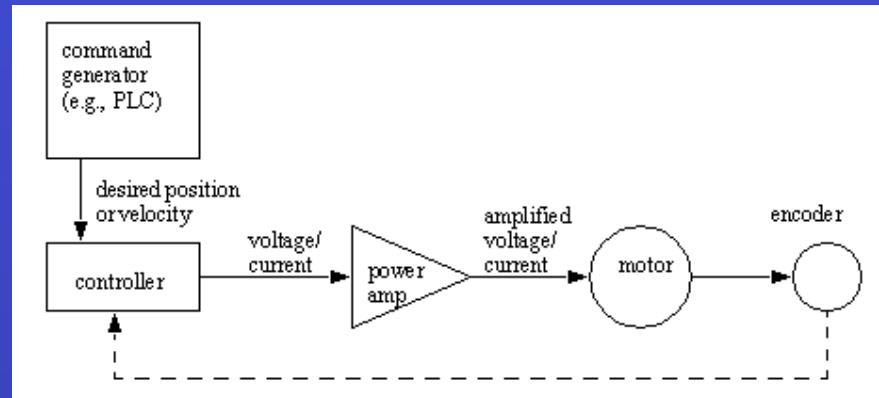
Scale to maintain full precision, perform computation, then scale result back.



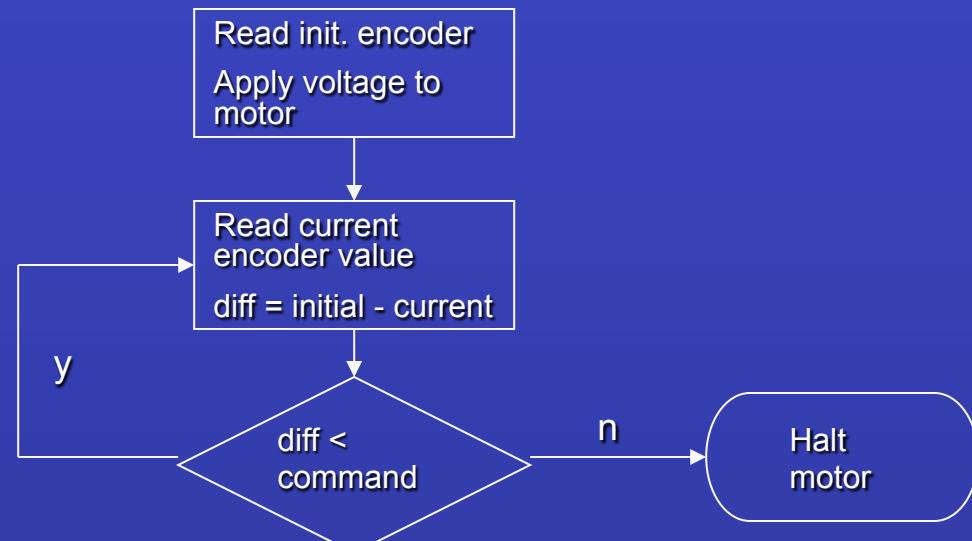
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Odo-6

Servo Motors



Basic Ideas





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Odo-7

Methods for dealing with servos

```
rotate(int angle, boolean return) // servos relative to current  
                                // angular position; angle is  
                                // degrees. Optional return  
                                // arg sets blocking on/off.  
  
rotateTo(int angle, boolean return) // angle is absolute here  
  
setSpeed(int speed)             // set speed, degrees/sec  
  
regulateSpeed(boolean yes)      // default is to regulate  
  
smoothAcceleration(boolean yes) // enables smoother acceleration
```

Threading

Motor servo methods run in independent threads and can (usually) be set to block or run asynchronously.

Methods available for synchronizing motors using the synchronizeWith method.



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Odo-8

A Simple Open Loop Demonstration

```
import lejos.hardware.ev3.LocalEV3;
import lejos.hardware.lcd.TextLCD;
import lejos.hardware.motor.EV3LargeRegulatedMotor;
import lejos.hardware.port.MotorPort;

// Simple trajectory generation using a two-wheeled cart

public class OpenLoop {

    // class variables

    static final int DISTTODEG=21;      // 360/(2xPixRw)  Rw=2.8cm      (20)
    static final int ORIENTTODEG=305;   //((Rc/Rw)*100   Rc=7.94cm  (283)
    static final int SIDE=5000;         // Dimension of square in units of 0.1mm
    static final int FWDSPEED=180;      // Forward speed of robot (deg/sec)
    static final int TRNSPEED=90;       // Rotational speed of robot (deg/sec +/-)

    // static objects (resources that are shared)

    static TextLCD t = LocalEV3.get().getTextLCD();          // LCD
    static EV3LargeRegulatedMotor leftMotor = new EV3LargeRegulatedMotor(MotorPort.A);
    static EV3LargeRegulatedMotor rightMotor = new EV3LargeRegulatedMotor(MotorPort.D);
```



