SYSC 5104

Methodologies for discrete event modelling and simulation

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ASSIGNMENT 01

DEVS model for one dimensional particle filter localization

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<u>Part 1</u>

A one dimensional particle filter based localization for a helicopter will be modelled. The model consists of two atomic models and one coupled model consisting of three atomic sub models.

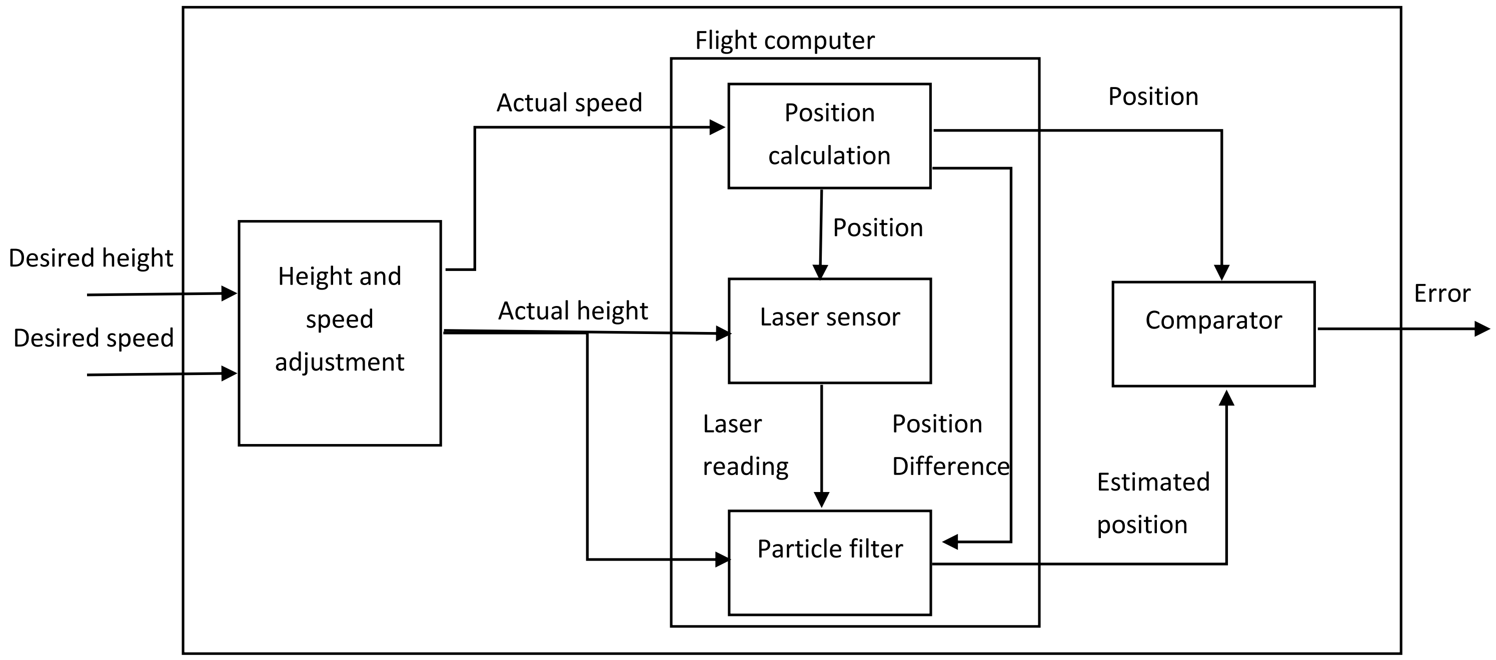


Figure 1: Block diagram of the particle filter

1) Height and speed adjustment unit: When the pilot issues a speed or height adjustment command, this unit gradually brings the height and speed of the helicopter to the desired value. In addition to adjusting height and speed, this model is also responsible for reporting the current speed and current height periodically to the other models.
2) Flight computer composite model with three sub models
   i. Position calculation: This model calculates the position of the helicopter depending on the current speed and reports it.
   ii. Laser sensor: The laser sensor is responsible for generating the measurements that would be obtained if a real sensor was fixed on a real helicopter. A preloaded one dimensional map of the ground is saved on this block and, measurements are based on the values obtained from the map depending on the actual height and position of the helicopter. Due to this reason, the height and position of the helicopter needs to be known by the sensor block to mimic the measurements of an actual laser sensor.

