Particle Filter Simulation for Two Ball Trajectory Estimation

Task P2.2

Realize an implementation of the **Particle Filter** in a programming language of your choice for a simulation of the ball-throwing example from the lecture slides. The task of your Particle Filter is to estimate the positions and velocity vectors of two balls flying simultaneously only from the observed erroneous positions over time.

Importing Modules

In [27]:
```
#importing modules
import pandas as pd
import numpy as np
from matplotlib import pyplot as plt
```

Constants

In [28]:
```
G = 9.81
dt = 0.1  # seconds
NUM_PARTICLES = 1000 #Number of particles
obs_noise_covar = np.diag([0.3, 0.3])**2
```

Ball Trajectory Simulation for Particle Filter

In [29]:
```
def ball_trajectory_simulation(launch_position, launch_speed, launc

    # Convert launch angle to radians
    launch_angle_rad = np.deg2rad(launch_angle)

    # Calculate initial velocity components
    initial_velocity_x = launch_speed * np.cos(launch_angle_rad)
    initial_velocity_y = launch_speed * np.sin(launch_angle_rad)

    # Calculate time array
    t = np.arange(0, duration, dt)

    # Calculate ball position at each time step
    x = launch_position[0] + initial_velocity_x * t
    y = launch_position[1] + initial_velocity_y * t - 0.5 * g * t**

    vx = initial_velocity_x * np.ones_like(t)
```

```
    vy = initial_velocity_y - g * t

    return x, y, vx, vy
```

Ball Observations Simulation for Particle Filter

In [30]:
```
def ball_observations_simulation(true_x, true_y, obs_noise_covar, o
    n = len(true_x)  # Number of time steps

    # Generate random noise for observations
    obs_noise = np.random.multivariate_normal([0, 0], obs_noise_cov

    # Simulate observations with dropout
    observations = np.empty((n, 2), dtype=np.float64)
    for i in range(n):
        if np.random.rand() > obs_dropout_prob:
            observations[i] = [true_x[i] + obs_noise[i, 0], true_y[
        else:
            observations[i] = [np.nan, np.nan]

    return observations

#filling the missing (NaN) values in the observations using linear 
def fill_observations(observations):
    df = pd.DataFrame(observations)
    df_filled = df.interpolate(method='linear', limit_direction='bo
    return df_filled.to_numpy()

#Adjusts observations by clipping y-values to ensure they are non-n
def adjust_observations(observations):
    adjusted_observations = observations.copy()
    adjusted_observations[:, 1] = np.maximum(adjusted_observations[
    return adjusted_observations
```

Particle Filter Implementation

In [31]:
```
#particle filter initialization
def initialize_particles(observations, num_particles, launch_speed,
    initial_observation = observations[0]
    if np.isnan(initial_observation).any():
        initial_observation = [0, 0]

    particles = np.zeros((num_particles, 4))
    particles[:, :2] = np.random.normal(initial_observation, scale=
    particles[:, 2] = launch_speed * np.cos(np.deg2rad(launch_angle
    particles[:, 3] = launch_speed * np.sin(np.deg2rad(launch_angle
    return particles


def resample_particles(particles, weights):
    indices = np.random.choice(np.arange(len(particles)), size=len(
    return particles[indices]

#particle filter implementation function
```

```
def particle_filter(observations, num_particles, time_step, total_t
    total_steps = int(total_time / time_step)
    particles = np.zeros((total_steps, num_particles, 4))
    weights = np.ones(num_particles) / num_particles
    estimated_position = np.zeros((total_steps, 2))

    particles[0] = initialize_particles(observations, num_particles

    for step in range(total_steps):
        if step > 0:
            particles[step, :, 0] = particles[step - 1, :, 0] + par
            particles[step, :, 1] = particles[step - 1, :, 1] + par
            particles[step, :, 2] = particles[step - 1, :, 2]
            particles[step, :, 3] = particles[step - 1, :, 3] - g *

        current_observation = observations[step]

        if not np.isnan(current_observation).any():
            diff = particles[step, :, :2] - current_observation
            distances = np.sum((diff @ np.linalg.inv(obs_noise_cova
            weights = np.exp(-0.5 * distances)

            weight_sum = np.sum(weights)
            if weight_sum == 0 or np.isnan(weight_sum):
                weights = np.ones(num_particles) / num_particles
            else:
                weights /= weight_sum

            particles[step] = resample_particles(particles[step], w

        estimated_position[step] = np.mean(particles[step, :, :2],

    return estimated_position
```