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Odo-9

A Simple Open Loop Demonstration cont.

```
public static void main(String[] args) {
    t.clear();                                // Clear display
    t.drawString("Open Loop Test", 0, 0);      // Print banner
    OpenLoop demo = new OpenLoop();
    demo.go();                                 // And do it
}

public void go() {
    MoveDistFwd(SIDE,FWDSPEED);              // Draw a side
    Rotate(90,TRNSPEED);                     //Rotate90°(repeat4times)
    MoveDistFwd(SIDE,FWDSPEED);
    Rotate(90,TRNSPEED);
    MoveDistFwd(SIDE,FWDSPEED);
    Rotate(90,TRNSPEED);
    MoveDistFwd(SIDE,FWDSPEED);
    Rotate(90,TRNSPEED);
}
```



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Odo-10

A Simple Open Loop Demonstration cont.

```
public void MoveDistFwd(int distance, int speed) {
    int WRotationAngle;

    // Pay attention to blocking vs. non-blocking motor methods.
    // To get 2 motors to start at the same time, first call must
    // be non-blocking.

    WRotationAngle=distance*DISTTODEG/100;           // Dist to turns
    leftMotor.setSpeed(speed);                      // Forward L+R
    rightMotor.setSpeed(speed);
    leftMotor.rotate(WRotationAngle,true);          // Apply turns
    rightMotor.rotate(WRotationAngle);

}

public void Rotate(int angle, int speed) {
    int CRotationAngle;

    CRotationAngle=angle*ORIENTTODEG/100;           // Orient to turns
    leftMotor.setSpeed(speed);                      // Slower in place
    rightMotor.setSpeed(speed);
    leftMotor.rotate(CRotationAngle,true);          // Left, non block
    rightMotor.rotate(-CRotationAngle);;            // Right can

}
```



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Observations

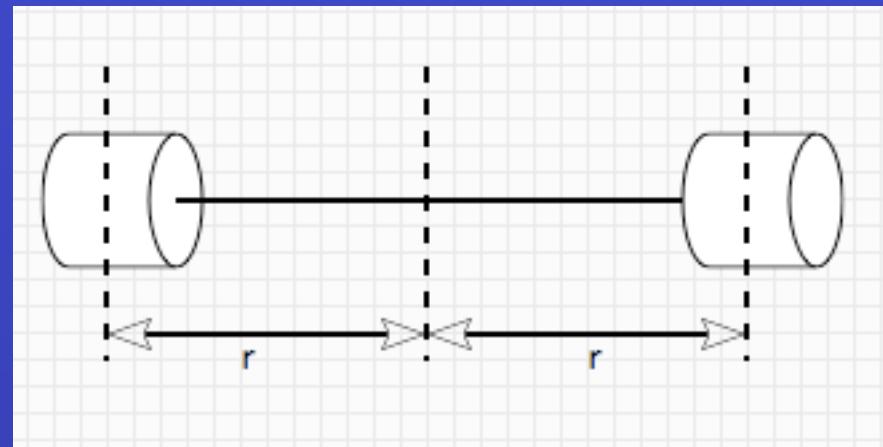
- The accuracy of the path depends on many factors
 - The amount of wheel slip against the floor
 - Motor synchronization (or lack thereof)
 - Control over acceleration and deceleration (sudden starts and stops throw the vehicle off it's trajectory).
 - Experiments with the Tribot in running a closed loop (square) show that return to the origin can be off from anywhere from 5 to 100 cm depending on the flooring.



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Odo - 12

Tracking Position via Odometry



Inputs

- Rotations of left and right wheels
- Radii of wheels
- Wheelbase of vehicle

Outputs (a vector)

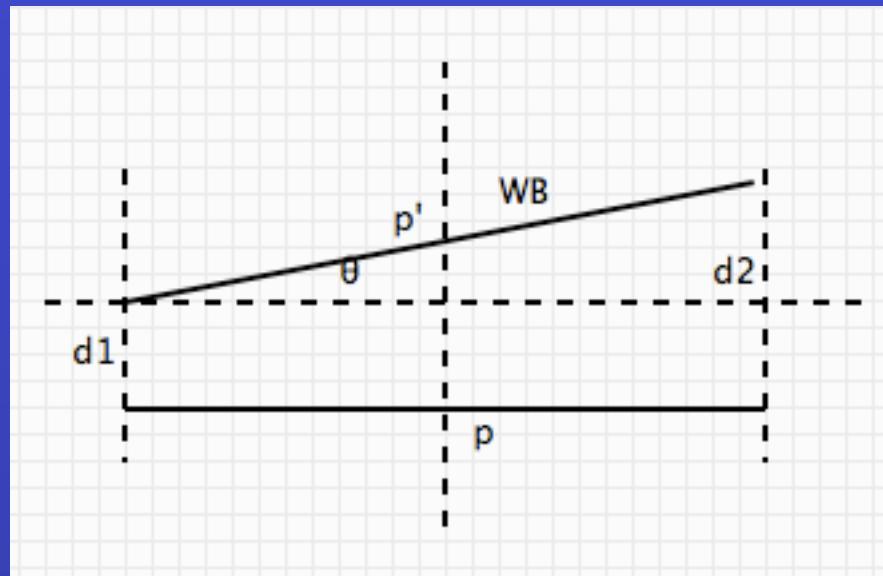
- Magnitude (length) of displacement
- Change in heading
- Compute new position from above



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Odo - 13

Calculating instantaneous displacement from measurements



Calculations:

- Measure Φ_l , Φ_r
 - Calculate $d_1 = (R_w \pi \Phi_l)/180$
 - Calculate $d_2 = (R_w \pi \Phi_r)/180$
 - Calculate $d = d_2 - d_1$
 - Calculate $\theta \approx d / WB$
- n.b. θ is in *radians*

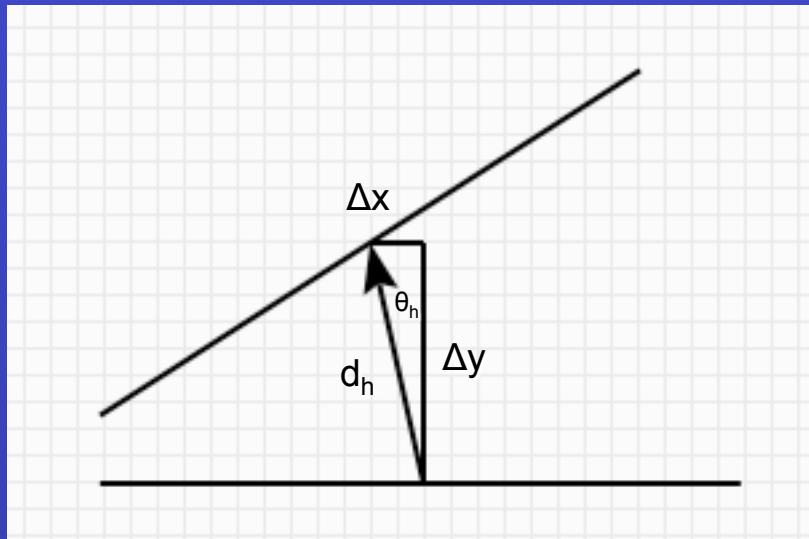
- New heading: $\theta_h = \text{old heading} + \theta$
- Displacement (magnitude): $d_h \approx (d_1 + d_2) / 2$



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Updating position



Calculations:

- $\Delta x = d_h \sin \theta_h$
- $\Delta y = d_h \cos \theta_h$

Current Position:

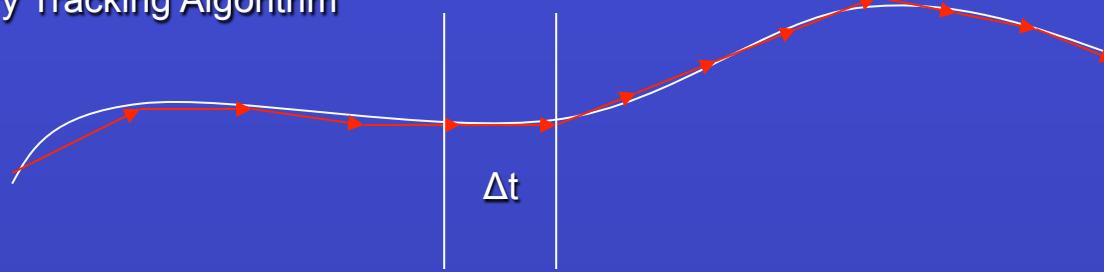
- $x_{\text{current}} = x_{\text{last}} + \Delta x$
- $y_{\text{current}} = y_{\text{last}} + \Delta y$



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Trajectory Tracking Algorithm



- Initialize
 - Set position to starting point (default = 0,0)
 - Read left and right tacho counts. Save as `last_tacho_l` and `last_tacho_r` respectively.
- Updating
 - Read left and right tacho counts. Determine Φ_l and Φ_r . Update `last_tacho_l` and `r`.
 - Calculate d_1 , d_2 , d , and $\theta \Rightarrow \theta_h$, d_h .
 - Calculate Δx , Δy to determine current position.
 - Wait Δt
 - Back to Updating step

n.b. Instructions are assumed to execute on the order of microseconds, i.e., negligible relative to the Wait instruction.



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```
import lejos.hardware.Button;
import lejos.hardware.ev3.LocalEV3;
import lejos.hardware.lcd.TextLCD;
import lejos.hardware.motor.EV3LargeRegulatedMotor;
import lejos.hardware.port.MotorPort;
import lejos.utility.Timer;
import lejos.utility.TimerListener;

//
// A simple odometry demonstration using the EV3 controller
//

public class OdoDemo implements TimerListener {

    // Class Constants

    public static final int SINTERVAL=50;                      // Period of sampling f (mSec)
    public static final int SLEEPINT=500;                         // Period of display update (mSec)
    public static final double WB=16.0;                           // Wheelbase (cm)
    public static final double WR=2.7;                            // Wheel radius (cm)
```



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// Class Variables

```
public static int lastTachoL;           // Tacho L at last sample
public static int lastTachoR;           // Tacho R at last sample
public static int nowTachoL;            // Current tacho L
public static int nowTachoR;            // Current tacho R
public static double X;                 // Current X position
public static double Y;                 // Current Y position
public static double Theta;             // Current orientation
```

// Resources

```
static TextLCD t = LocalEV3.get().getTextLCD();
static EV3LargeRegulatedMotor leftMotor = new EV3LargeRegulatedMotor(MotorPort.A); // L
static EV3LargeRegulatedMotor rightMotor = new EV3LargeRegulatedMotor(MotorPort.D); // R
```



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```
public static void main(String[] args) throws InterruptedException {  
  
    boolean noexit;  
    int status;  
  
    // Set up display area  
  
    t.clear();  
    t.drawString("Odometer Demo",0,0,false);  
    t.drawString("Current X ",0,4,false);  
    t.drawString("Current Y ",0,5,false);  
    t.drawString("Current T ",0,6,false);  
  
    // Set up timer interrupt. Creates a thread which services the timer interrupt. Here  
    // control will be transferred to OdoDemo.timedOut().  
  
    Timer myTimer = new Timer(SINTERVAL,new OdoDemo());  
  
    // Create thread to move the cart simultaneously with odometer operation  
    // (You will need to create a doSquare class for this that extends thread)  
  
    doSquare cart = new doSquare(leftMotor, rightMotor);
```



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```
// Clear tacho counts and put motors in freewheel mode. Then initialize tacho count
// variable to its current state.
    leftMotor.resetTachoCount();
    rightMotor.resetTachoCount();
    lastTachoL=leftMotor.getTachoCount();
    lastTachoR=rightMotor.getTachoCount();

// Enable timer interrupts (i.e. start the odometer), and start the cart moving.
    myTimer.start();                                // These are both threads
    cart.start();                                  // that operate concurrently

// Enter display loop. Terminate on any button push. (This is actually thread #3)
    noexit=true;
    while(noexit) {
        status=Button.readButtons();           // Terminate on ENTER button
        if (status==Button.ID_ENTER) {
            System.exit(0);
        }
        t.drawInt((int)X,4,11,4);             // Current X estimate
        t.drawInt((int)Y,4,11,5);             // Current Y estimate
        t.drawInt((int)(Theta*57.2598),4,11,6); // Current heading
        Thread.sleep(SLEEPINT);              // Put thread to sleep
    }
}
```



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```
// The "odometer" is implemented in the timer listener (aka interrupt service routine).  
// It follows the recipe described in the class notes.
```

```
public void timedOut() {  
    double distL, distR, deltaD, deltaT, dX, dY;  
  
    nowTachoL = leftMotor.getTachoCount();          // get tacho counts  
    nowTachoR = rightMotor.getTachoCount();  
    distL = 3.14159*WR*(nowTachoL-lastTachoL)/180; // compute wheel  
    distR = 3.14159*WR*(nowTachoR-lastTachoR)/180; // displacements  
    lastTachoL=nowTachoL;                // save tacho counts for next iteration  
    lastTachoR=nowTachoR;  
    deltaD = 0.5*(distL+distR);      // compute vehicle displacement  
    deltaT = (distL-distR)/WB;        // compute change in heading  
    Theta += deltaT;                  // update heading  
    dX = deltaD * Math.sin(Theta);   // compute X component of displacement  
    dY = deltaD * Math.cos(Theta);   // compute Y component of displacement  
    X = X + dX;                      // update estimates of X and Y position  
    Y = Y + dY;  
}  
}
```