   iii. Particle filter: The particle filter compares the data obtained from the sensor to a known map and estimates the position of the helicopter on an axis in 1D.

3) Comparator: The comparator compares the positon value calculated using the position calculation block and the particle filter block and outputs the error in the particle filter based estimation.

In a real helicopter, the position calculated using the speed of the helicopter accumulates errors due to linearization error, speed sensor errors, etc. This error can be corrected using the ground distance sensor if the helicopter is flying above a known environment. Even though particle filter based localization is mostly used in ground robots for localization, a helicopter is modelled here because a one dimensional particle filter makes more sense on a helicopter rather than a ground robot.

<u>Part 2</u>

As shown in the figure 1, the helicopter control system consists of two inputs and one output. When a desired speed and height is given into the helicopter, it slowly adjusts the speed and height using a proportional controller and then position is estimated using odometry (simulated) data and cross checked with the position estimated using a particle filter.

Formal Specifications

The formal specifications <S, X, Y, δint, δext, λ, ta> for the atomic models are defined as follows:

Height and speed adjustment unit:

```
S = {{phase, speed, height, referenceSpeed, referenceHeight}}
X = {Desired Speed, Desired Height}
Y = {Actual Height, Actual Speed}
δint ( phase, speed, height, referenceSpeed, referenceHeight )
{
    case phase:
    active:
        if ( speed == referenceSpeed==0 && height == referenceHeight == 0)
        {       phase = passive;        //the helicopter has landed
                sigma = infinity; }
        else
        {       adjust speed by a small step, if different from reference
                adjust height by a small step, if different from reference
        }
    passive: //Never happens
}
δext (**phase**, **referenceSpeed**, **referenceHeight,** e, x)
{
    if ( x is from desiredSpeed port)
    {       referenceSpeed = desiredSpeed;}
    if (x is from desiredHeight port)
    {       referenceHeight = desiredHeight;}
}
λ(active)
{       Send speed and height values on the output ports "actualSpeedOut" and
        "actualHeightOut"
}
ta(passive) = INFINITY
ta(active) = publishPeriod
```

Position calculation unit:

```
S = {{phase, position, positionDifferenc}}
X = {speed}
Y = {position, position difference}
δint (active) = passive
δext (phase, position, position difference, e, speed)
{
    calculate new position and position difference values
    phase = active;
    sigma = calculationTime; //simulate the delay in calculating positions
}
```

```
λ(active)
{       send position and position difference on output ports "positionOut" and
        "positionDiffOut"}
ta(passive) = INFINITY
ta(active) = calculationTime
```

Laser sensor unit:

```
S = {{phase, currentPosition, laserReading, currentHeight}}
X = {position, height}
Y = {laser reading}
δint (active) = passive
δext (phase,currentPosition,laserReading,currentHeight, e, x)
{
        if (x is from positionIn port)
        {       currentPosition = msg.value();
                Calculate laser reading;
                phase = active;
                sigma = laser read time;
        }
        If(x is from actualHeightIn port)
        {       currentHeight = msg.value();
        }
}
λ(active)
{       send laser reading
}
ta(passive) = INFINITY
ta(active) = laser read time
```

Particle filter

```
S = {{phase, laserReading, estimatedPose, particles [NUM_PARTICLES], height}}
X = {height, position difference, laser reading}
Y = {estimated position}
```

```
δint (active) = passive
δext (phase, laserReading, estimatedPose, particles [NUM_PARTICLES], height, e, x)
{       if (x is from laserReadingIn port)
        {       laserReading = msg.value();
                Estimate new weights of the particles[NUM_PARTICLES]
                Resample particles depending on the new weights
                Choose particle with maximum weight from new particles
                Phase = active;
                Sigma = calculation time
        }
        If(x is from positionDiffferenceIn port)
        {       update all particles in the particles[NUM_PARTICLES] array }
        If(x is from actualHeightIn port)
        {       height = msg.value();}
}
λ(active)
{       send estimated position
}
ta(passive) = INFINITY
ta(active) = calculation time
```

Comparator

```
S = {{phase, pfPosition, odomPosition, error}}
X = {Odometry_Position, Estimated_pose_PF}
Y = {error}
δint (active) = passive
δext (phase, pfPosition, odomPosition, error, e, x)
 {      if (x is from Estimated_pose_PF)
        {       pfPosition = msg.value();
                Calculate new error
                Phase = active;
                Sigma = 0; }
        if (x is from Odometry_Position)
        {       odomPosition = msg.value();     }
}
λ(active)
{       send the error value on output port "errorOut"
}
ta(passive) = INFINITY
ta(active) = 0
```

The formal specification of the coupled models are as follows:

<X, Y, D, {M_i}, {I_i}, {Z_{ij}}, SELECT >

Flight computer:

X = {speed, height};

Y = {position, estimated position};

D = {position calculation, laser sensor, particle filter};

I (position calculation) = {self, laser sensor, particle filter};

I (laser sensor) = particle filter;

I (particle filter) = self;

Z(position calculation) = self; Z(position calculation) = particle filter;

Z(position calculation) = laser sensor;

Z(laser sensor) = particle filter;

Z(particle filter) = self;

SELECT: ({position calculation, laser sensor, particle filter}) = position calculation;

({laser sensor, particle filter}) = laser sensor

PF_Localization:

X = {desired speed, desired height};

Y = {error};

D = {height and speed adjustment, flight computer, comparator};

I (height and speed adjustment) = {flight computer};

I (flight computer) = comparator;

I (comparator) = self;

Z (height and speed adjustment) = {flight computer};

Z (flight computer) = comparator;

Z (comparator) = self;

SELECT:

({height and speed adjustment, flight computer, comparator}) = height and speed adjustment

({flight computer, comparator }) = flight computer

Testing strategy:

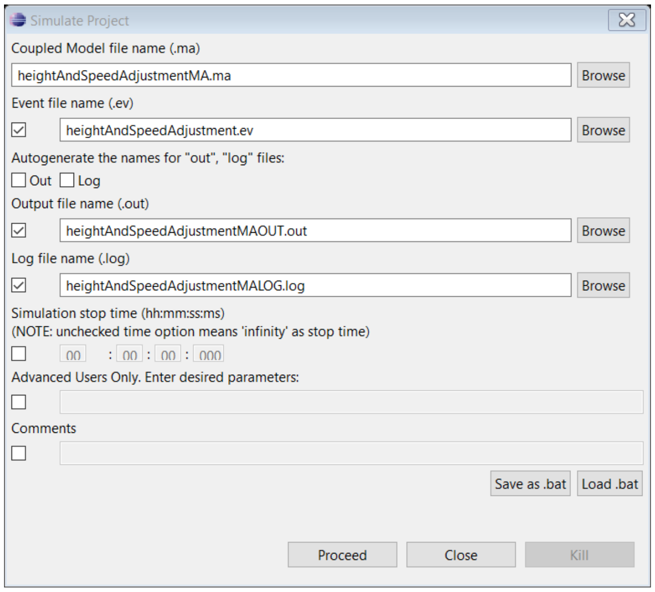
The Height and speed adjustment unit, position calculation unit, laser sensor unit and the comparator unit can be tested individually. Individual event files and models has been created in order to facilitate the unit testing.

Part 3

Height and speed adjustment unit

The height and speed adjustment unit can be tested by inputting desired heights and speeds and observing the output of the actual speed and actual height outputs. The actual speed and actual height should move towards the desired speed and heights.

(Run **1d_ParticleFilter_LocalizationheightAndSpeedAdjustment.bat**)


Simulate Project

Coupled Model file name (.ma): heightAndSpeedAdjustmentMA.ma

Event file name (.ev): [✓] heightAndSpeedAdjustment.ev

Autogenerate the names for "out", "log" files: [ ] Out [ ] Log

Output file name (.out): [✓] heightAndSpeedAdjustmentMAOUT.out

Log file name (.log): [✓] heightAndSpeedAdjustmentMALOG.log

Simulation stop time (hh:mm:ss:ms)
(NOTE: unchecked time option means 'infinity' as stop time)
[ ] 00 : 00 : 00 : 000

Advanced Users Only. Enter desired parameters: [ ]

Comments: [ ]

”heightAndSpeedAdjustment.ev”

```
00:00:00:00 desiredSpeedIn 10
00:00:00:00 desiredHeightIn 15
00:00:16:00 desiredSpeedIn 8
00:00:17:00 desiredHeightIn 15
00:00:20:00 desiredSpeedIn 8.5
```

```
00:00:21:00 desiredHeightIn 17
00:00:22:00 desiredSpeedIn 0
00:00:23:00 desiredHeightIn 0
```

"heightAndSpeedAdjustmentMAOUT.out" contains the results of this simulation. Some of the extracted data are as follows:

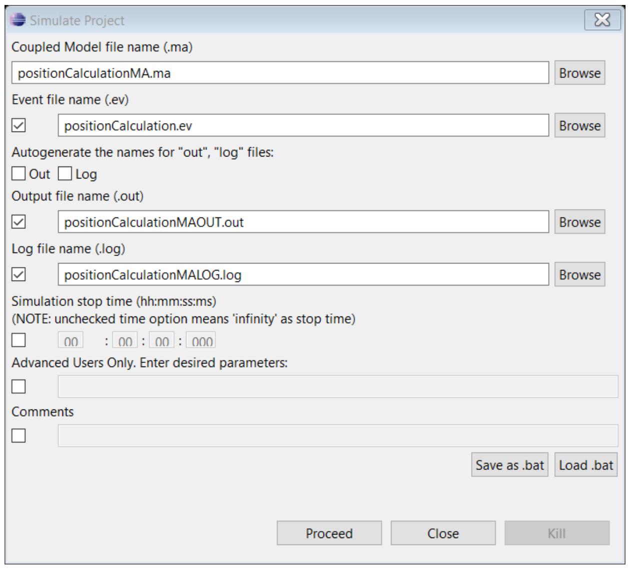
```
00:00:00:000 actualspeedout 0
00:00:00:000 actualheightout 10

………

00:00:05:000 actualspeedout 9.23055
00:00:05:000 actualheightout 14.6153
00:00:05:100 actualspeedout 9.26902
00:00:05:100 actualheightout 15
00:00:05:200 actualspeedout 9.30557
00:00:05:200 actualheightout 15
00:00:05:300 actualspeedout 9.34029
00:00:05:300 actualheightout 15
00:00:05:400 actualspeedout 9.37328
00:00:05:400 actualheightout 15
00:00:05:500 actualspeedout 9.40461
00:00:05:500 actualheightout 15
00:00:05:600 actualspeedout 9.43438
00:00:05:600 actualheightout 15
00:00:05:700 actualspeedout 9.46266
00:00:05:700 actualheightout 15
00:00:05:800 actualspeedout 9.48953
00:00:05:800 actualheightout 15
00:00:05:900 actualspeedout 9.51505
00:00:05:900 actualheightout 15
00:00:06:000 actualspeedout 9.5393
00:00:06:000 actualheightout 15
00:00:06:100 actualspeedout 9.56234
00:00:06:100 actualheightout 15
00:00:06:200 actualspeedout 9.58422
00:00:06:200 actualheightout 15
00:00:06:300 actualspeedout 9.60501
00:00:06:300 actualheightout 15
00:00:06:400 actualspeedout 10
00:00:06:400 actualheightout 15
```

It can be seen that the outputs have settled at the desired values after 6.4 seconds. Similarly, the outputs have settled for the other inputs too after similar periods.

Position calculation unit

The position calculation unit can be tested by inputting speeds and examining the calculated position and the difference in the positions as follows,

(Run **1d_ParticleFilter_LocalizationpositionCalculation.bat**)


Simulate Project

Coupled Model file name (.ma): positionCalculationMA.ma

Event file name (.ev): [✓] positionCalculation.ev

Autogenerate the names for "out", "log" files: [ ] Out [ ] Log

Output file name (.out): [✓] positionCalculationMAOUT.out

Log file name (.log): [✓] positionCalculationMALOG.log

Simulation stop time (hh:mm:ss:ms)
(NOTE: unchecked time option means 'infinity' as stop time)
[ ] 00 : 00 : 00 : 000

Advanced Users Only. Enter desired parameters: [ ]

Comments: [ ]

"positionCalculation.ev"

```
00:00:00:00 speedIn 10
00:00:20:00 speedIn 20
00:00:30:00 speedIn 40
00:00:40:00 speedIn 20
00:00:50:00 speedIn 14
```

Output with the above event file is as follows:

```
00:00:00:000 positionout 0
00:00:20:000 positionout 300
00:00:30:000 positionout 600
00:00:40:000 positionout 900
00:00:50:000 positionout 1070
```

As seen above, the position calculation unit assumes the helicopter is moving with constant acceleration. Therefore, between 0 and 20 seconds, the velocity is assumed to be linearly increasing. This would give a position of:

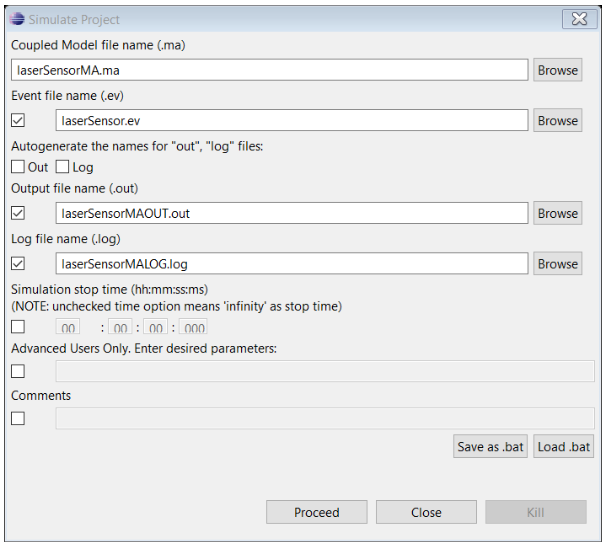
Position at 20 seconds = (20-0)*(10+20)/2 = 300

Similarly, the other positions can also be verified

Laser sensor:

The laser sensor can be verified by inputting pseudo positions and heights and observing its output:

Run: **1d_ParticleFilter_LocalizationlaserSensor.bat**


Simulate Project

Coupled Model file name (.ma): laserSensorMA.ma

Event file name (.ev): [✓] laserSensor.ev

Autogenerate the names for "out", "log" files: [ ] Out [ ] Log

Output file name (.out): [✓] laserSensorMAOUT.out

Log file name (.log): [✓] laserSensorMALOG.log

Simulation stop time (hh:mm:ss:ms)
(NOTE: unchecked time option means 'infinity' as stop time)
[ ] 00 : 00 : 00 : 000

Advanced Users Only. Enter desired parameters: [ ]

Comments: [ ]

"laserSensor.ev"

```
00:00:00:00 position 1
00:00:00:00 height 1
00:00:01:00 position 2
00:00:01:00 height 5
00:00:02:00 position 2.5
00:00:02:00 height 8
00:00:03:00 position 3
00:00:03:00 height 8
00:00:04:00 position 5
00:00:04:00 height 7
00:00:05:00 position 7
00:00:05:00 height 6
00:00:06:00 position 10
00:00:06:00 height 5
```

The output with the above inputs are as follows:

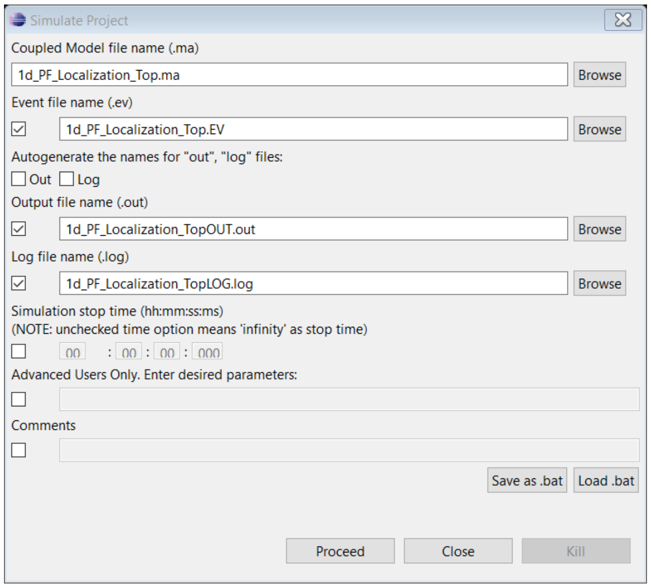
```
00:00:00:010 laserreading 0.846672
00:00:01:010 laserreading 1.85809
00:00:02:010 laserreading 5.50097
00:00:03:010 laserreading 8.02925
00:00:04:010 laserreading 8.64277
00:00:05:010 laserreading 7.29843
00:00:06:010 laserreading 6.14592
```

As seen above, each output is 10 milliseconds delayed from each input. This simulates the delay in obtaining measurements from the laser sensor. As seen above, it can be seen that the laser reading changes according to the height and position of the plane. Since the ground level is modelled as below 0 level in this simulation, it can also be seen that the laser reading is always higher than the "height" value of the helicopter.

1D_PF_Localization_Top:

The complete model can be simulated using the following file:

1d_ParticleFilter_Localization1D_PF_Localization_top.bat



Coupled Model file name (.ma)
1d_PF_Localization_Top.ma

Event file name (.ev)
☑ 1d_PF_Localization_Top.EV

Autogenerate the names for "out", "log" files:
☐ Out ☐ Log

Output file name (.out)
☑ 1d_PF_Localization_TopOUT.out

Log file name (.log)
☑ 1d_PF_Localization_TopLOG.log

Simulation stop time (hh:mm:ss:ms)
(NOTE: unchecked time option means 'infinity' as stop time)
☐ 00 : 00 : 00 : 000

Advanced Users Only. Enter desired parameters:
☐

Comments
☐

"1D_PF_Localization_Top.ev"

```
00:00:00:00 speed 1
00:00:00:00 height 10
00:00:01:00 speed 0.5
00:00:02:00 height 10
00:00:03:00 speed 1
00:00:03:00 height 10
00:00:04:00 speed 0
00:00:04:00 height 0
```

The output after running with the above input is as follows:

```
00:00:00:013 error 0.687438
00:00:00:113 error 0.702549
00:00:00:213 error 0.710487
00:00:00:313 error 0.723658
00:00:00:413 error 0.734193
00:00:00:513 error 0.747181
00:00:00:613 error 0.751051
00:00:00:713 error 0.764728
00:00:00:813 error 0.778228
00:00:00:913 error 0.770646
00:00:01:013 error 0.775652
00:00:01:113 error 0.779322
00:00:01:213 error 0.777582
00:00:01:313 error 0.798334
00:00:01:413 error 0.802469
00:00:01:513 error 0.79408
00:00:01:613 error 0.800082
00:00:01:713 error 0.824246
00:00:01:813 error 0.80945
00:00:01:913 error 0.833059
```

```
00:00:02:013 error 0.799281
00:00:02:113 error 0.759375
00:00:02:213 error 0.737666
00:00:02:313 error 0.71524
00:00:02:413 error 0.690805
00:00:02:513 error 0.667998
00:00:02:613 error 0.647539
00:00:02:713 error 0.623756
00:00:02:813 error 0.600779
00:00:02:913 error 0.581642
00:00:03:013 error 0.636505
00:00:03:113 error 0.64624
00:00:03:213 error 0.670378
00:00:03:313 error 0.693789
00:00:03:413 error 0.718438
00:00:03:513 error 0.743433
00:00:03:613 error 0.767262
00:00:03:713 error 0.781049
00:00:03:813 error 0.790033
00:00:03:913 error 0.772231
00:00:04:013 error 0.767756
00:00:04:113 error 0.79162
00:00:04:213 error 0.766856
00:00:04:313 error 0.753287
00:00:04:413 error 0.744724
00:00:04:513 error 0.731641
00:00:04:613 error 0.707387
00:00:04:713 error 0.682625
00:00:04:813 error 0.657774
00:00:04:913 error 0.635553
00:00:05:013 error 0.665397
00:00:05:113 error 0.689609
00:00:05:213 error 0.714499
00:00:05:313 error 0.712695
00:00:05:413 error 0.697192
00:00:05:513 error 0.699523
00:00:05:613 error 0.723914
00:00:05:713 error 0.737401
00:00:05:813 error 0.756902
00:00:05:913 error 0.759782
00:00:06:013 error 0.757429
00:00:06:113 error 0.76097
00:00:06:213 error 0.76746
00:00:06:313 error 0.74492
00:00:06:413 error 0.722024
00:00:06:513 error 0.742731
00:00:06:613 error 0.749181
00:00:06:713 error 0.760978
00:00:06:813 error 0.780822
00:00:06:913 error 0.764705
00:00:07:013 error 0.765068
00:00:07:113 error 0.782959
00:00:07:213 error 0.790019
00:00:07:313 error 0.812369
00:00:07:413 error 0.82133
00:00:07:513 error 0.818713
00:00:07:613 error 0.81655
```

```
00:00:07:713 error 0.802558
00:00:07:813 error 0.823447
00:00:07:913 error 0.830001
00:00:08:013 error 0.835341
00:00:08:113 error 0.831864
00:00:08:213 error 0.823686
00:00:08:313 error 0.815193
00:00:08:413 error 0.828173
00:00:08:513 error 0.852081
00:00:08:613 error 0.861087
00:00:08:713 error 0.877007
00:00:08:813 error 0.900832
00:00:08:913 error 0.921463
00:00:09:013 error 0.906604
00:00:09:113 error 0.901672
00:00:09:213 error 0.901347
00:00:09:313 error 0.881768
00:00:09:413 error 0.884214
00:00:09:513 error 0.862811
00:00:09:613 error 0.859742
00:00:09:713 error 0.871221
00:00:09:813 error 0.893394
00:00:09:913 error 0.884264
00:00:10:013 error 0.878837
00:00:10:113 error 0.902705
00:00:10:213 error 0.909499
00:00:10:313 error 0.900987
00:00:10:413 error 0.886214
```

It can be seen that the difference between the position estimated using the particle filter and the position calculated using the odometry data is always less than 1. The implemented particle filter assumes a Gaussian distribution for the sensor noise and, a uniform distribution for the odometry noise. The resampling step is done by a simple method of eliminating particles with weights less than a random number between 0 and the cumulative weight of all particle weights. Adjustments to these methods such as using a more accurate model for the odometry noise or using a more advanced resampling method can improve the accuracy of the particle filter even further.