Ball Simulation Parameters1

In [32]:

```
# Set up simulation parameters
initial_position_1 = [10, 10]
launch_speed_1 = 40  # m/s
launch_angle_1 = 25  # degrees

initial_position_2 = [0, 0]
launch_speed_2 = 50  # m/s
launch_angle_2 = 15  # degrees

duration = 3  # seconds
obs_noise_covar = np.diag([0.3, 0.3])**2
observation_dropout_prob = 0.1  #dropout probability


# Simulate ball trajectory and observations for ball 1
true_x_1, true_y_1, vx_1, vy_1  = ball_trajectory_simulation(initia
observations_1 = ball_observations_simulation(true_x_1, true_y_1, o
adjusted_observations_1 = adjust_observations(fill_observations(obs
```

```
# Simulate ball trajectory and observations for ball 2
true_x_2, true_y_2, vx_2, vy_2  = ball_trajectory_simulation(initia
observations_2 = ball_observations_simulation(true_x_2, true_y_2, o
adjusted_observations_2 = adjust_observations(fill_observations(obs
```

Running particle filter for both balls

In [33]:
```
# Run particle filter for ball 1 with adjusted observations
estimated_position_1 = particle_filter(np.array(adjusted_observatio

# Run particle filter for ball 2 with adjusted observations
estimated_position_2 = particle_filter(np.array(adjusted_observatio
```

Plotting results for both balls on a single graph(Parameters 1)

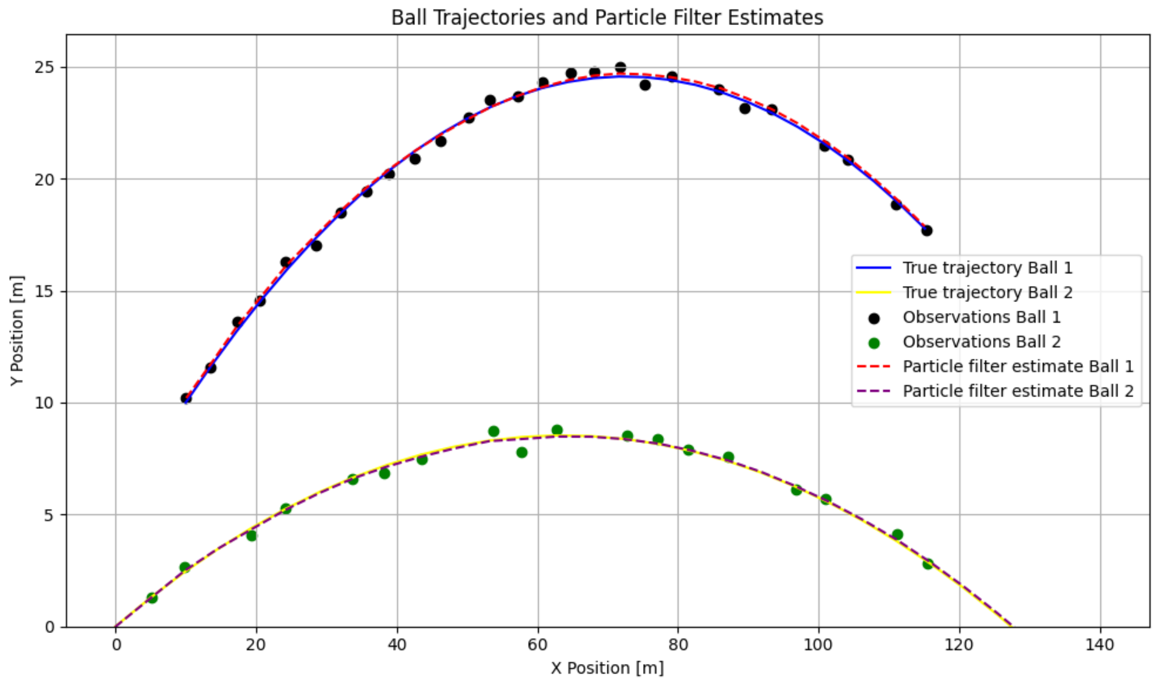
In [34]:
```
# Plot results for both balls on a single graph
plt.figure(figsize=(10, 6)) # Adjust figure size as needed

# Plot true trajectories for both balls
plt.plot(true_x_1, true_y_1, label="True trajectory Ball 1", color=
plt.plot(true_x_2, true_y_2, label="True trajectory Ball 2", color=


# Scatter observations for both balls
plt.scatter(observations_1[:, 0], observations_1[:, 1], label="Obse
plt.scatter(observations_2[:, 0], observations_2[:, 1], label="Obse

# Plot particle filter estimates for both balls
plt.plot(estimated_position_1[:, 0], estimated_position_1[:, 1], la
plt.plot(estimated_position_2[:, 0], estimated_position_2[:, 1], la

# Add labels, legend, and title
plt.legend()
plt.xlabel("X Position [m]")
plt.ylabel("Y Position [m]")
plt.title("Ball Trajectories and Particle Filter Estimates")
plt.grid(True)       # Add grid for better readability
plt.ylim(bottom=0)   # Ensure y-axis starts from 0
plt.tight_layout()   # Ensure tight layout
plt.show()
```



Function to calculate error between estimated trajectory and real trajectory(Parameters 1)

In [35]:
```
def calculate_rmse(estimated_trajectory, true_trajectory):
    error = estimated_trajectory - true_trajectory
    rmse = np.sqrt(np.mean(error ** 2))
    return rmse


# Calculate RMSE for ball 1
rmse_1 = calculate_rmse(estimated_position_1, np.column_stack((true_
print(f'RMSE for Ball 1: {rmse_1}')

# Calculate RMSE for ball 2
rmse_2 = calculate_rmse(estimated_position_2, np.column_stack((true_
print(f'RMSE for Ball 2: {rmse_2}')
```

```
RMSE for Ball 1: 0.09182203867383147
RMSE for Ball 2: 0.0813863745491705
```

Ball Simulation Parameters2

In [36]:
```
# Set up simulation parameters
initial_position_1 = [0, 0]
launch_speed_1 = 40  # m/s
launch_angle_1 = 30  # degrees

initial_position_2 = [10, 20]
launch_speed_2 = 50  # m/s
launch_angle_2 = 45  # degrees

duration = 5  # seconds
obs_noise_covar = np.diag([0.3, 0.3])**2
observation_dropout_prob = 0.1  #dropout probability
```

```
# Simulate ball trajectory and observations for ball 1
true_x_1, true_y_1, vx_1, vy_1  = ball_trajectory_simulation(initia
observations_1 = ball_observations_simulation(true_x_1, true_y_1, o
adjusted_observations_1 = adjust_observations(fill_observations(obs

# Simulate ball trajectory and observations for ball 2
true_x_2, true_y_2, vx_2, vy_2  = ball_trajectory_simulation(initia
observations_2 = ball_observations_simulation(true_x_2, true_y_2, o
adjusted_observations_2 = adjust_observations(fill_observations(obs
```

Running particle filter for both balls

In [37]:
```
# Run particle filter for ball 1 with adjusted observations
estimated_position_1 = particle_filter(np.array(adjusted_observatio

# Run particle filter for ball 2 with adjusted observations
estimated_position_2 = particle_filter(np.array(adjusted_observatio
```

Plotting results for both balls on a single graph(Parameters 2)

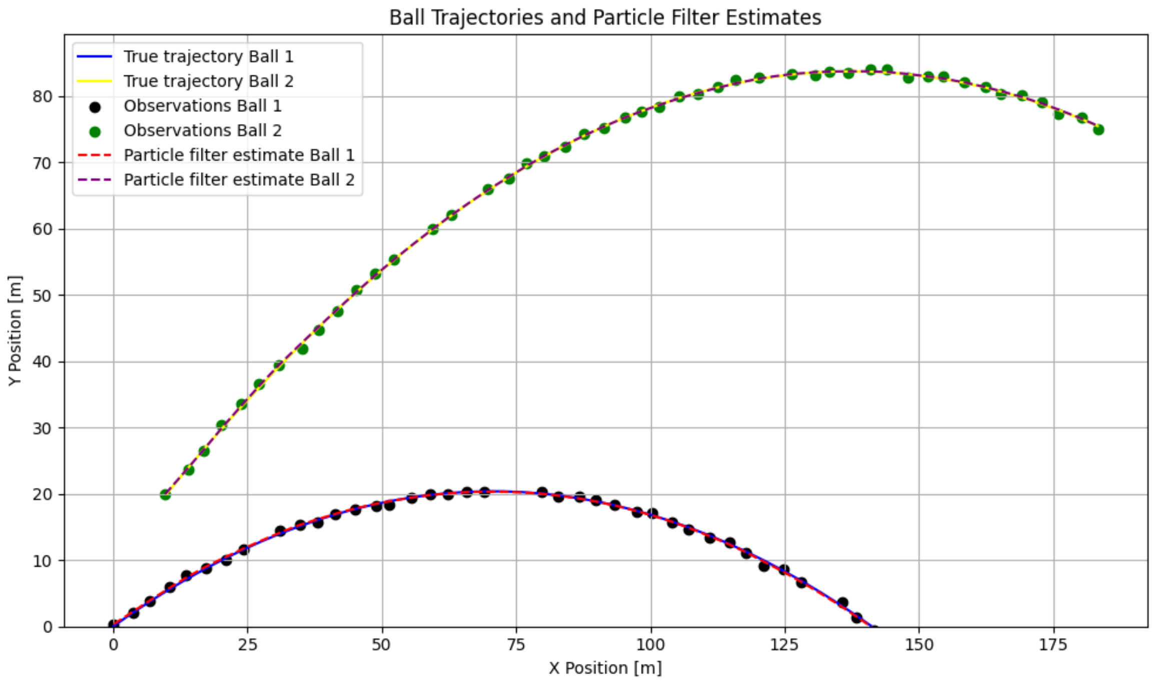
In [38]:
```
# Plot results for both balls on a single graph
plt.figure(figsize=(10, 6)) # Adjust figure size as needed

# Plot true trajectories for both balls
plt.plot(true_x_1, true_y_1, label="True trajectory Ball 1", color=
plt.plot(true_x_2, true_y_2, label="True trajectory Ball 2", color=


# Scatter observations for both balls
plt.scatter(observations_1[:, 0], observations_1[:, 1], label="Obse
plt.scatter(observations_2[:, 0], observations_2[:, 1], label="Obse

# Plot particle filter estimates for both balls
plt.plot(estimated_position_1[:, 0], estimated_position_1[:, 1], la
plt.plot(estimated_position_2[:, 0], estimated_position_2[:, 1], la

# Add labels, legend, and title
plt.legend()
plt.xlabel("X Position [m]")
plt.ylabel("Y Position [m]")
plt.title("Ball Trajectories and Particle Filter Estimates")
plt.grid(True)       # Add grid for better readability
plt.ylim(bottom=0)   # Ensure y-axis starts from 0
plt.tight_layout()   # Ensure tight layout
plt.show()
```



Function to calculate error between estimated trajectory and real trajectory(Parameters 2)

In [39]:
```
def calculate_rmse(estimated_trajectory, true_trajectory):
    error = estimated_trajectory - true_trajectory
    rmse = np.sqrt(np.mean(error ** 2))
    return rmse


# Calculate RMSE for ball 1
rmse_1 = calculate_rmse(estimated_position_1, np.column_stack((true_
print(f'RMSE for Ball 1: {rmse_1}')

# Calculate RMSE for ball 2
rmse_2 = calculate_rmse(estimated_position_2, np.column_stack((true_
print(f'RMSE for Ball 2: {rmse_2}')
```

```
RMSE for Ball 1: 0.10139089401314572
RMSE for Ball 2: 0.09052233912128187
```

THANK YOU

In [ ]: