Pre-Work

March 2, 2024

1 Lab 2

Authors
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[ ]:
```python
# Necessary Libraries
import json
import copy
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
from scipy.stats import norm
from scipy.optimize import curve_fit
from scipy.interpolate import interp1d
from sklearn.metrics import r2_score
import pathlib
import statistics

# Read Raw Data
with open(r"data.json") as f:
    data = json.load(f)

# Accessible sensor names
Sensors = [
    {
        "name": "Long Range",
        "model": lambda x: 49.890422 / x + 0.046704563,
        "conversion": lambda x: 49.890422 / (x - 0.046704563),
        "std_dev": 0.012409
    },
    {
        "name": "Medium Range",
        "model": lambda x: 24.334172 / x - 0.030560244,
        "conversion": lambda x: 24.334172 / (x + 0.030560244),
```

```
        "std_dev": 0.010606
    }
]

# A matrix
A = np.array([[1.0,  0.05,   0.00125],
              [  0,   1.0,      0.05],
              [  0,     0,       1.0]])

# Noise applied to the forward kinematics.
process_noise_v_k_minus_1 = np.array([0.01,0.01,0.003])

# State model noise covariance matrix Q_k
Q_k = np.array([[0.3,   0,   0],
                [  0, 0.3,   0],
                [  0,   0, 0.3]])


# Sensor measurement noise covariance matrix R_k
R_k = np.array([[1.0,   0],
                [  0, 1.0]])

# Sensor noise
v_k = np.array([Sensors[0]["std_dev"], Sensors[1]["std_dev"]])


# Function to generate simulated sensor data for a given movement function
def generate_data(movement_function, noise_factor=1):
    # Create time span of 0 to 10 secons with 20hz sampling
    n = 200
    time = np.linspace(0, 10, n)
    x = movement_function(time)
    # For each sensor
    data = []
    for sensor in Sensors:
        # Generate a sensor data using the movement function, sensor function,␣
 ↪and adding noise
        sensor_data = sensor["model"](x) + np.random.normal(0,␣
 ↪sensor["std_dev"]*noise_factor, n)
        data.append(sensor_data)
    # Return the sensor data
    return data

# Single interation of the Extended Kalman Filter execution
def ekf(z_k_observation_vector, x_k_minus_1, P_k_minus_1, dk, H_k, h_x, R_k,␣
 ↪Q_k):
    ######################### Predict #############################
```

```
    # Predict the state estimate at time k based on the state
    # estimate at time k-1 and the control input applied at time k-1.
    x_k = A @ (x_k_minus_1)

    # print(f'State Estimate Before EKF={x_k}')

    # Predict the state covariance estimate based on the previous
    # covariance and some noise
    P_k = A @ P_k_minus_1 @ A.T + (Q_k)

    # Update
    measurement_residual_y_k = z_k_observation_vector - ((H_k @ x_k))

    # Calculate the measurement residual covariance
    S_k = H_k @ P_k @ H_k.T + R_k

    # Calculate the near-optimal Kalman gain
    K_k = P_k @ H_k.T @ np.linalg.pinv(S_k)

    # Calculate an updated state estimate for time k
    x_k = x_k + (K_k @ measurement_residual_y_k)

    # Update the state covariance estimate for time k
    P_k = P_k - (K_k @ H_k @ P_k)

    # Print the best (near-optimal) estimate of the current state of the robot
   # print(f'State Estimate After EKF={x_k}')

    # Return the updated state and covariance estimates
    return x_k, P_k

# Process dual sensor data using the Extended Kalman Filter
def ekfMain(Vdata, state, sens_cov, sys_cov):
     # We start at time k=1
    k = 1
    filtered_data = []
    # Time interval in seconds
    dk = 0.05
    # print(Vdata)

    # [cm, cm/s, cm/s^2]
    state_estimate_k_minus_1 = np.array(state)

    # State covariance matrix P_k_minus_1
    P_k_minus_1 = np.array([[0.1,  0,   0],
                            [  0,0.1,   0],
                            [  0,  0, 0.1]])
```

```
    vData = np.swapaxes(Vdata,0,1)
    for k, obs_vector_z_k in enumerate(vData,start=1):
        V_m = obs_vector_z_k[1]
        V_l = obs_vector_z_k[0]

        obs_vector_z_k[1] = 24.334172/(V_m+0.030560244)
        obs_vector_z_k[0] = 49.89042/(V_l-0.046704563)

        h_x = np.array([-49.89042/(V_l-0.046704563),
                        -24.334172/(V_m+0.030560244)])

        # Jacobian matrix H_k
        H_k = np.array([[1,   0, 0],
                        [1,  0, 0]])


        # Run the Extended Kalman Filter and store the
        # near-optimal state and covariance estimates
        optimal_state_estimate_k, covariance_estimate_k = ekf(
            obs_vector_z_k, # Most recent sensor measurement
            state_estimate_k_minus_1, # Our most recent estimate of the state
            P_k_minus_1, # Our most recent state covariance matrix
            dk, # Time interval
            H_k,
            h_x,
            sens_cov,
            sys_cov)

        filtered_data.append(optimal_state_estimate_k[0])

        # Get ready for the next timestep by updating the variable values
        state_estimate_k_minus_1 = optimal_state_estimate_k
        P_k_minus_1 = covariance_estimate_k

    return filtered_data

# Run a suite of test on data and a given motion profile to illustrate␣
 ↪performance of the EKF
def calculate_and_gen_graphs(title, file, data, profile, states=[80,30],␣
 ↪show_attempted_profile=True):
    time = data["time"]
    distances = [np.array(sensor) for sensor in data["data"]]
    gen_distances = generate_data(profile)
    gen_distances_noisy = generate_data(profile, 2)

    # Plot the real and generated data
    plt.figure()
```

```
    for sensor in range(len(gen_distances)):
        plt.scatter(time, gen_distances[sensor], label=f"{Sensors[sensor]['name']} Generated", s=0.6)
    for sensor in range(len(distances)):
        plt.scatter(time, distances[sensor], label=f"{Sensors[sensor]['name']}", s=0.6)
    plt.title(f"Sensor Readings | {title}")
    plt.xlabel("Time (sec)")
    plt.ylabel("Sensor Reading (Volts)")
    plt.legend()
    plt.savefig(f"out/plots/{file}.png")
    plt.show()

    # Keep track of R^2 for various simulated data sets
    r2 = []

    # Kalman filter on the generated data
    processed_gen = ekfMain(gen_distances, [states[0],0.0,0.0], R_k, Q_k)
    r2.append({
        "Title": "Default",
        "R^2": r2_score(profile(time), processed_gen)
    })
    plt.figure()
    plt.plot(time, profile(time), label="Profile", color="red", linewidth=0.75)
    plt.plot(time, processed_gen, label="Filtered", color="green")
    for i, sensor in enumerate(Sensors):
        plt.scatter(time, sensor["conversion"](gen_distances[i]), label=f"{sensor['name']} Generated", s=0.5, color=["blue", "orange"][i])
    plt.title(f"Filtered vs Generated | {title}")
    plt.xlabel("Time (sec)")
    plt.ylabel("Distance (cm)")
    plt.ylim(0,100)
    plt.legend()
    plt.savefig(f"out/plots/{file}_kalman_gen.png")
    plt.show()

    # Kalman filter on the generated data, bad state estimate
    processed_gen = ekfMain(gen_distances, [states[1],-5.0,-10.0], R_k, Q_k)
    r2.append({
        "Title": "Bad State Est.",
        "R^2": r2_score(profile(time), processed_gen)
    })
    plt.figure()
    plt.plot(time, profile(time), label="Profile", color="red", linewidth=0.75)
    plt.plot(time, processed_gen, label="Filtered", color="green")
    for i, sensor in enumerate(Sensors):
```

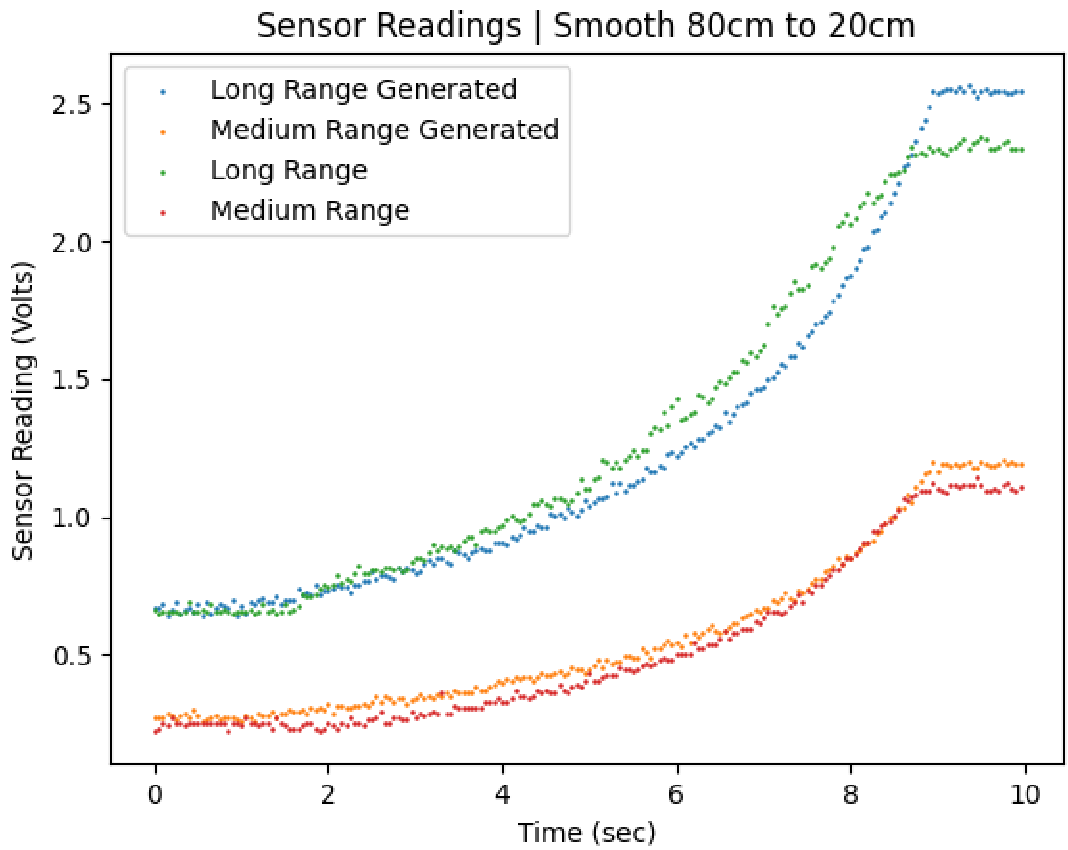
```
        plt.scatter(time, sensor["conversion"](gen_distances[i]),␣
↪label=f"{sensor['name']} Generated", s=0.5, color=["blue", "orange"][i])
    plt.title(f"Filtered vs Generated | {title} | Bad State Estimate")
    plt.xlabel("Time (sec)")
    plt.ylabel("Distance (cm)")
    plt.ylim(0,100)
    plt.legend()
    plt.savefig(f"out/plots/{file}_kalman_gen_bad_state.png")
    plt.show()

    # Kalman filter on the generated data, noisy sensors
    processed_gen = ekfMain(gen_distances_noisy, [states[0],0.0,0.0], R_k, Q_k)
    r2.append({
        "Title": "Noisy Sensors",
        "R^2": r2_score(profile(time), processed_gen)
    })
    plt.figure()
    plt.plot(time, profile(time), label="Profile", color="red", linewidth=0.75)
    plt.plot(time, processed_gen, label="Filtered", color="green")
    for i, sensor in enumerate(Sensors):
        plt.scatter(time, sensor["conversion"](gen_distances_noisy[i]),␣
↪label=f"{sensor['name']} Generated", s=0.5, color=["blue", "orange"][i])
    plt.title(f"Filtered vs Generated | {title} | Noisy Sensors")
    plt.xlabel("Time (sec)")
    plt.ylabel("Distance (cm)")
    plt.ylim(0,100)
    plt.legend()
    plt.savefig(f"out/plots/{file}_kalman_gen_noisy_sensors.png")
    plt.show()

    # Kalman filter on the generated data, noisy system
    processed_gen = ekfMain(gen_distances, [states[0],0.0,0.0], R_k, Q_k*2)
    r2.append({
        "Title": "Noisy System",
        "R^2": r2_score(profile(time), processed_gen)
    })
    plt.figure()
    plt.plot(time, profile(time), label="Profile", color="red", linewidth=0.75)
    plt.plot(time, processed_gen, label="Filtered", color="green")
    for i, sensor in enumerate(Sensors):
        plt.scatter(time, sensor["conversion"](gen_distances[i]),␣
↪label=f"{sensor['name']} Generated", s=0.5, color=["blue", "orange"][i])
    plt.title(f"Filtered vs Generated | {title} | Noisy System")
    plt.xlabel("Time (sec)")
    plt.ylabel("Distance (cm)")
    plt.ylim(0,100)
    plt.legend()
```

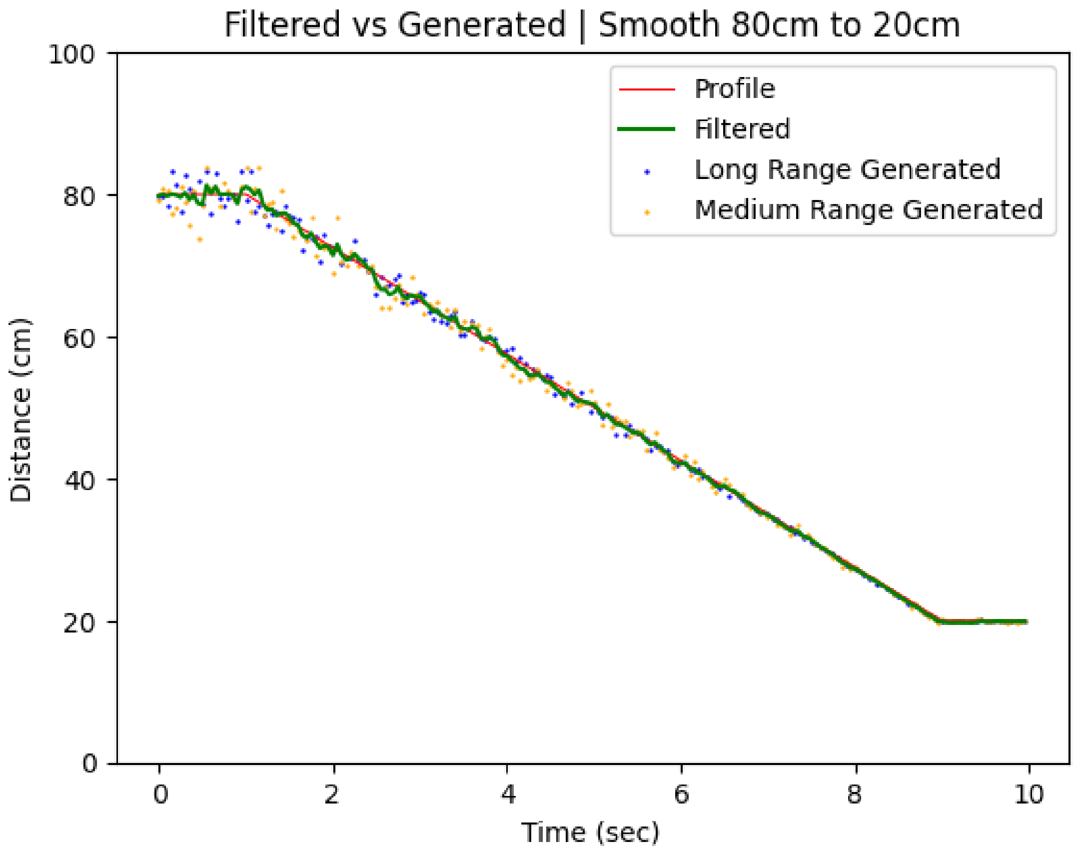
```
    plt.savefig(f"out/plots/{file}_kalman_gen_noisy_sensors.png")
    plt.show()

    # Create a pretty table of R^2 values
    r2_df = pd.DataFrame(r2)
    print(r2_df.to_string(index=False))

    # Kalman filter on the real data
    processed_real = ekfMain(distances, [states[0],0.0,0.0], R_k, Q_k)
    plt.figure()
    if show_attempted_profile:
        plt.plot(time, profile(time), label="Attempted Profile", color="red",␣
 ↪linewidth=0.75)
    plt.plot(time, processed_real, label="Filtered", color="green")
    for i, sensor in enumerate(Sensors):
        plt.scatter(time, sensor["conversion"](distances[i]),␣
 ↪label=f"{sensor['name']}", s=0.5, color=["blue", "orange"][i])
    plt.title(f"Filtered vs Experimental | {title}")
    plt.xlabel("Time (sec)")
    plt.ylabel("Distance (cm)")
    plt.ylim(0,100)
    plt.legend()
    plt.savefig(f"out/plots/{file}_kalman_real.png")
    plt.show()
```

1.1 Part 1 - Smooth Point-to-Point Motion

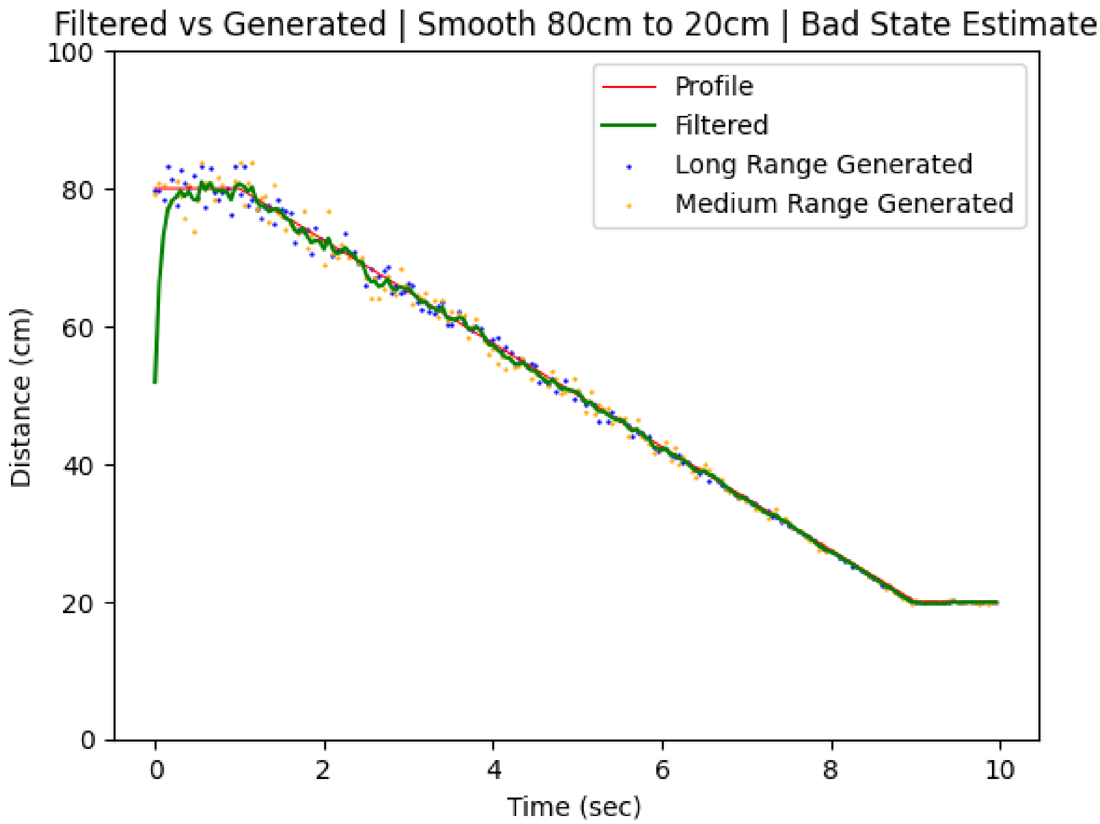
[ ]:
```
# Stay still for 1 second, move at a constant speed for 8 seconds, pause for 1␣
 ↪second
def movement_profile(times):
    data = []
    for t in times:
        if t < 1:
            data.append(80)
        elif t > 9:
            data.append(20)
        else:
            data.append(80 - 60 / 8 * (t - 1))
    return np.array(data)

# Process Graphs for Part 1
p1 = data["Part1"]
part_a = p1["smooth_80_to_20"]
calculate_and_gen_graphs(
    title = "Smooth 80cm to 20cm",
    file="Part1_smooth",
    data=part_a,
```

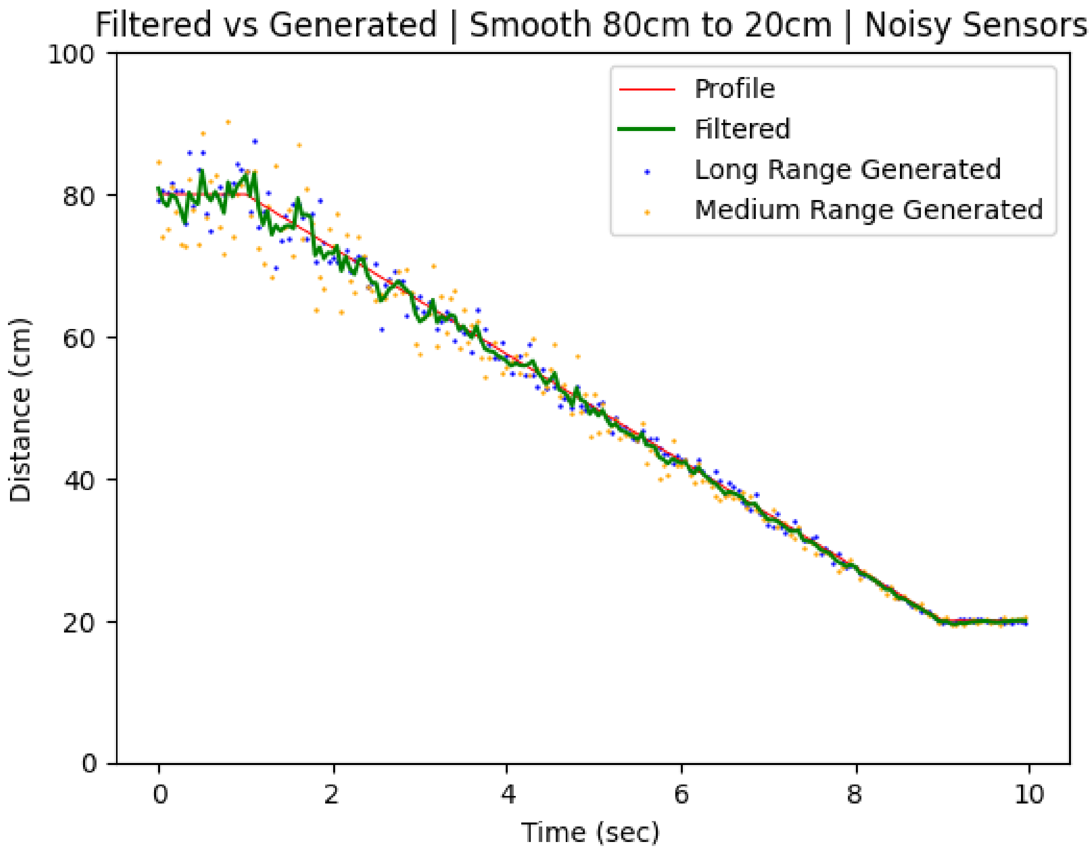
```
    profile=movement_profile
)
```

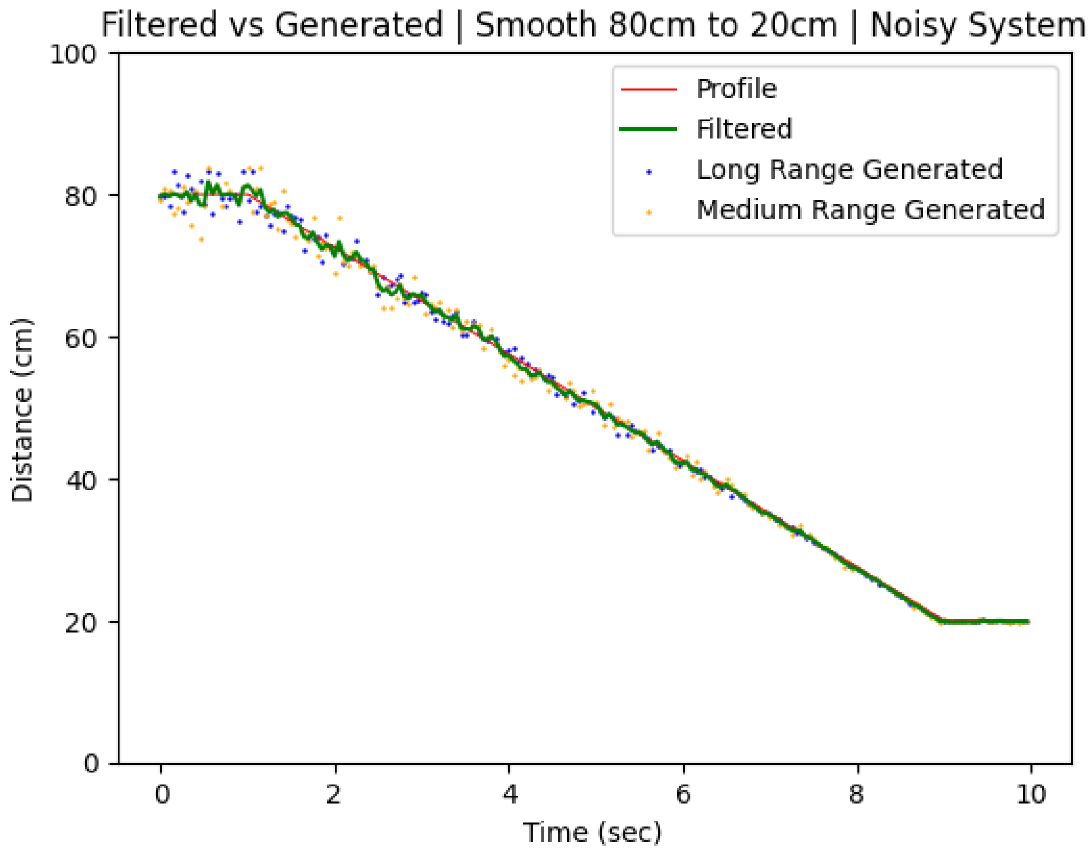




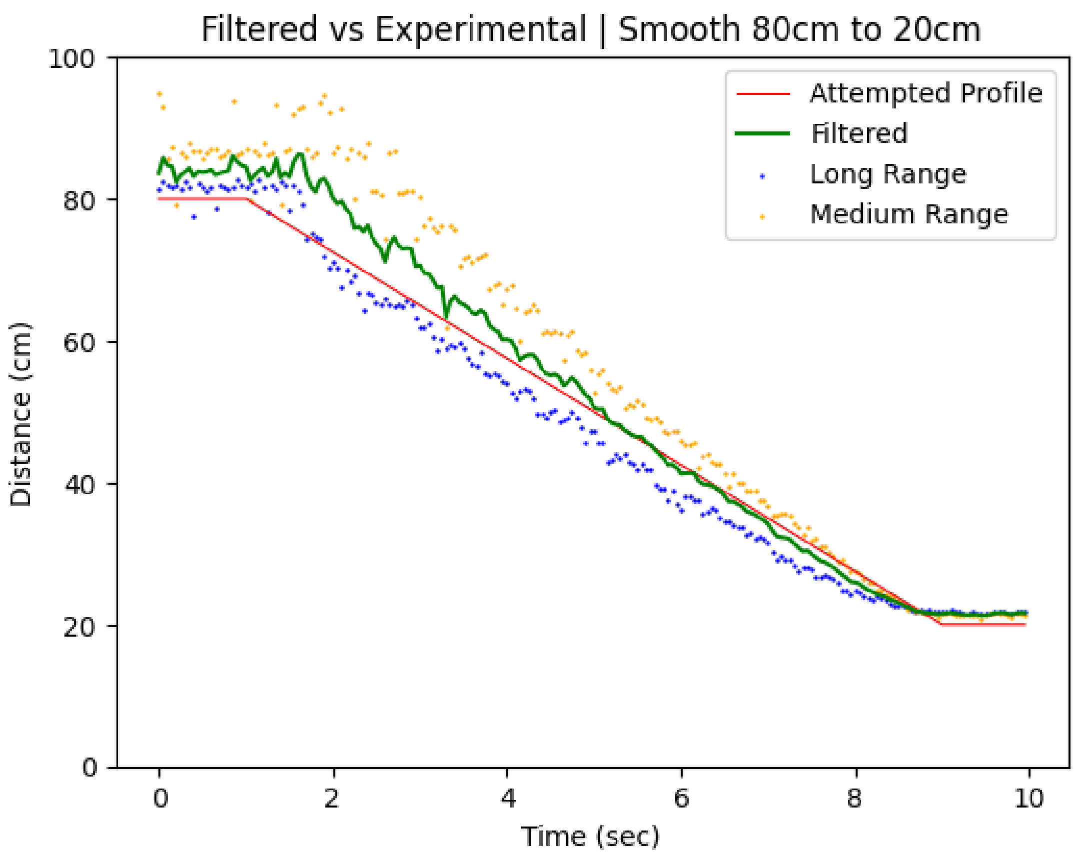
Filtered vs Generated | Smooth 80cm to 20cm
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10


Filtered vs Generated | Smooth 80cm to 20cm | Bad State Estimate
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10


Filtered vs Generated | Smooth 80cm to 20cm | Noisy Sensors
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10



Title	R^2
Default	0.999345
Bad State Est.	0.986862
Noisy Sensors	0.996896
Noisy System	0.999188

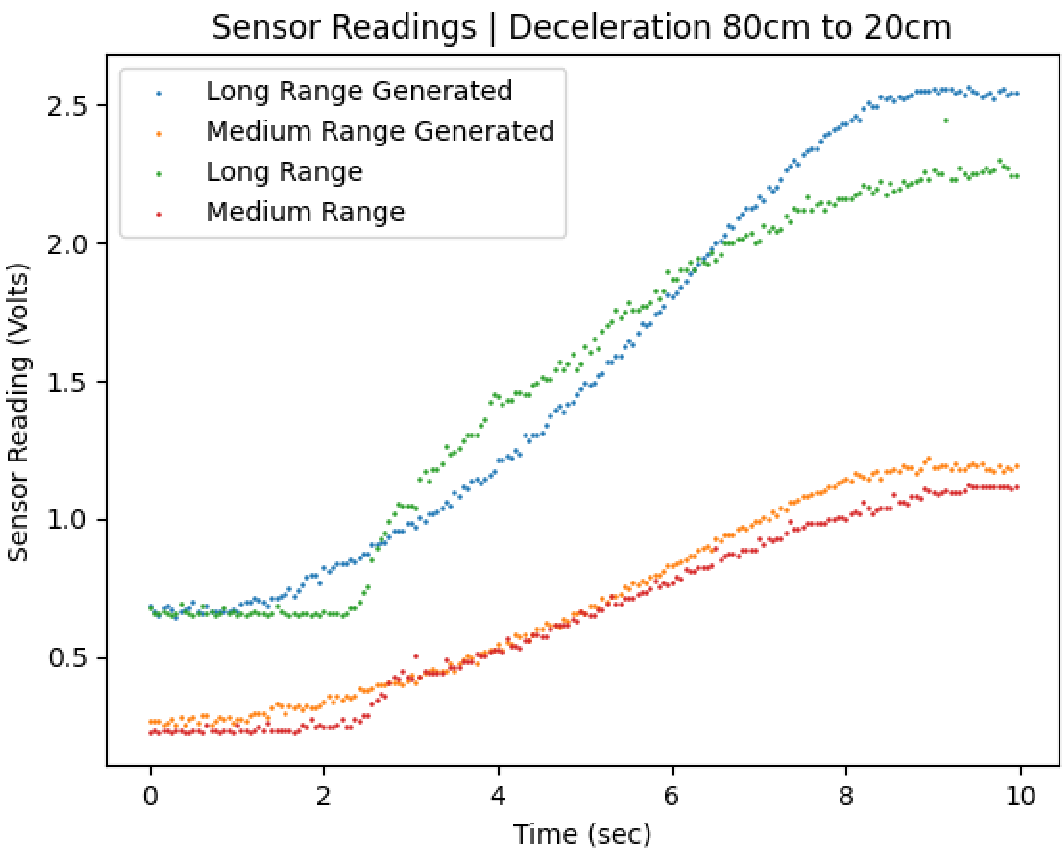


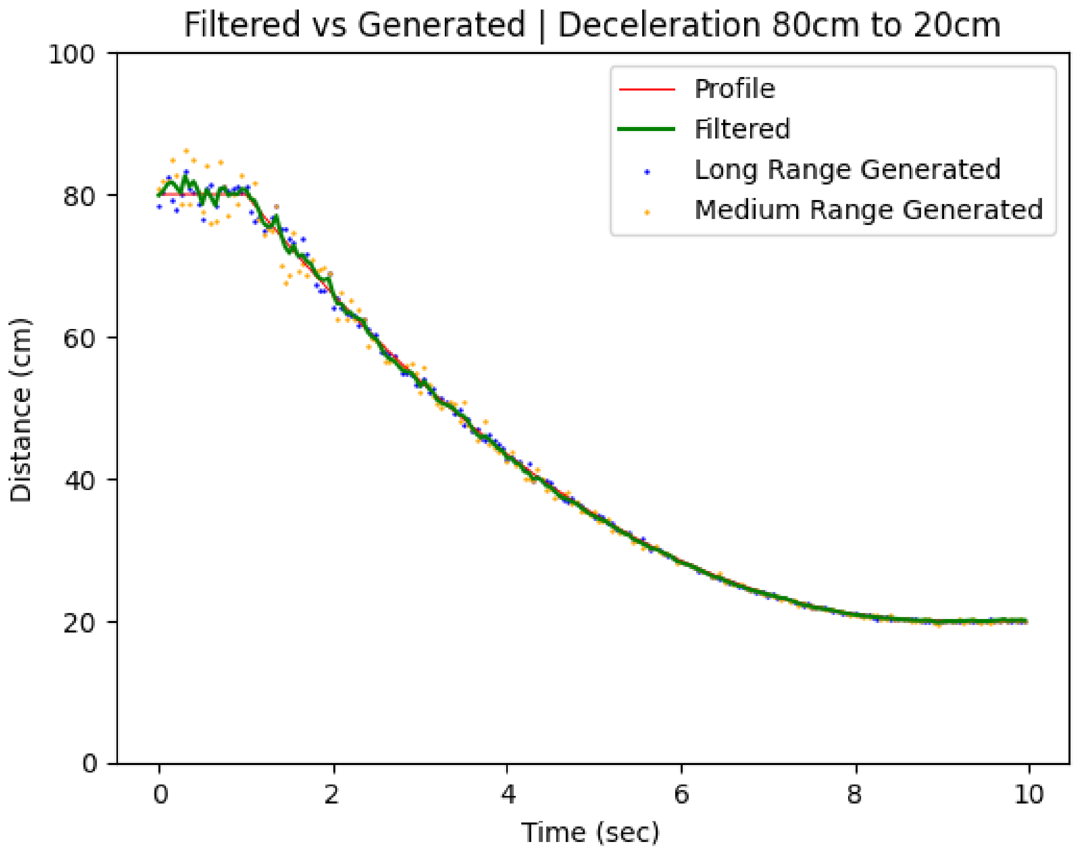
1.2 Part 2 - Unsmooth Point-to-Point Motion

1.2.1 deccelerate

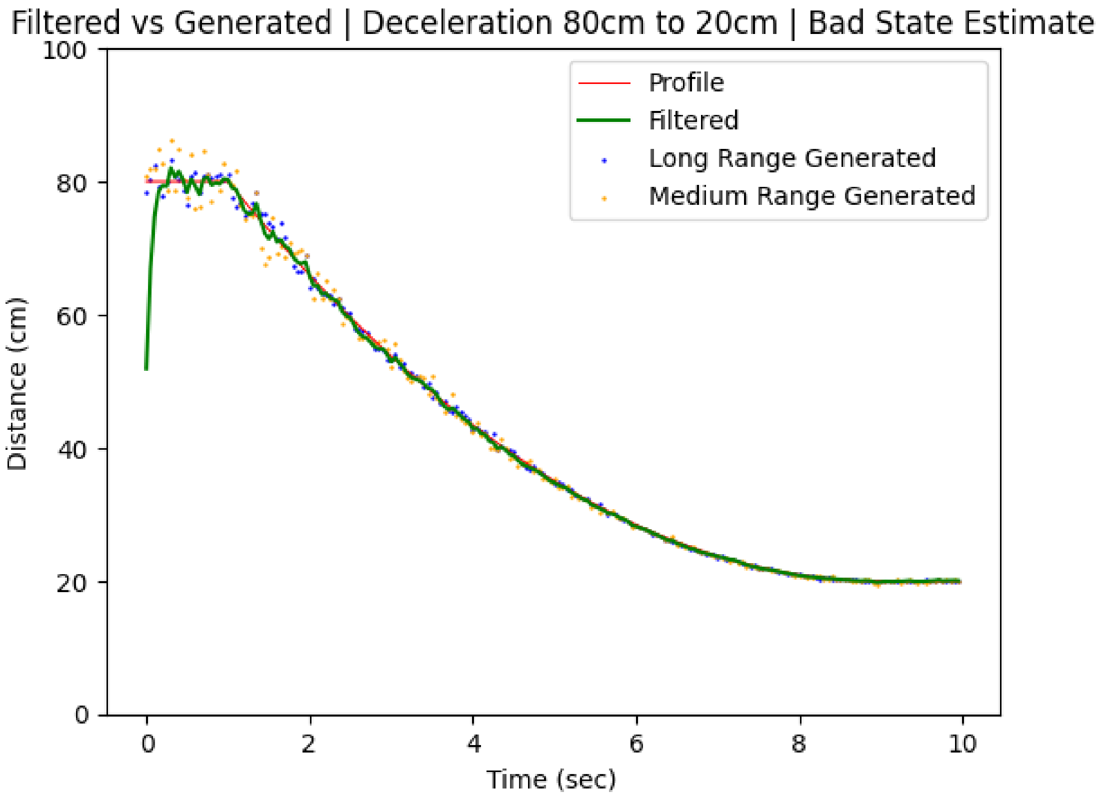
[ ]:
```
# Stay still for 1 second, instant movement and decelerate to stop for 8␣
↪seconds, pause 1 second
def movement_profile(times):
    data = []
    for t in times:
        if t < 1:
            data.append(80)
        elif t > 9:
            data.append(20)
        else:
            data.append(15/16 * (t-1)**2 - 15*(t-1) + 80)
    return np.array(data)

# Grab Part A data from the dictionary, make relevant copies
p2 = data["Part2"]
decel = p2["deccelerate"]
```

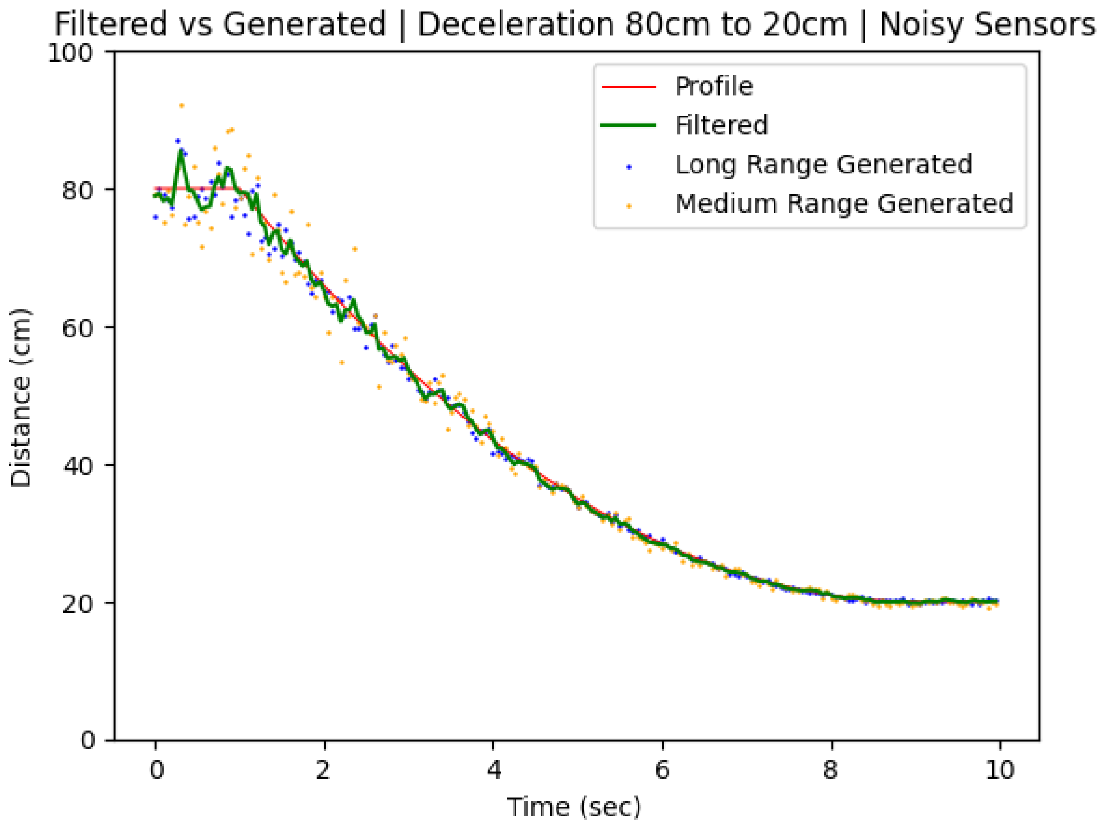
```
calculate_and_gen_graphs(
    title = "Deceleration 80cm to 20cm",
    file="Part2_decel",
    data=decel,
    profile=movement_profile
)
```

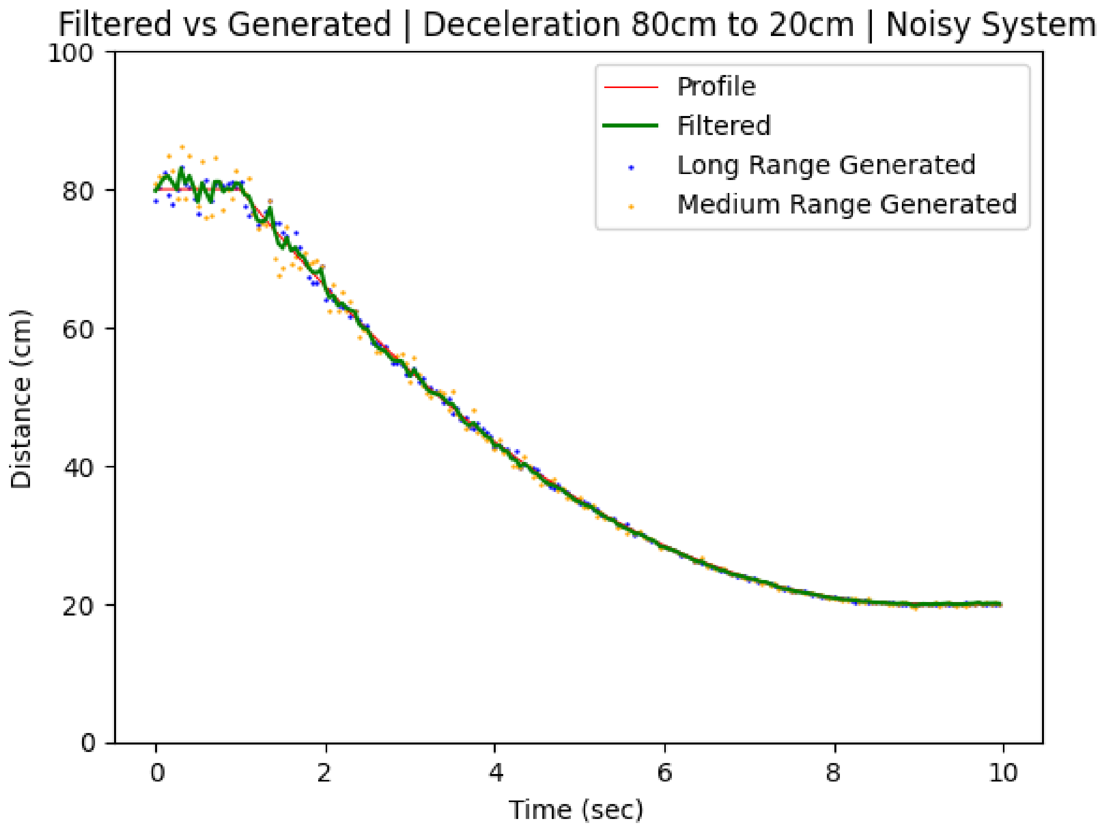




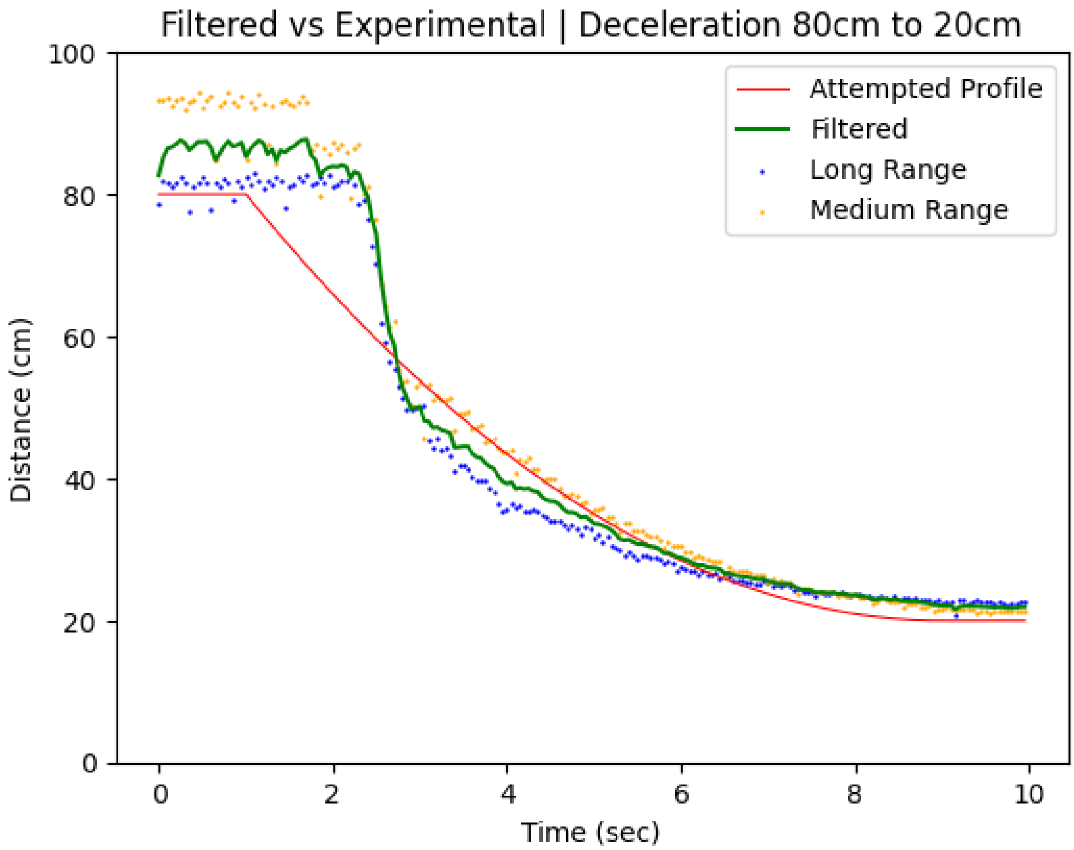
Filtered vs Generated | Deceleration 80cm to 20cm
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10


Filtered vs Generated | Deceleration 80cm to 20cm | Bad State Estimate
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10


Filtered vs Generated | Deceleration 80cm to 20cm | Noisy Sensors
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10



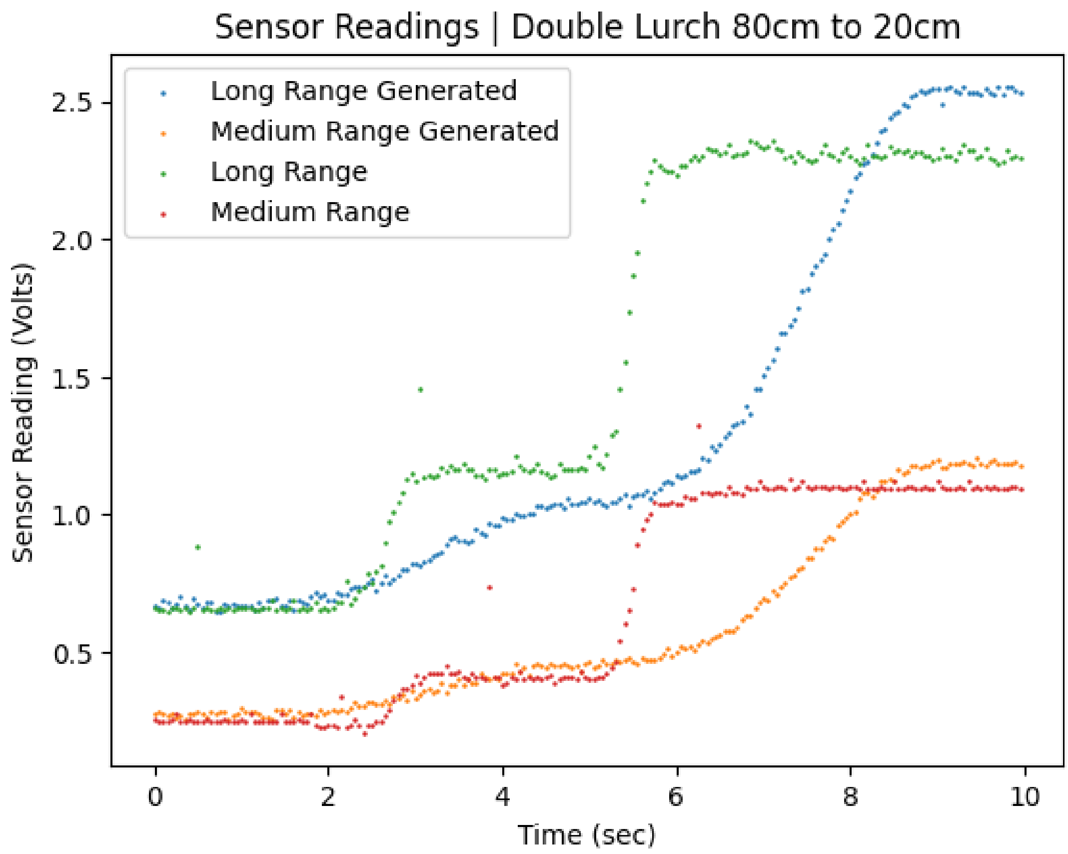
Title	R^2
Default	0.999418
Bad State Est.	0.988576
Noisy Sensors	0.997932
Noisy System	0.999246



1.2.2 double_lurch

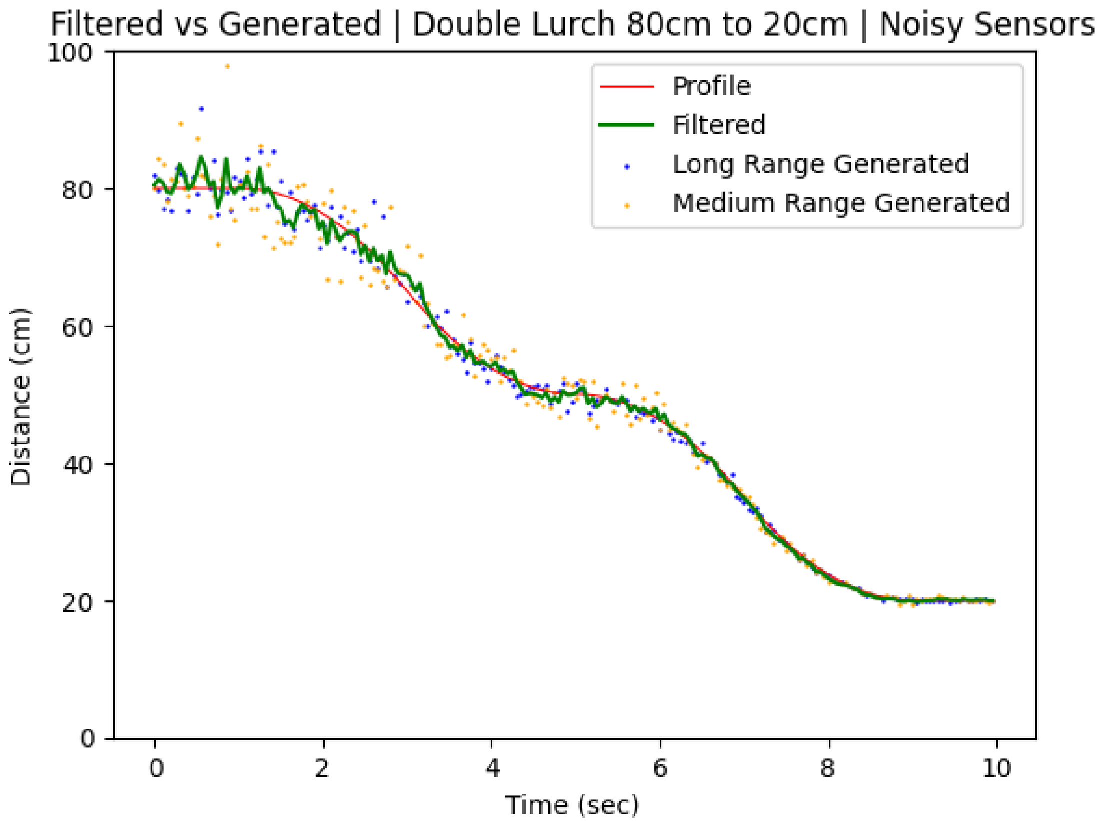
[ ]:
```
# Stay still for 1 seconds, double lurch to 20cm, pause 1 second
def movement_profile(times):
    data = []
    for t in times:
        if t < 1:
            data.append(80)
        elif t < 3:
            data.append(80 - (15/4) *(t-1)**2)
        elif t < 5:
            data.append(80 - 15 - (15/4)*4*(t-3) + (15/4)*(t-3)**2)
        elif t < 7:
            data.append(80 - 30 - (15/4) * (t-5)**2)
        elif t < 9:
            data.append(80 - 45 - (15/4)*4*(t-7) + (15/4)*(t-7)**2)
        else:
            data.append(20)
    return np.array(data)
```

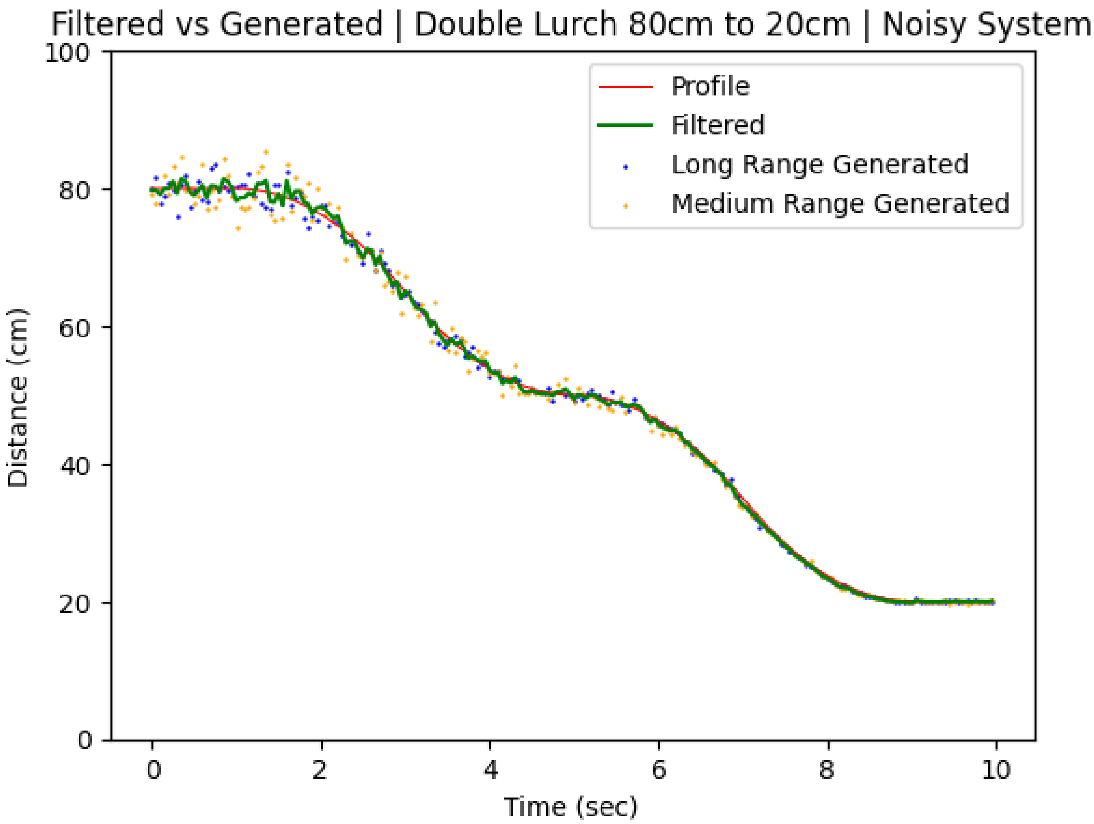
```python
# Graph the sensor readings for double_lurch movement
double_lurch = p2["double_lurch"]
calculate_and_gen_graphs(
    title = "Double Lurch 80cm to 20cm",
    file="Part2_double_lurch",
    data=double_lurch,
    profile=movement_profile
)
```



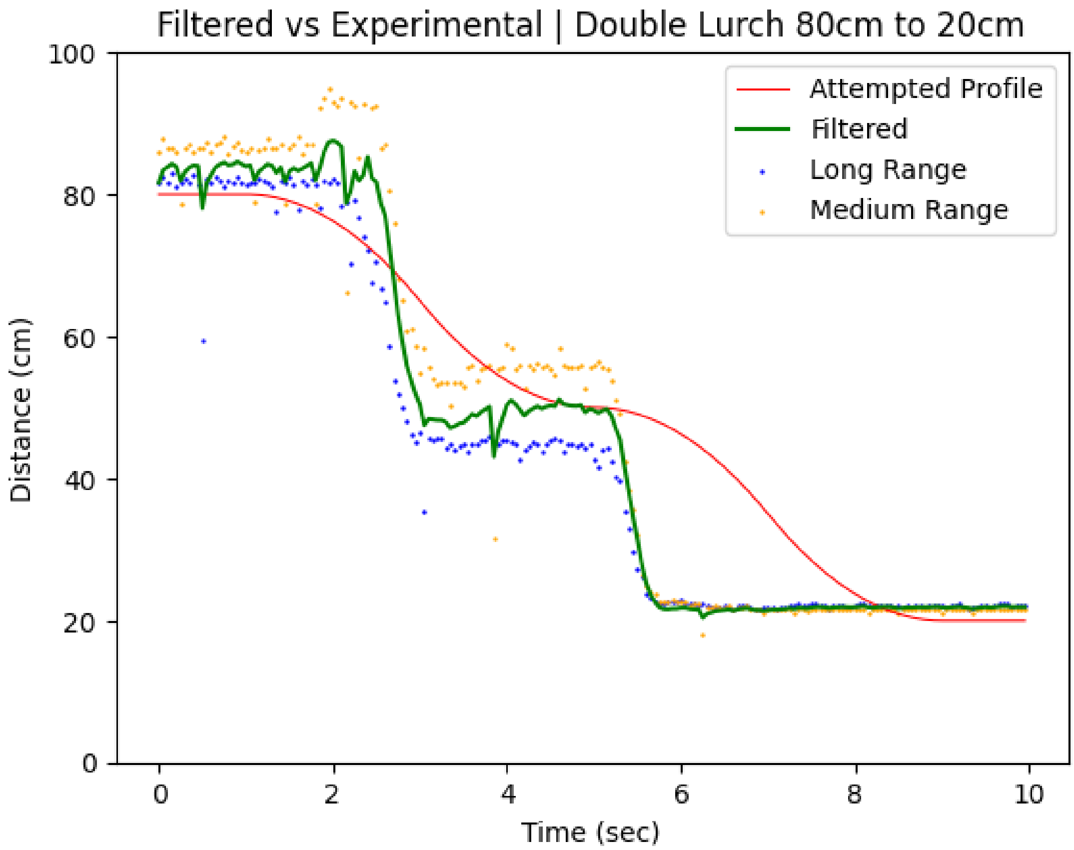

Filtered vs Generated | Double Lurch 80cm to 20cm
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
100
80
60
40
20
0
0
2
4
6
8
10

Filtered vs Generated | Double Lurch 80cm to 20cm | Bad State Estimate
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10


Filtered vs Generated | Double Lurch 80cm to 20cm | Noisy Sensors
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10



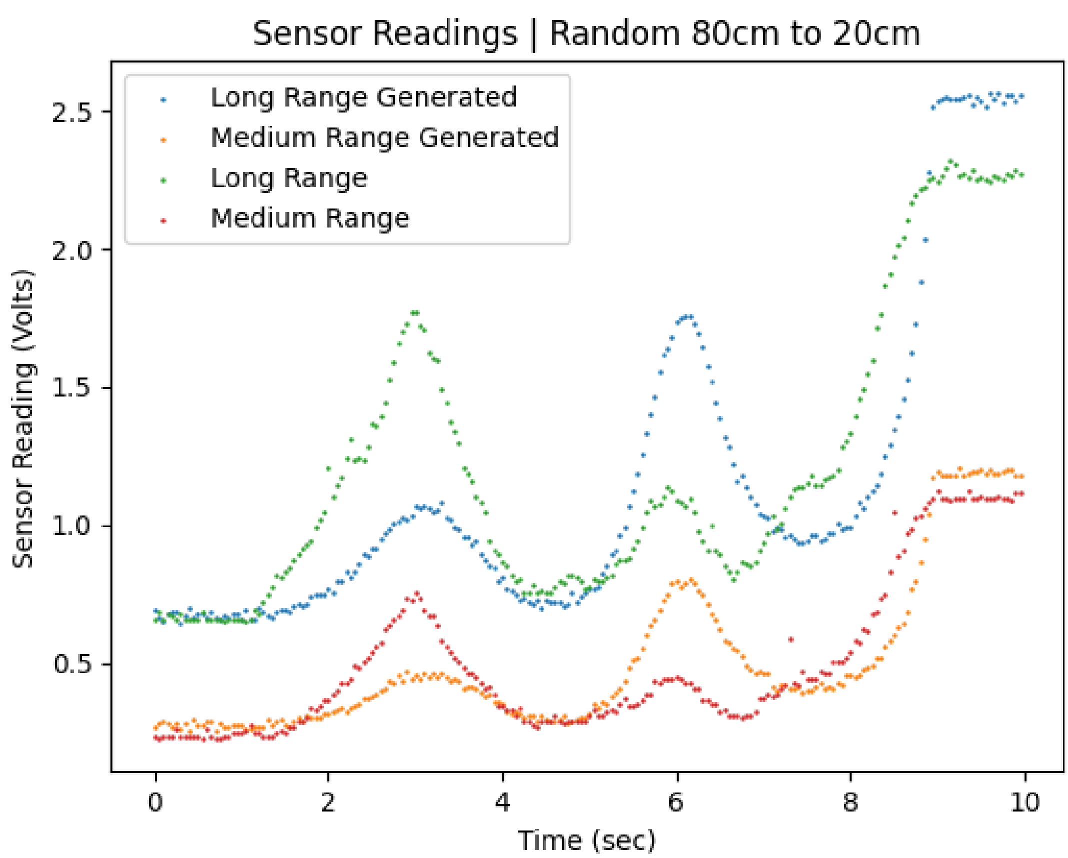
Title	R^2
Default	0.999240
Bad State Est.	0.987675
Noisy Sensors	0.996927
Noisy System	0.999034

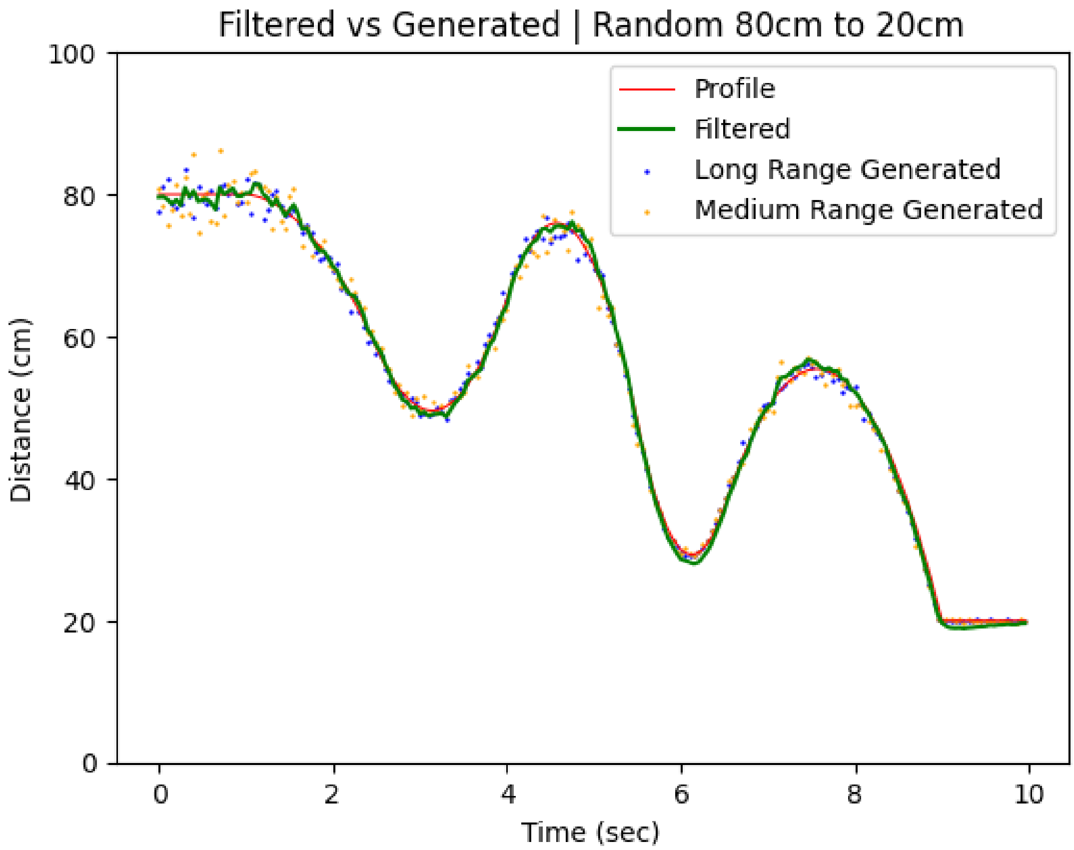


1.3 Part 3 - Random Motion

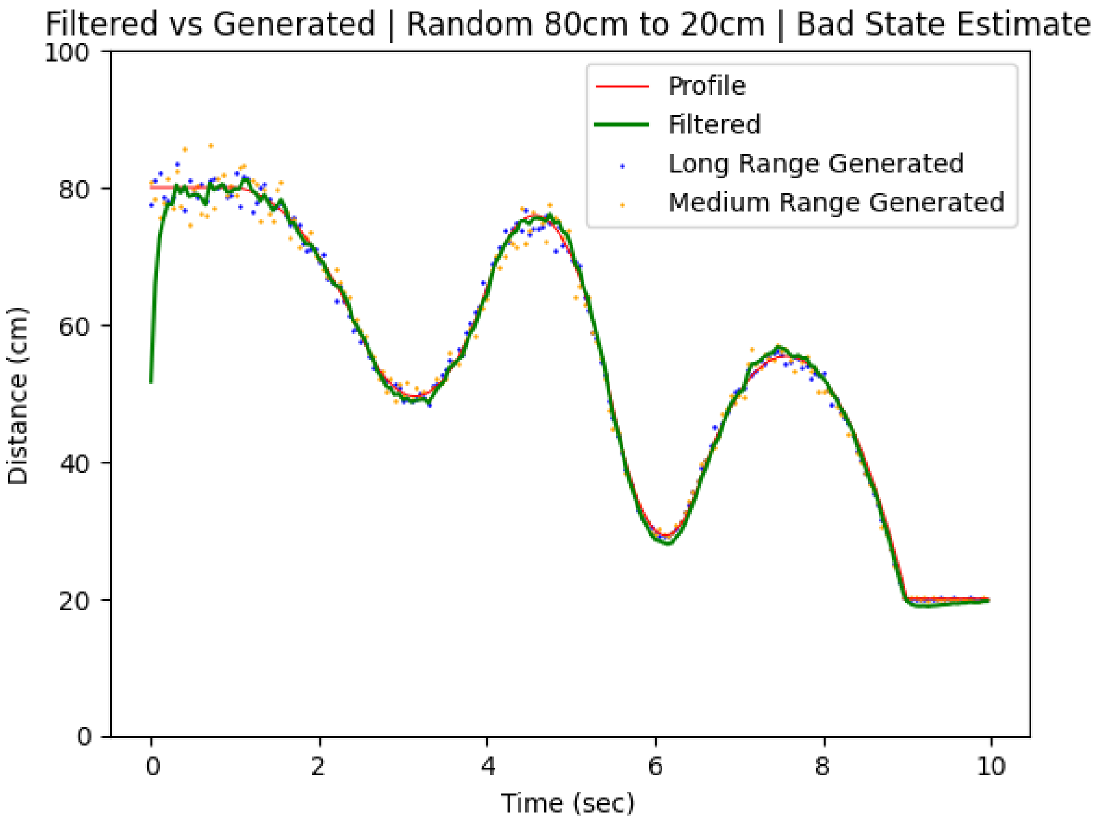
[ ]:
```
# Random Movement profile
def random_spline_curve():
    # Define time points (0 to 8 seconds) and corresponding y values
    t_points = np.array([0, 1, 2, 4, 5, 6, 8])  # Initial time points (start␣
↪and end)
    y_points = np.array([80, 70, 50, 70, 30, 50, 20])  # Corresponding y values

    # Interpolate a smooth spline curve
    spline_curve = interp1d(t_points, y_points, kind='quadratic')

    return spline_curve

def movement_profile(times):
    spline_curve = random_spline_curve()
    values = []
    for t in times:
        if t < 1:
            values.append(80)
```

```
        elif t > 9:
            values.append(20)
        else:
            values.append(spline_curve(t-1))
    return np.array(values)

# Grab Part A data from the dictionary, make relevant copies
p3 = data["Part3"]
random = p3["random"]
calculate_and_gen_graphs(
    title = "Random 80cm to 20cm",
    file="Part3_random",
    data=random,
    profile=movement_profile,
    show_attempted_profile=False
)
```

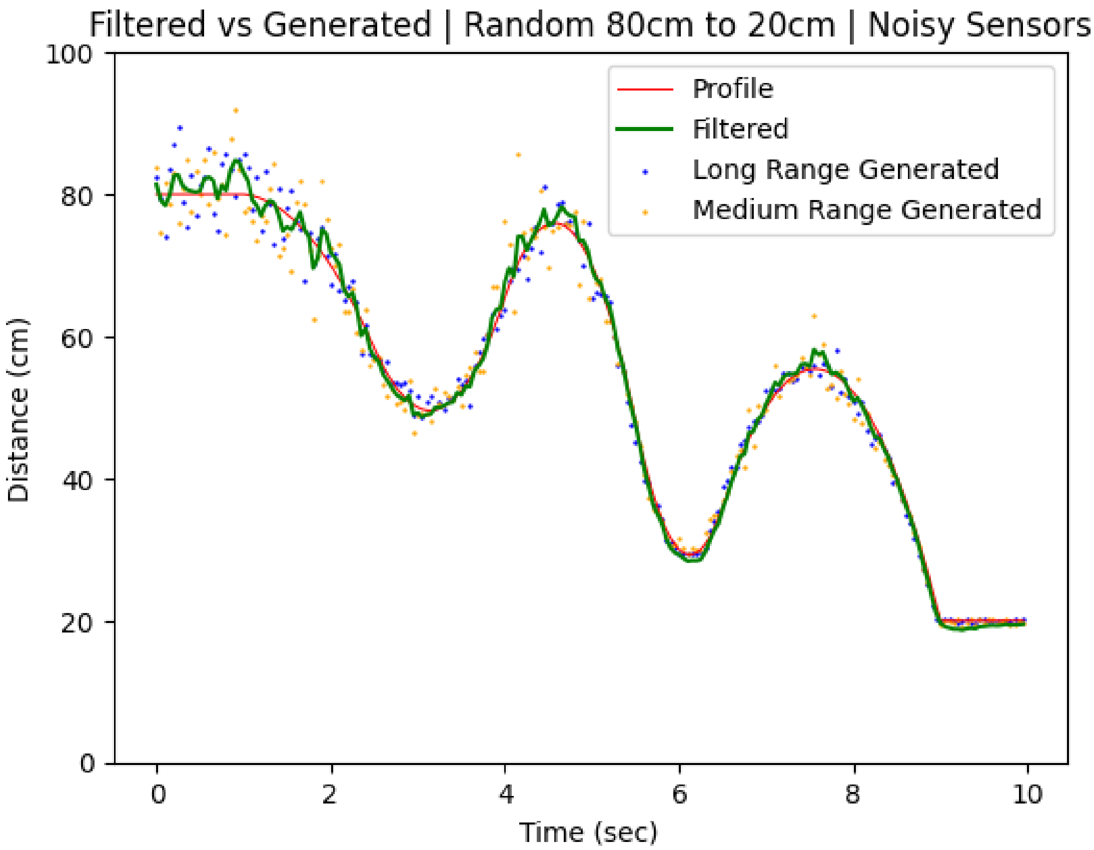


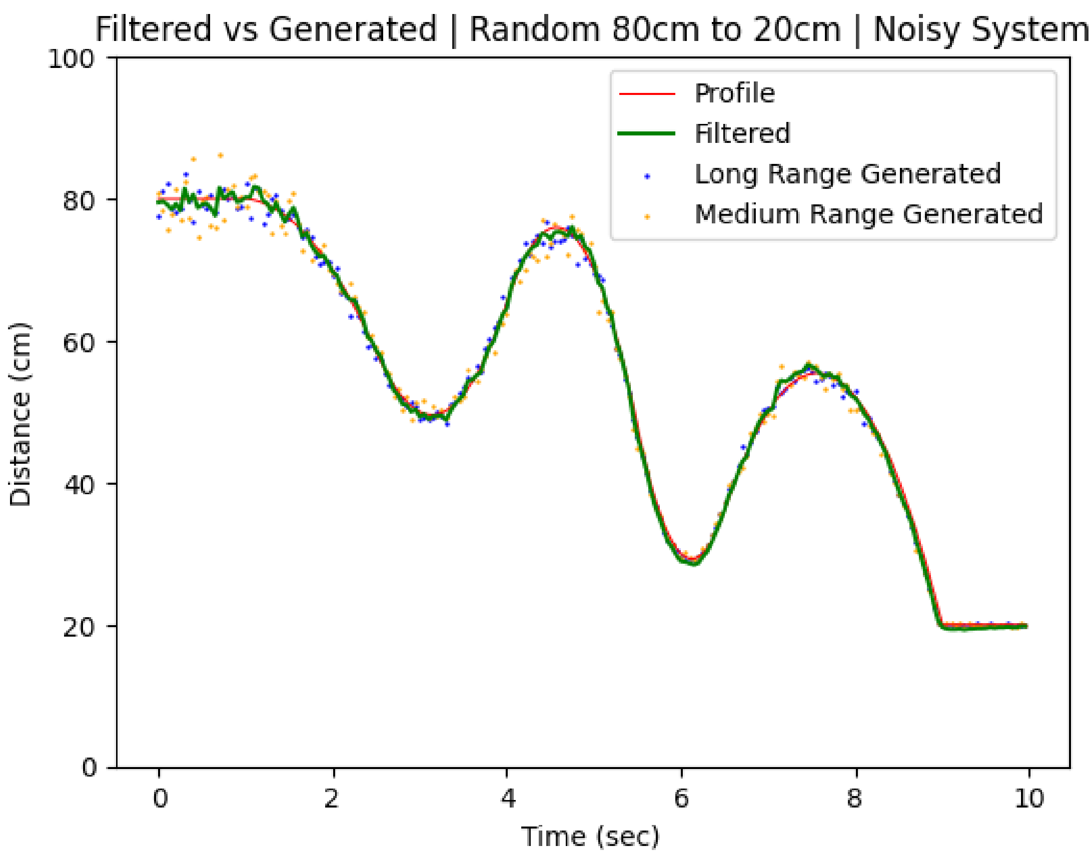


Filtered vs Generated | Random 80cm to 20cm
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10

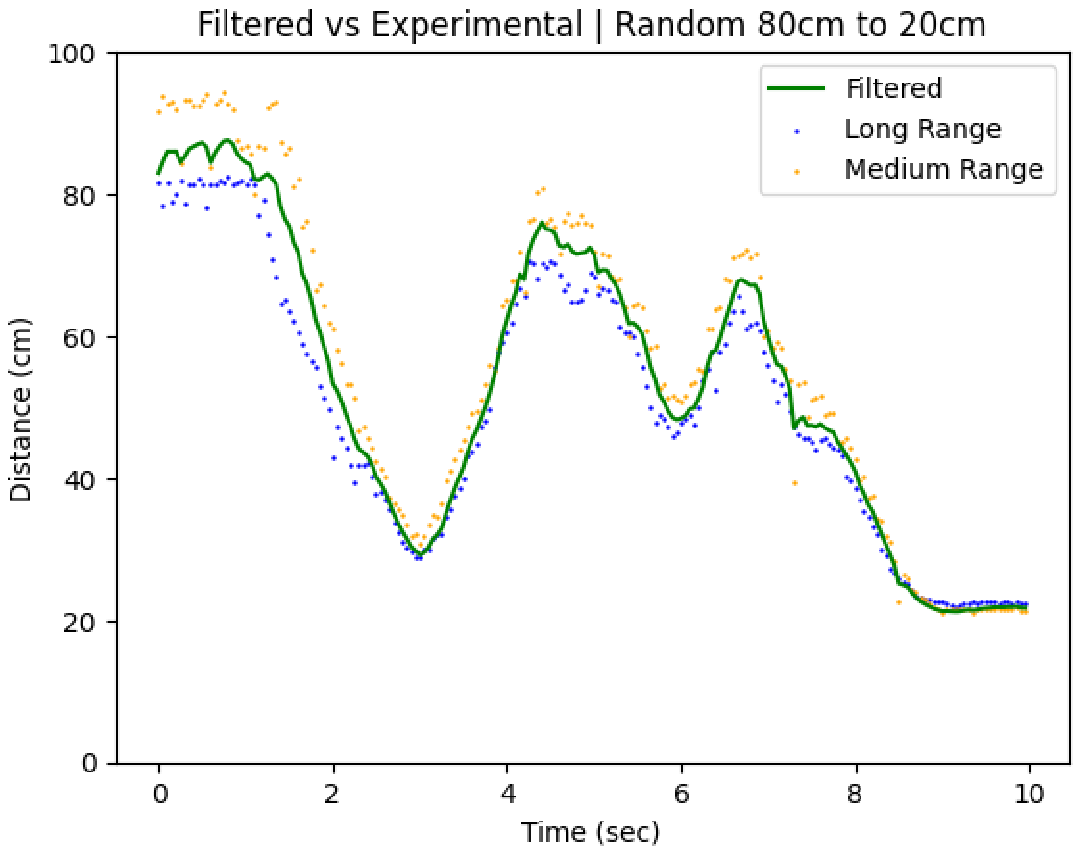


Filtered vs Generated | Random 80cm to 20cm | Bad State Estimate
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10


Filtered vs Generated | Random 80cm to 20cm | Noisy Sensors
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10



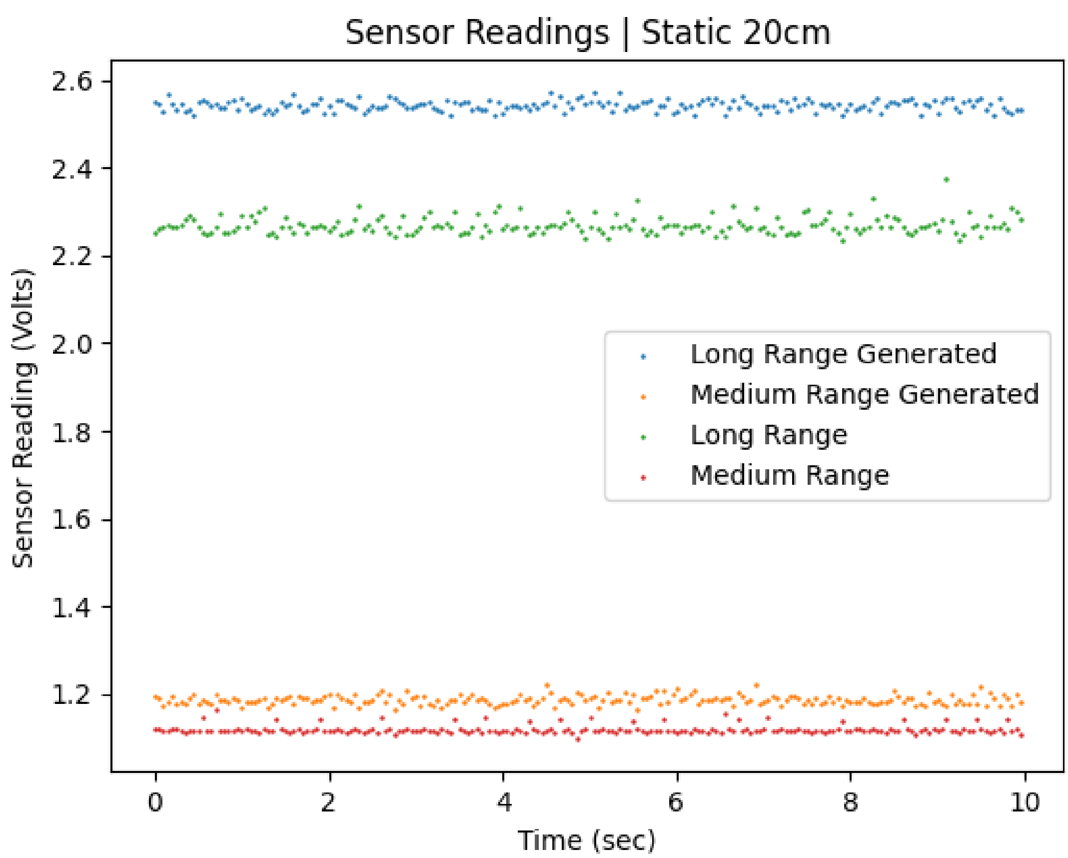
Title	R^2
Default	0.998201
Bad State Est.	0.983306
Noisy Sensors	0.994943
Noisy System	0.998177

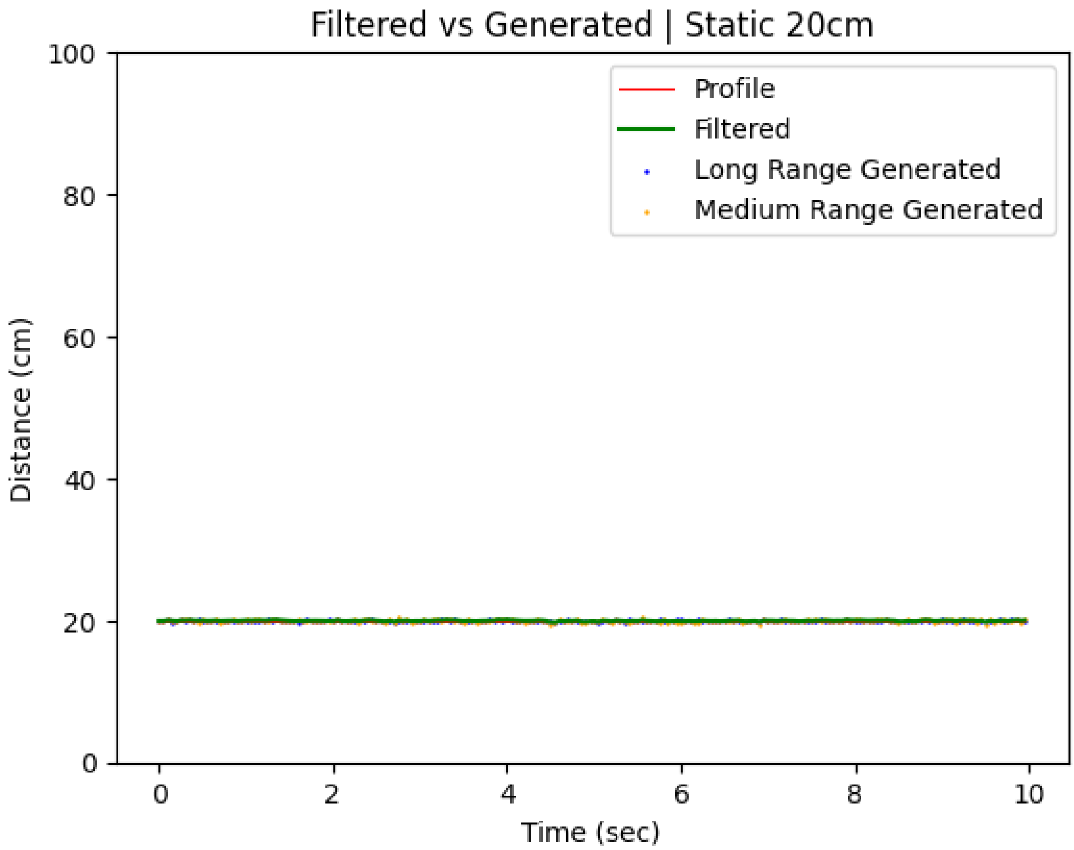


1.4 Part 4 - Stationary

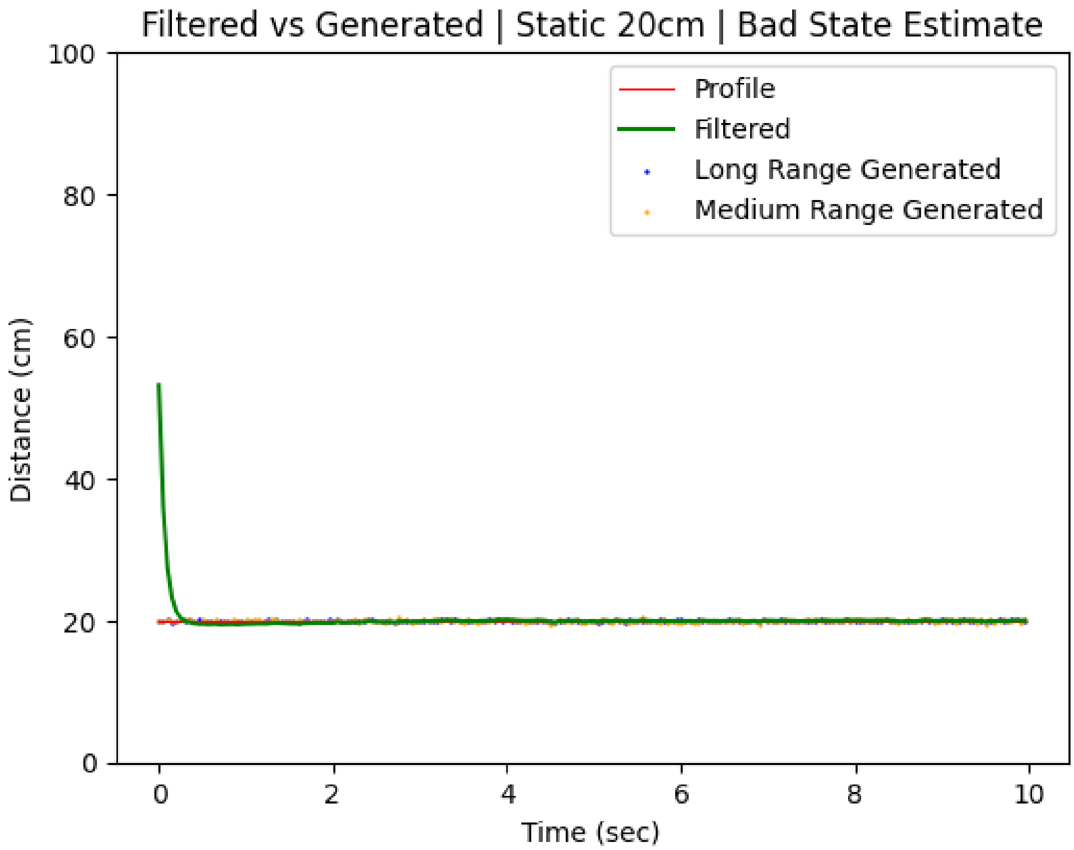
[ ]:
```
# Grab Part A data from the dictionary, make relevant copies
p4 = data["Part4"]
static_20 = p4["20cm_stationary"]
calculate_and_gen_graphs(
    title = "Static 20cm",
    file="Part4_static_20",
    data=static_20,
    profile=lambda times: np.array([20]*len(times)),
    states=[20, 80],
    show_attempted_profile=True
)
static_50 = p4["50cm_stationary"]
calculate_and_gen_graphs(
    title = "Static 50cm",
    file="Part4_static_50",
    data=static_50,
    profile=lambda times: np.array([50]*len(times)),
```

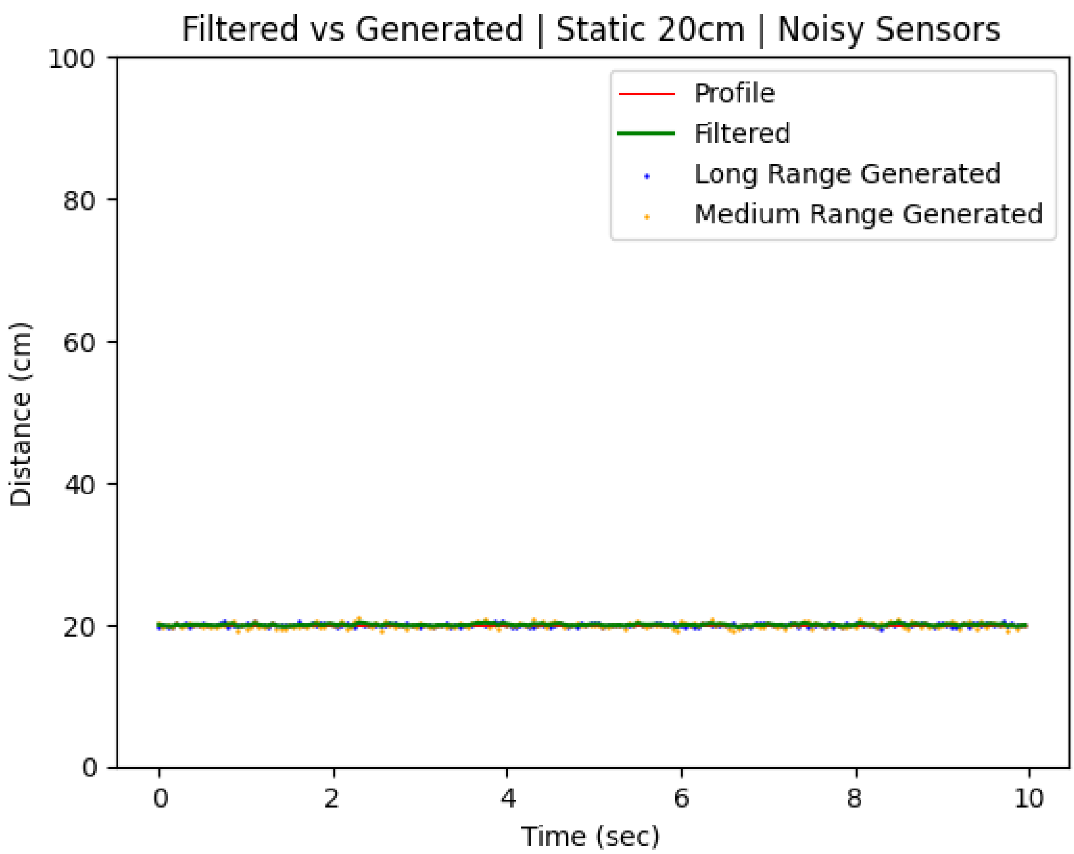
```
    states=[50, 80],
    show_attempted_profile=True
)
static_80 = p4["80cm_stationary"]
calculate_and_gen_graphs(
    title = "Static 80cm",
    file="Part4_static_80",
    data=static_80,
    profile=lambda times: np.array([80]*len(times)),
    states=[80,30],
    show_attempted_profile=True
)
```

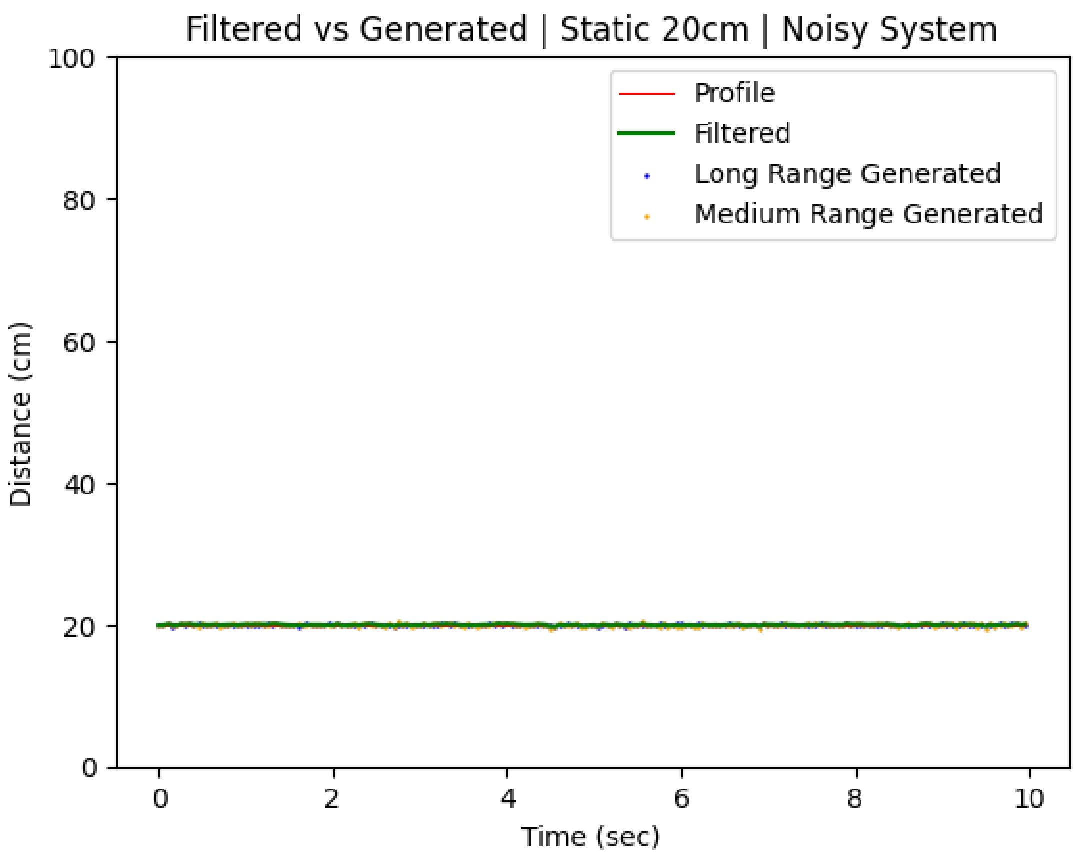




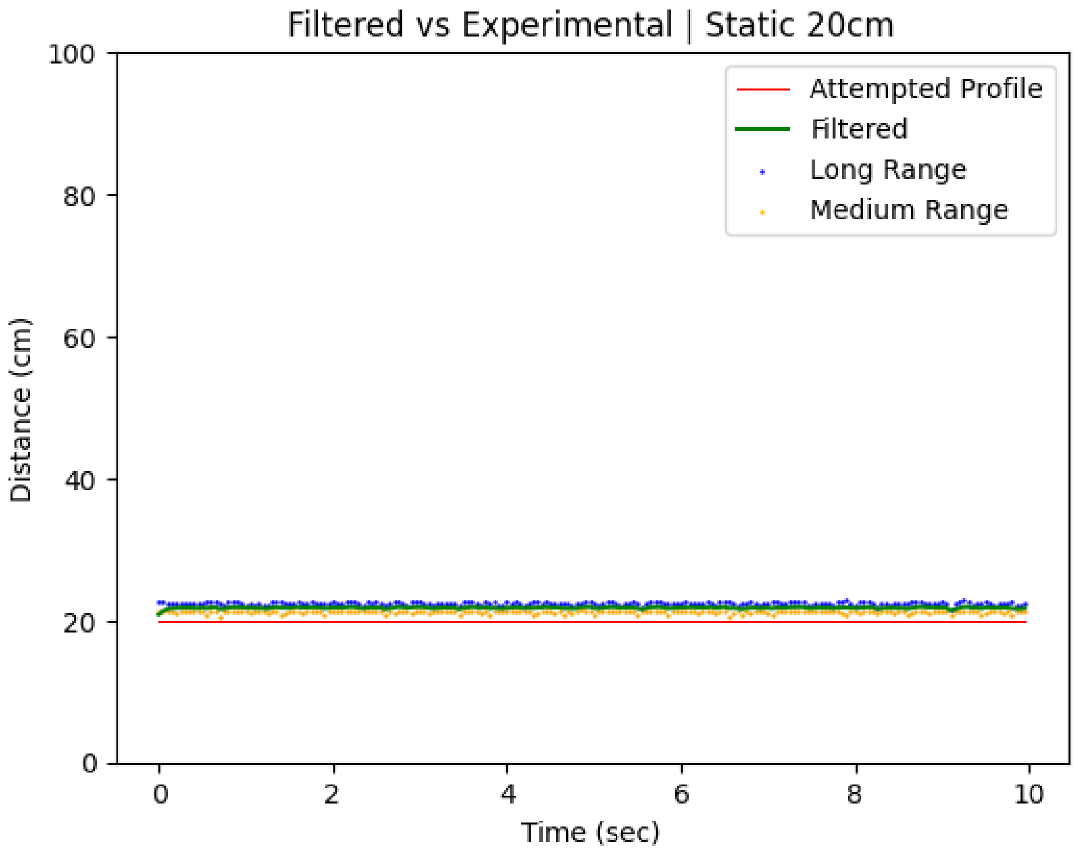
Filtered vs Generated | Static 20cm
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
100
80
60
40
20
0
0
2
4
6
8
10


Filtered vs Generated | Static 20cm | Bad State Estimate
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10

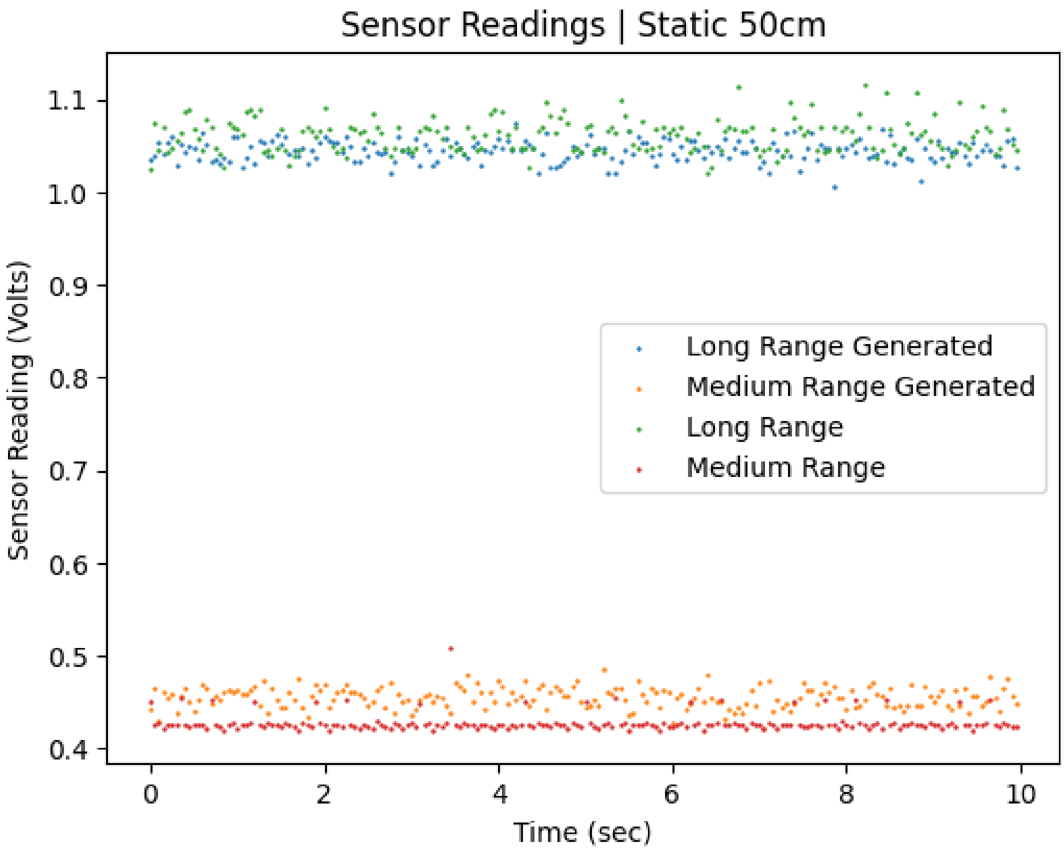

Filtered vs Generated | Static 20cm | Noisy Sensors
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10

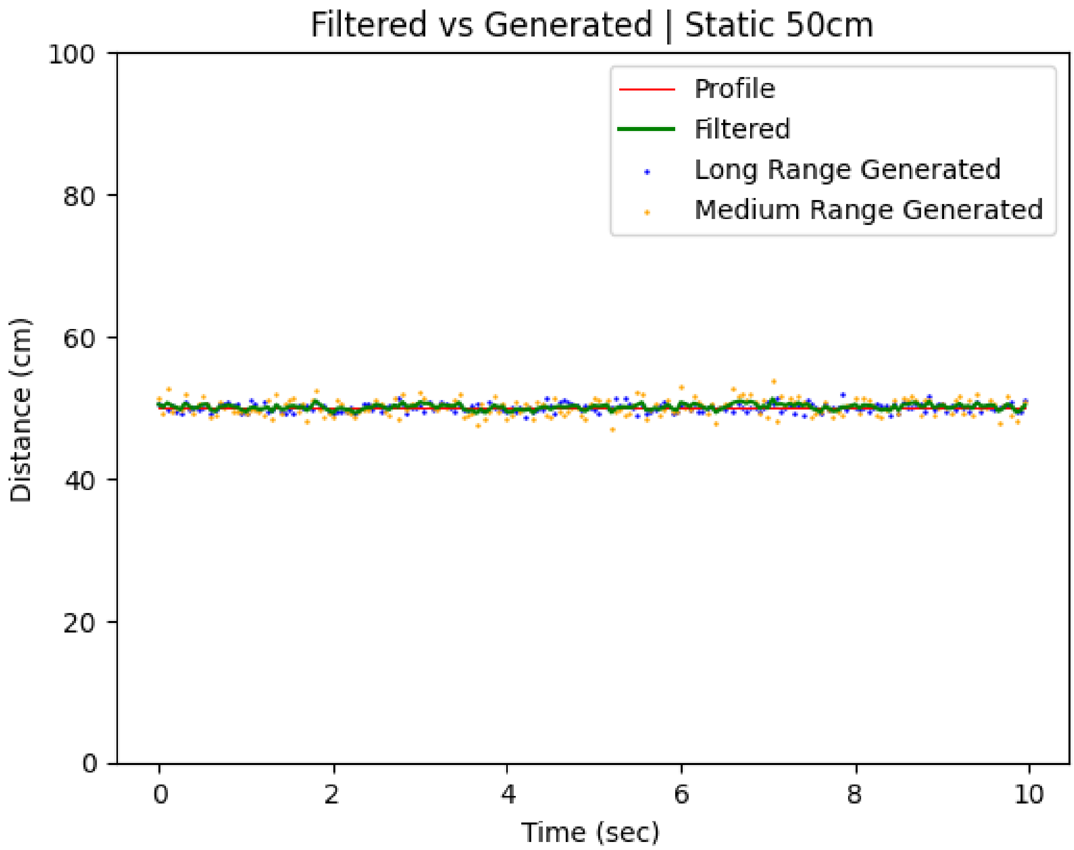


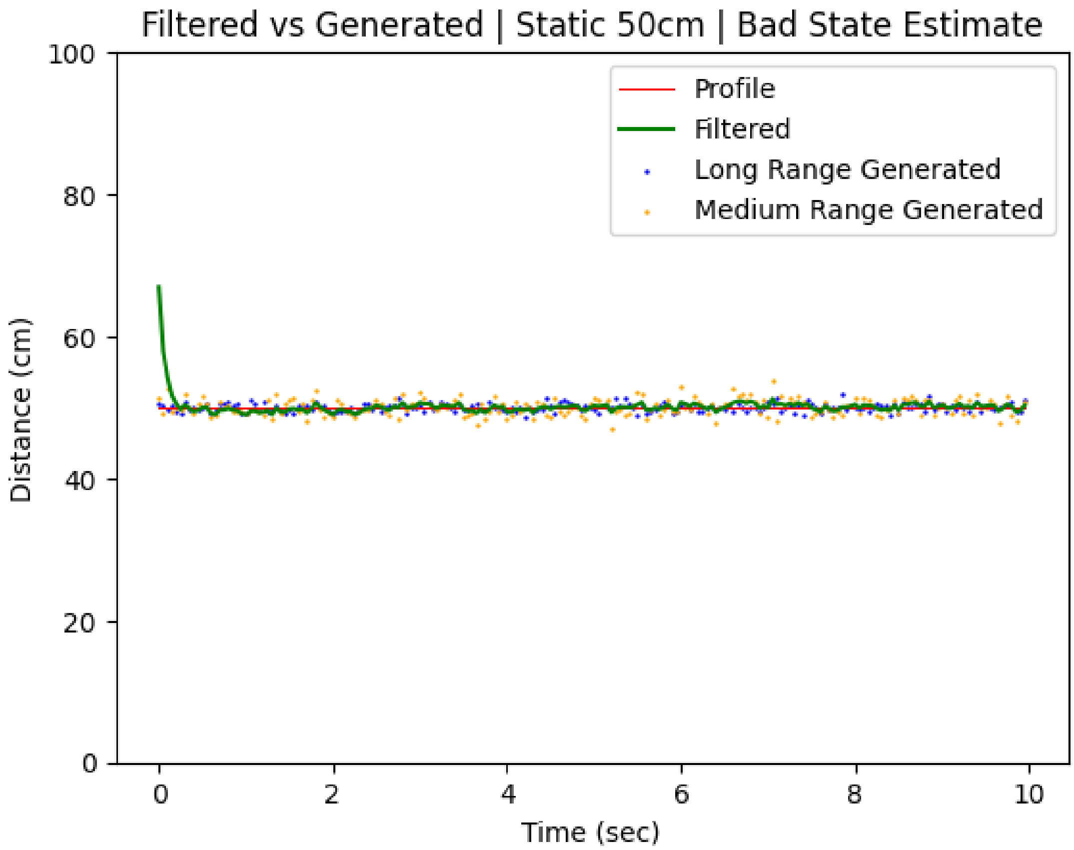
Title	R^2
Default	0.0
Bad State Est.	0.0
Noisy Sensors	0.0
Noisy System	0.0



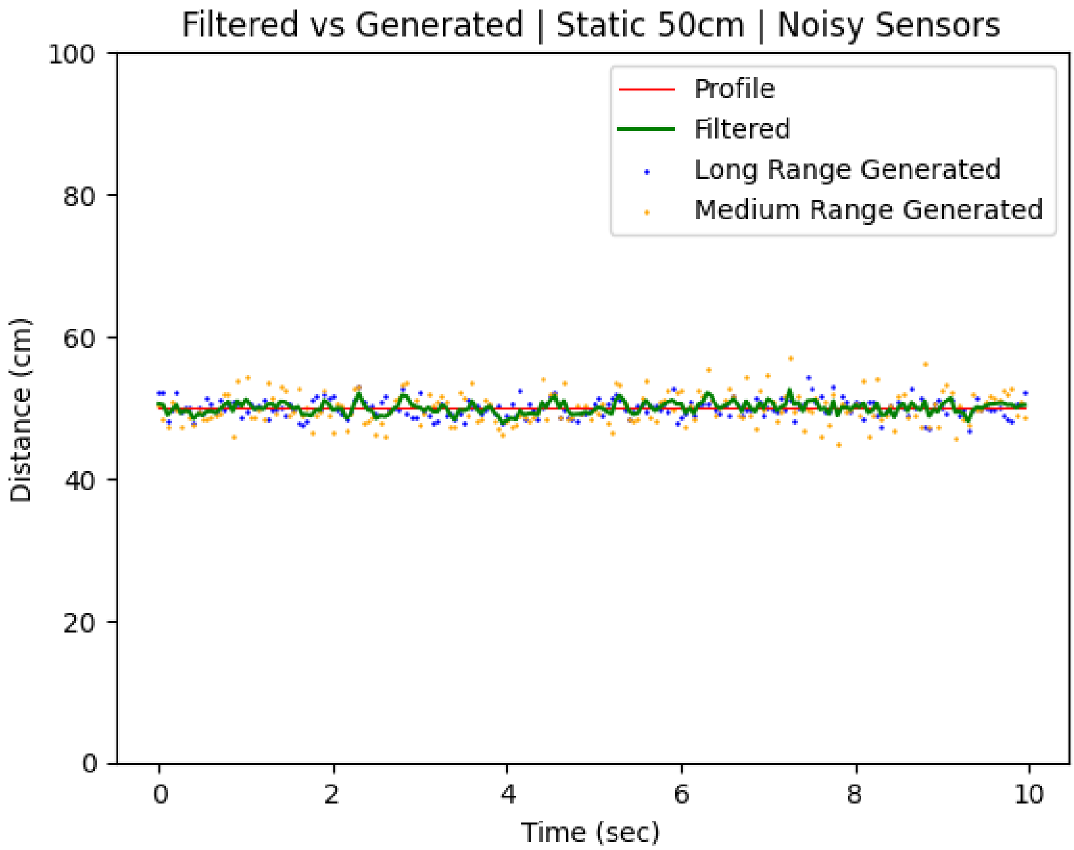
Filtered vs Experimental | Static 20cm
Attempted Profile
Filtered
Long Range
Medium Range
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10

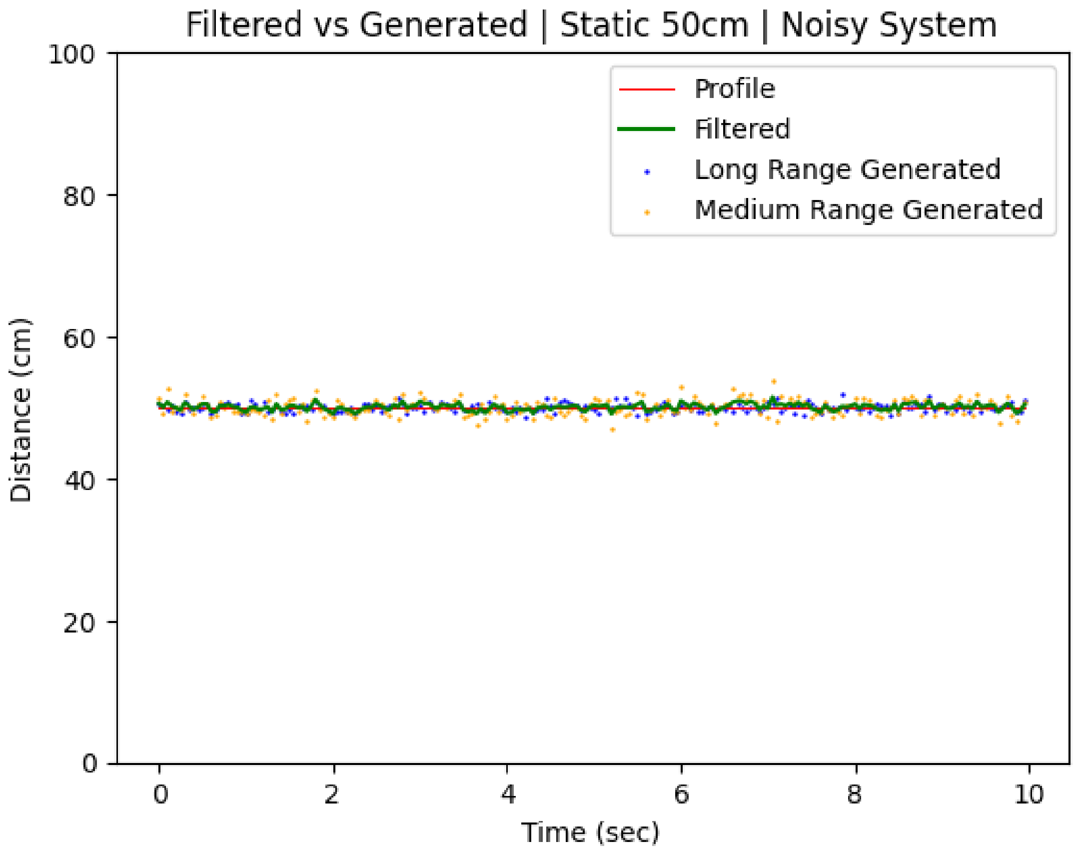

Sensor Readings | Static 50cm
Sensor Reading (Volts)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0
2
4
6
8
10
Time (sec)
Long Range Generated
Medium Range Generated
Long Range
Medium Range


Filtered vs Generated | Static 50cm
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10

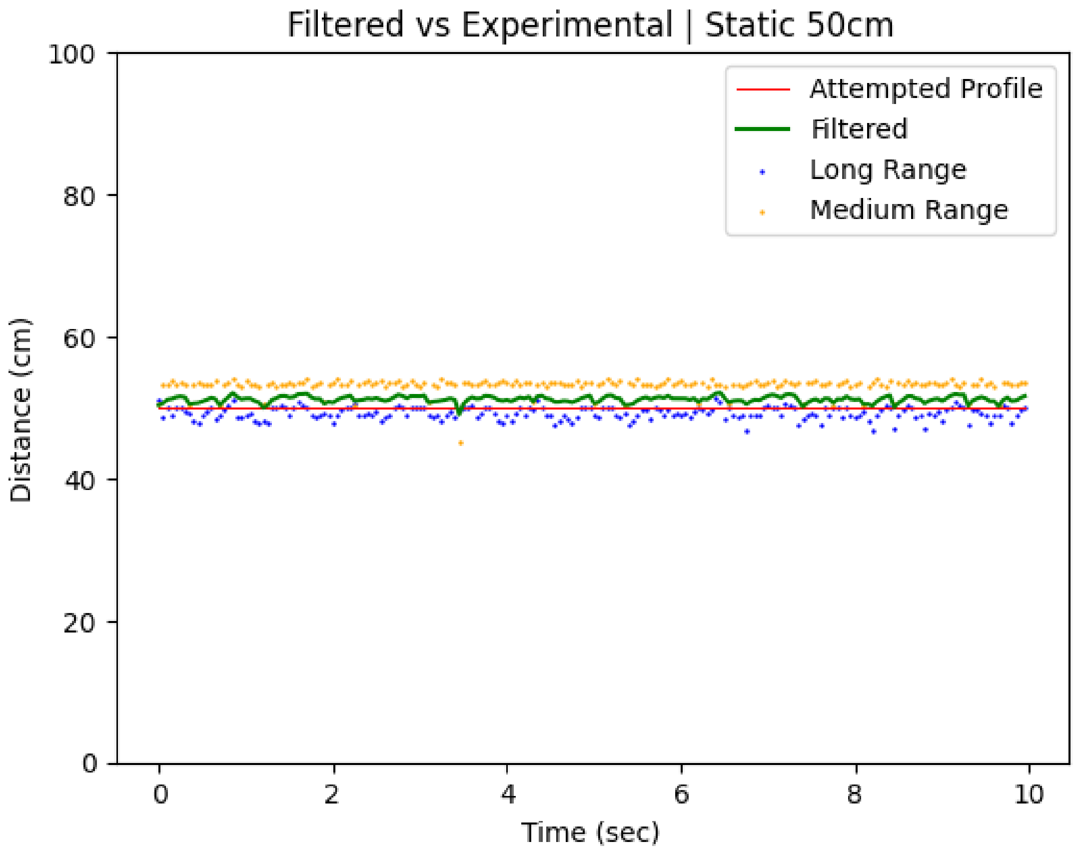


Filtered vs Generated | Static 50cm | Bad State Estimate
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
100
80
60
40
20
0
0
2
4
6
8
10

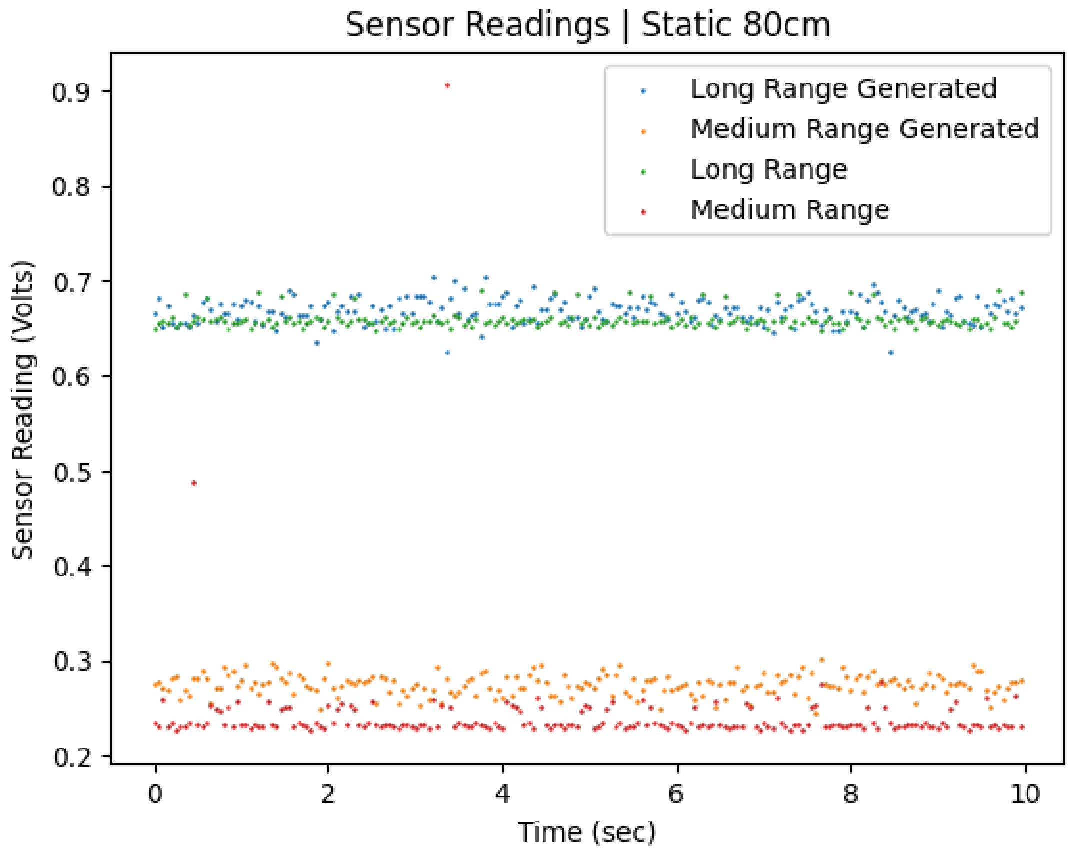

Filtered vs Generated | Static 50cm | Noisy Sensors
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10

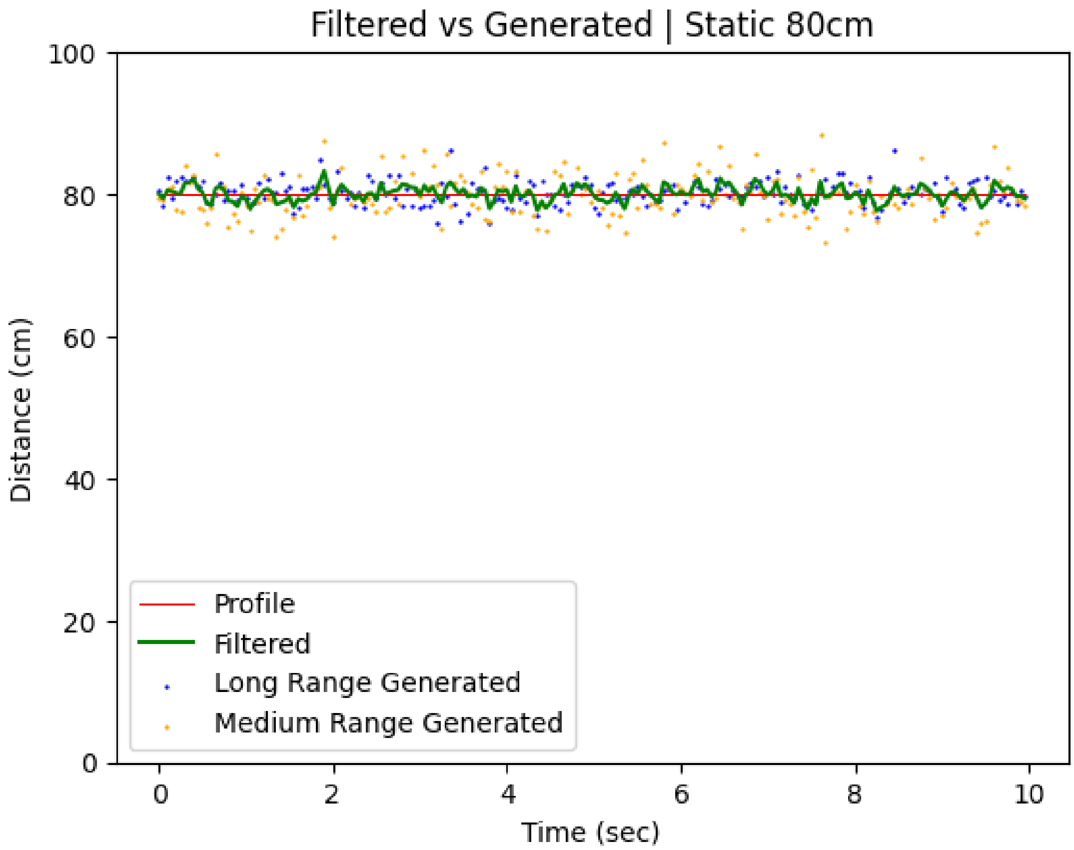


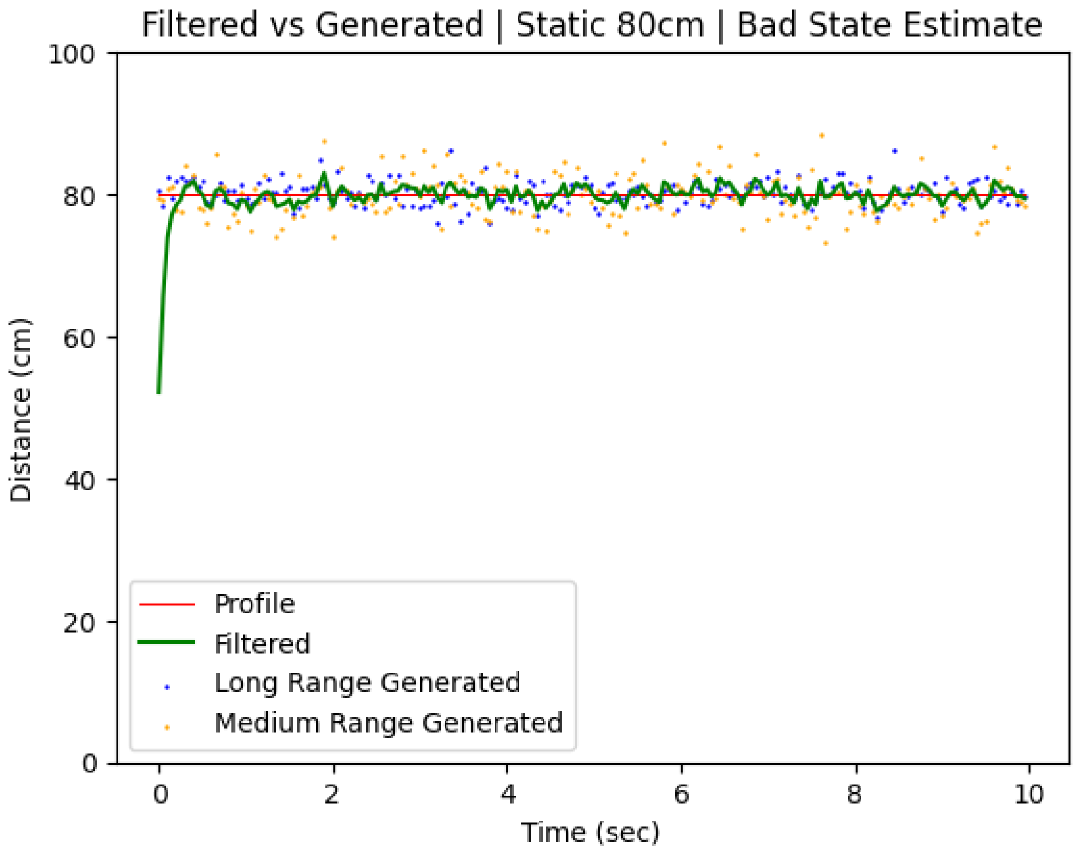
Title	R^2
Default	0.0
Bad State Est.	0.0
Noisy Sensors	0.0
Noisy System	0.0



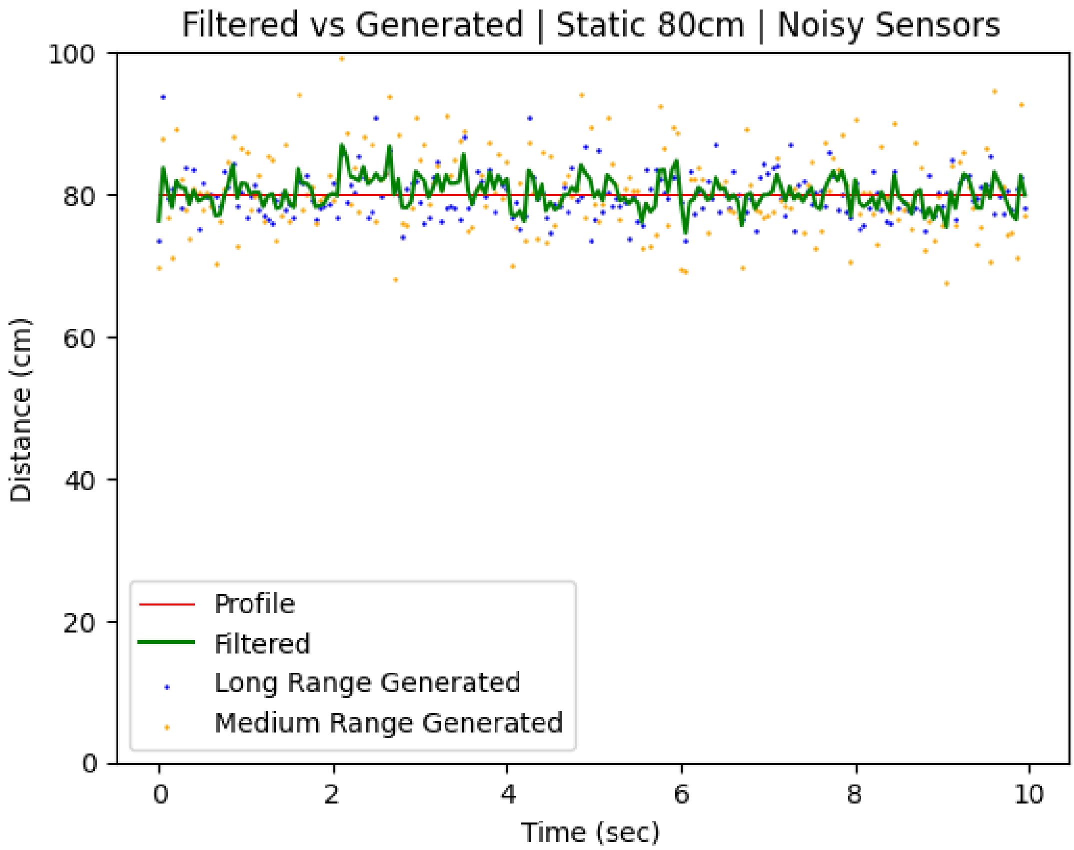
Filtered vs Experimental | Static 50cm
Attempted Profile
Filtered
Long Range
Medium Range
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10


Sensor Readings | Static 80cm
Long Range Generated
Medium Range Generated
Long Range
Medium Range
Sensor Reading (Volts)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
2
4
6
8
10
Time (sec)

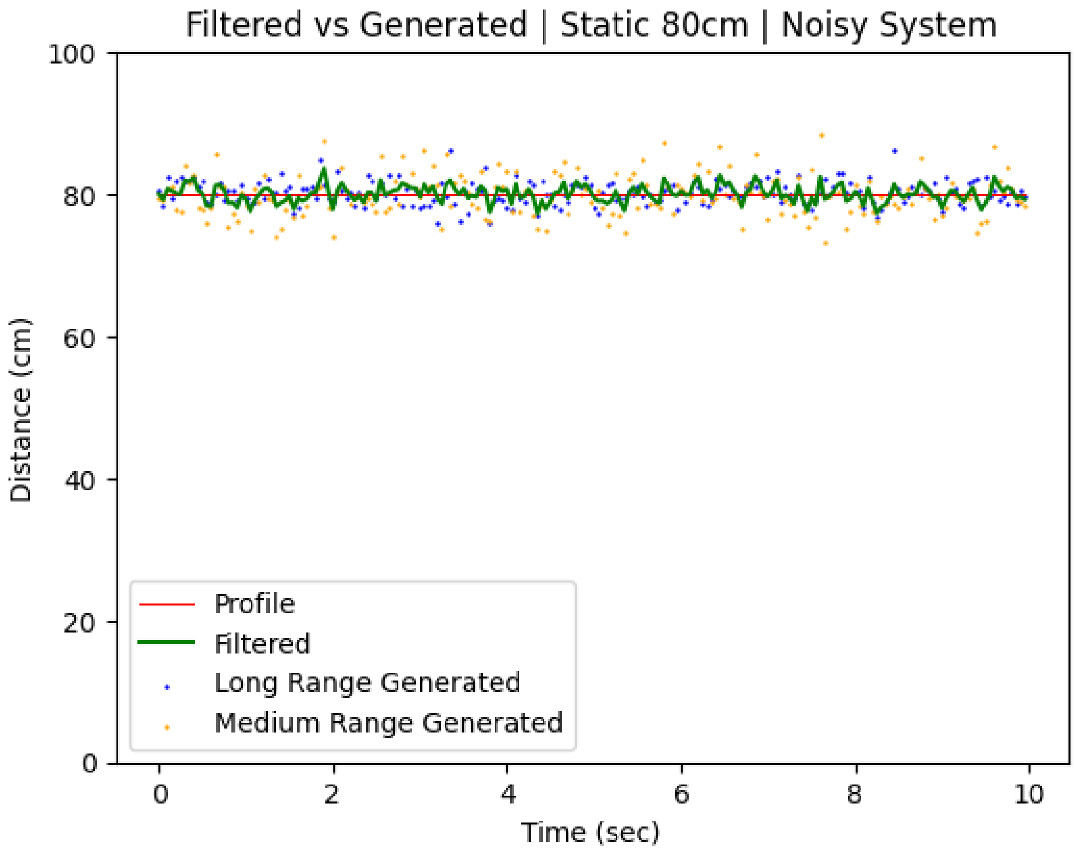

Filtered vs Generated | Static 80cm
100
80
60
40
20
0
Distance (cm)
0
2
4
6
8
10
Time (sec)
Profile
Filtered
Long Range Generated
Medium Range Generated



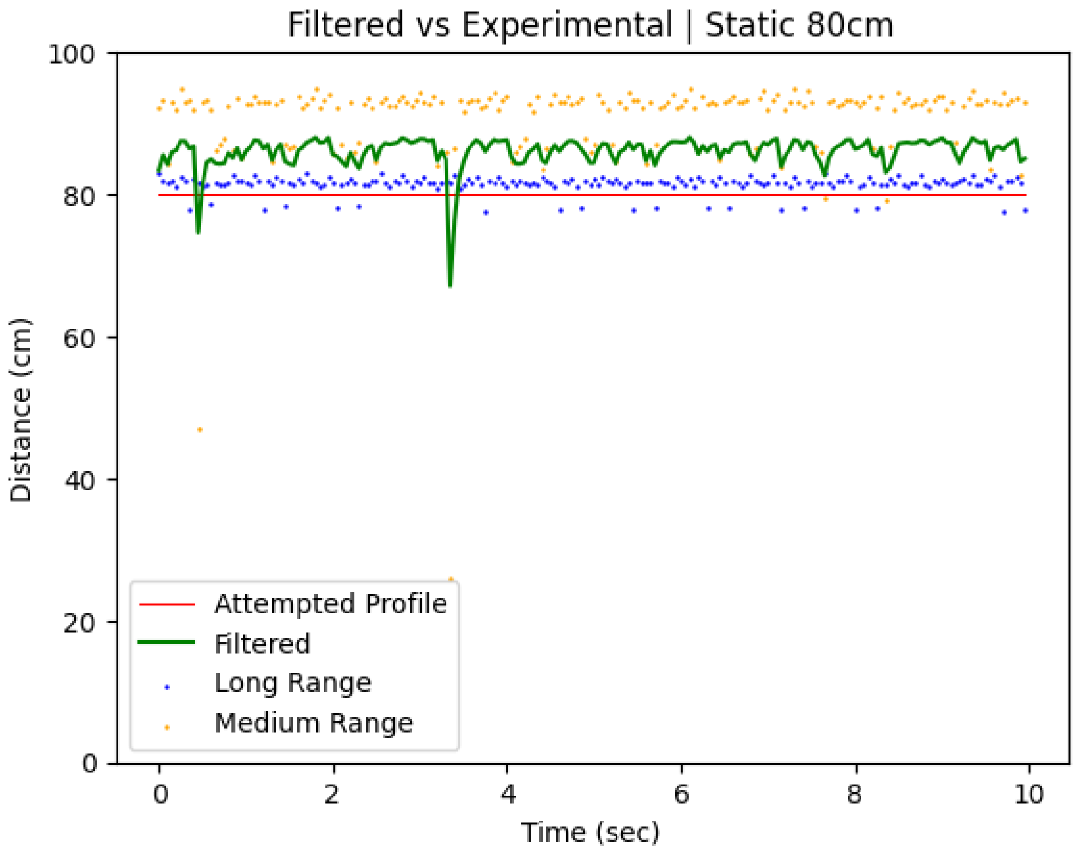
Filtered vs Generated | Static 80cm | Bad State Estimate
Distance (cm)
Time (sec)
Profile
Filtered
Long Range Generated
Medium Range Generated
0
20
40
60
80
100
0
2
4
6
8
10



Filtered vs Generated | Static 80cm | Noisy Sensors
Distance (cm)
Time (sec)
100
80
60
40
20
0
0
2
4
6
8
10
Profile
Filtered
Long Range Generated
Medium Range Generated



Title	R^2
Default	0.0
Bad State Est.	0.0
Noisy Sensors	0.0
Noisy System	0.0

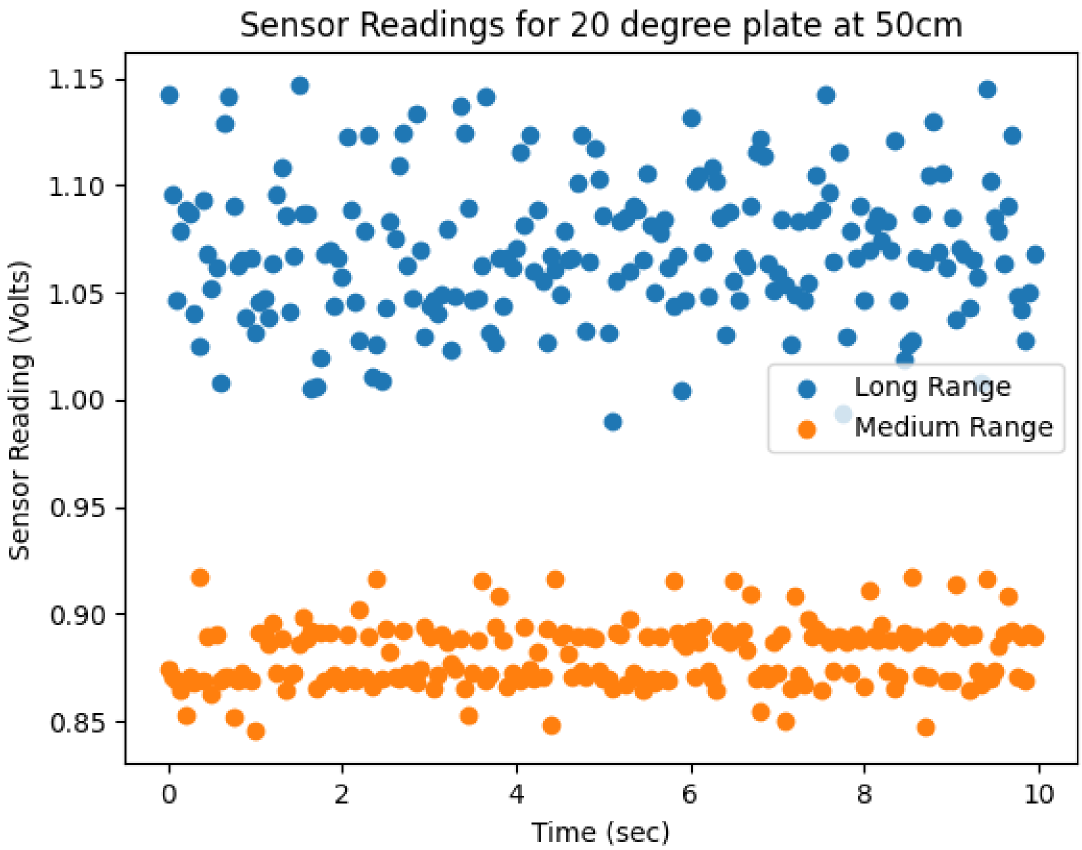


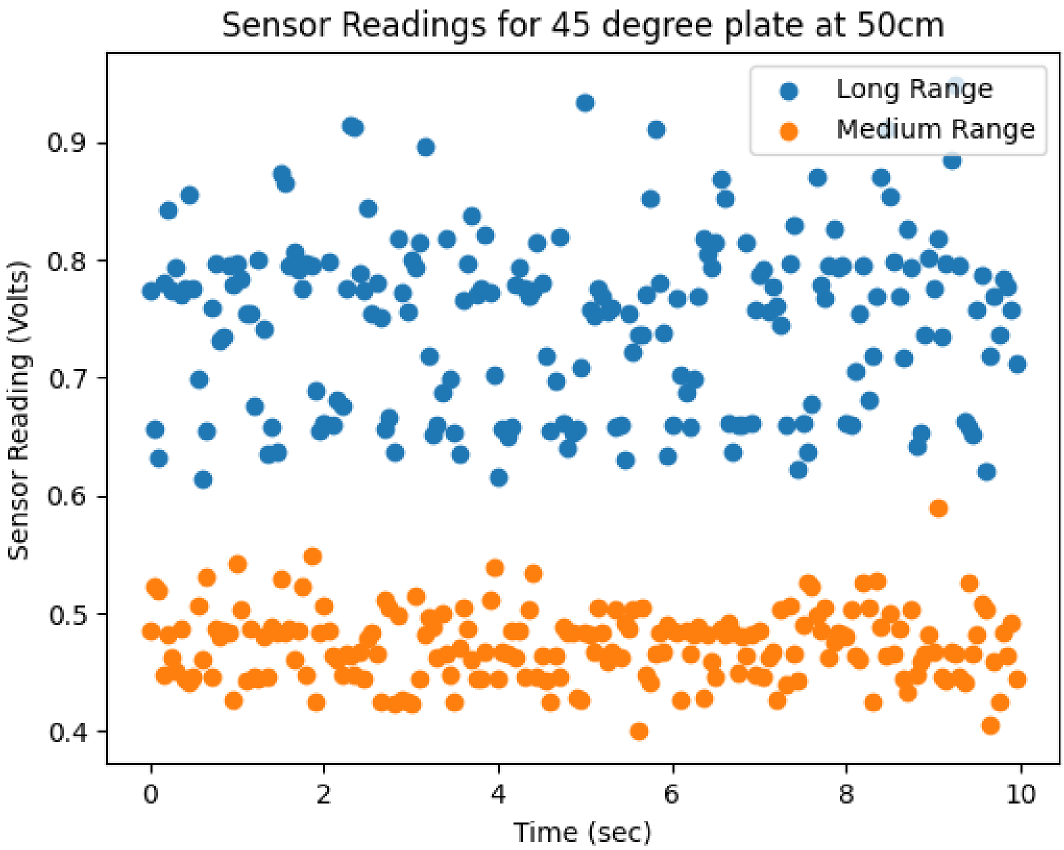
1.5 Part 5 - Poor Sensing Conditions

1.5.1 stationary

[ ]:
```
# Grab Part A data from the dictionary, make relevant copies
p5 = data["Part5"]
variances = []

# Graph the sensor readings for 20 degree plate at 50cm␣
↪(50cm_stationary_20deg_CCW_metal_plate)
plate_20deg_50cm = p5["50cm_stationary_20deg_CCW_metal_plate"]
time = plate_20deg_50cm["time"]
distances = plate_20deg_50cm["data"]
variances.append({
    "Case": "20 deg Plate",
    "Long Var.": statistics.variance(distances[0]),
    "Long Std. Dev.": statistics.stdev(distances[0]),
    "Medium Var.": statistics.variance(distances[1]),
    "Medium Std. Dev.": statistics.stdev(distances[1]),
})
```

```python
plt.figure()
for sensor in range(len(distances)):
    plt.scatter(time, distances[sensor], label=f"{Sensors[sensor]['name']}")
plt.title("Sensor Readings for 20 degree plate at 50cm")
plt.legend()
plt.xlabel("Time (sec)")
plt.ylabel("Sensor Reading (Volts)")
plt.savefig(f"out/plots/Part5_20deg_50cm.png")
plt.show()

# Graph sensor reading for 45 degree plate at 50cm␣
 ↪(50cm_stationary_45deg_CCW_metal_plate)
plate_45deg_50cm = p5["50cm_stationary_45deg_CCW_metal_plate"]
time = plate_45deg_50cm["time"]
distances = plate_45deg_50cm["data"]
variances.append({
    "Case": "45 deg Plate",
    "Long Var.": statistics.variance(distances[0]),
    "Long Std. Dev.": statistics.stdev(distances[0]),
    "Medium Var.": statistics.variance(distances[1]),
    "Medium Std. Dev.": statistics.stdev(distances[1]),
})

plt.figure()
for sensor in range(len(distances)):
    plt.scatter(time, distances[sensor], label=f"{Sensors[sensor]['name']}")
plt.title("Sensor Readings for 45 degree plate at 50cm")
plt.legend()
plt.xlabel("Time (sec)")
plt.ylabel("Sensor Reading (Volts)")
plt.savefig(f"out/plots/Part5_45deg_50cm.png")
plt.show()

# Display the variances
var_df = pd.DataFrame(variances)
print(var_df.to_string(index=False))
```


Sensor Readings for 20 degree plate at 50cm
Sensor Reading (Volts)
1.15
1.10
1.05
1.00
0.95
0.90
0.85
Time (sec)
0
2
4
6
8
10
Long Range
Medium Range



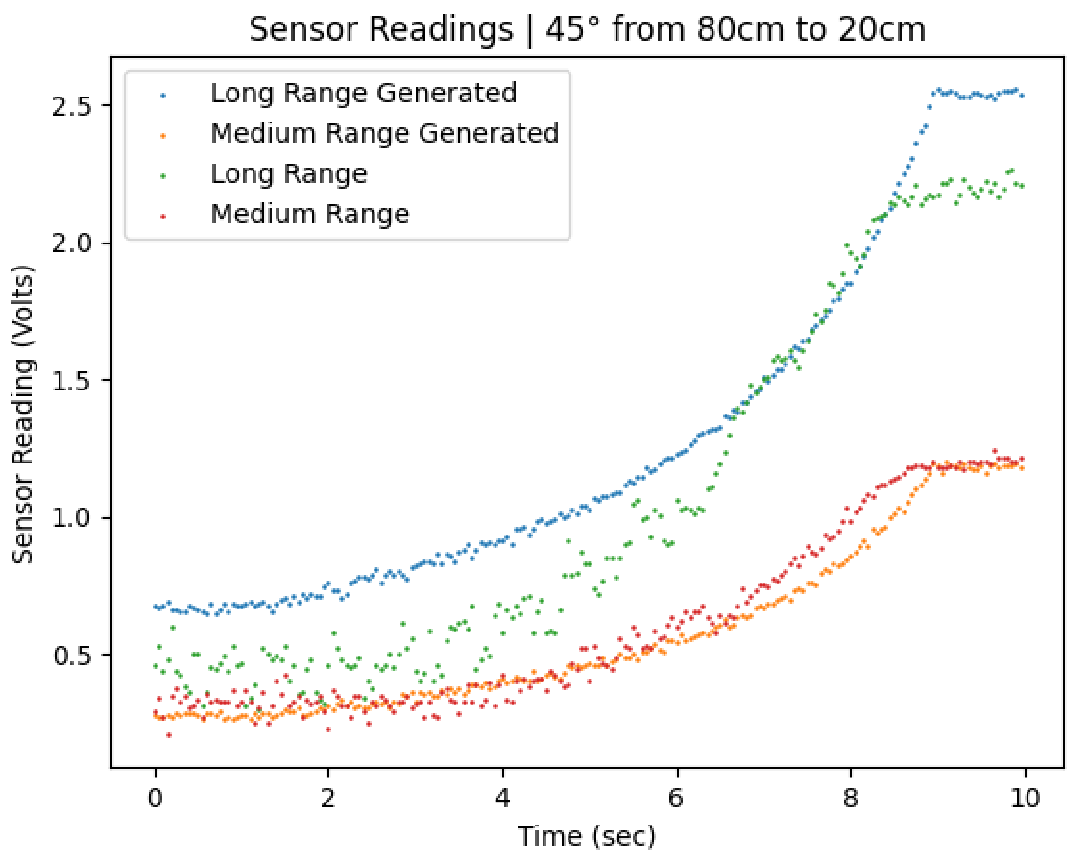
Case	Long Var.	Long Std. Dev.	Medium Var.	Medium Std. Dev.
20 deg Plate	0.001083	0.032907	0.000216	0.014694
45 deg Plate	0.005398	0.073473	0.000879	0.029653

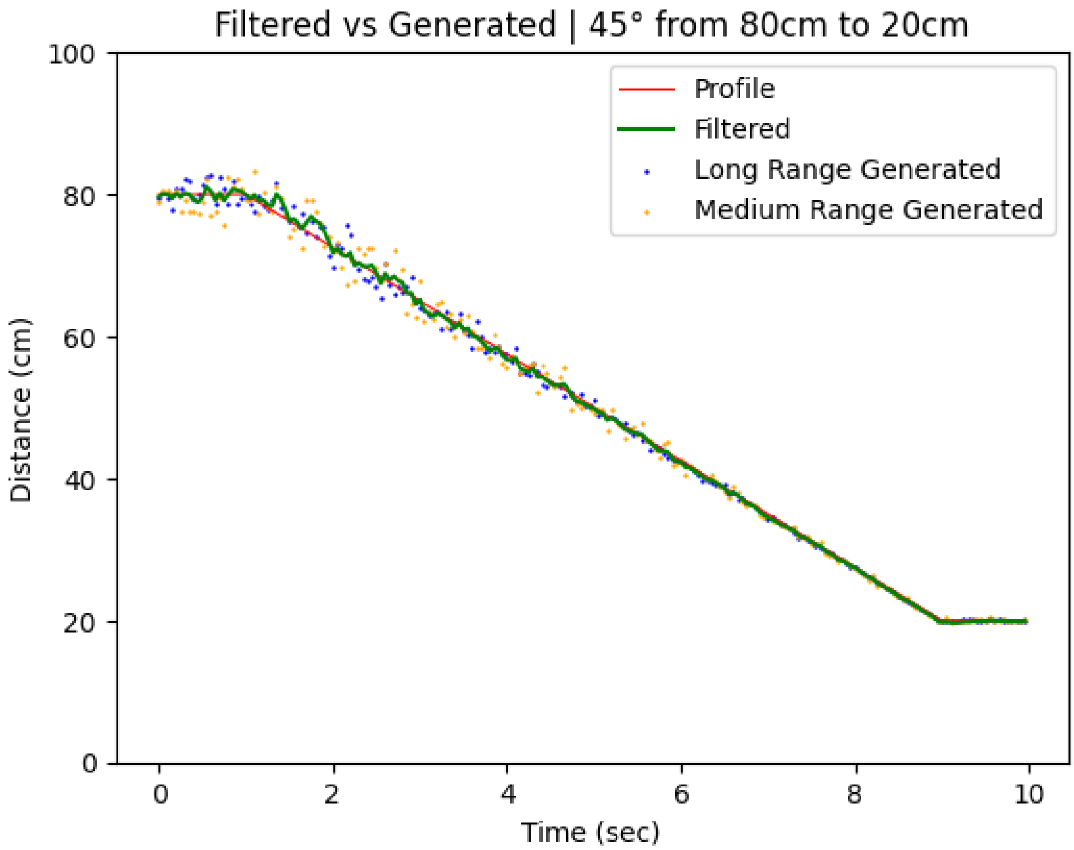
1.5.2 movement

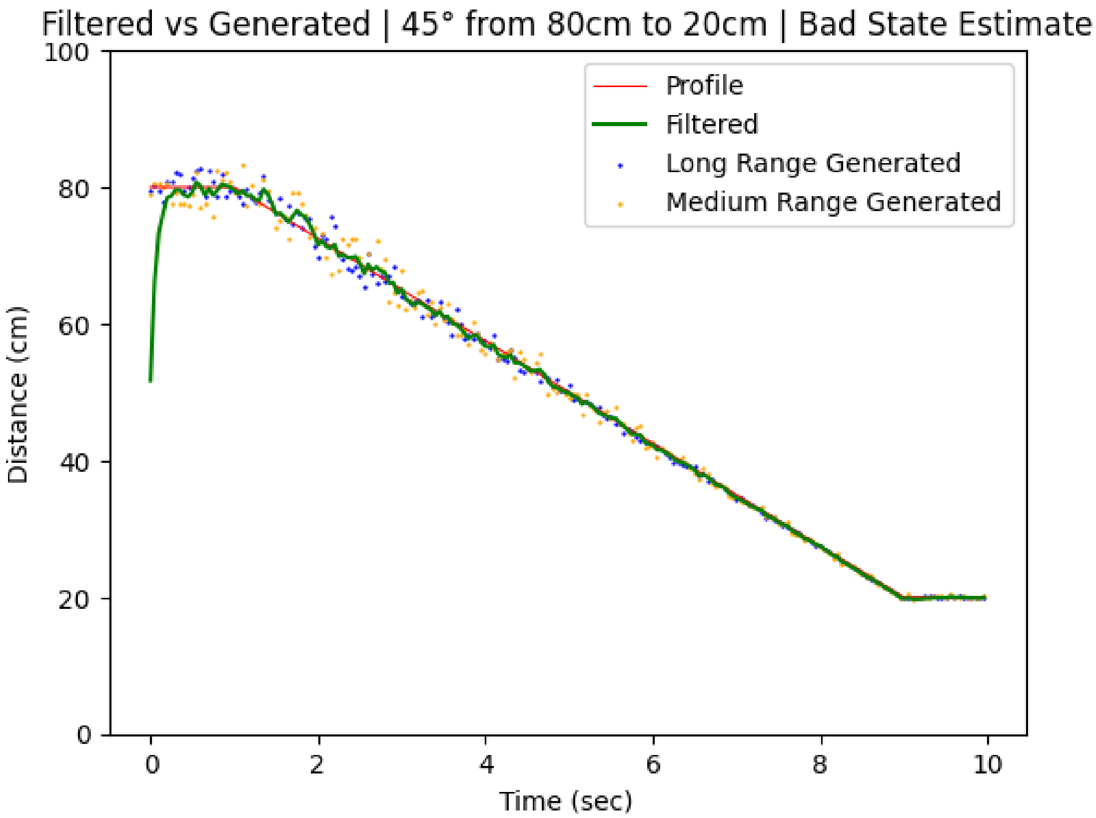
[ ]:

```
# Still for 1 second, move at a constant speed for 8 seconds, pause for 1 second
def movement_profile (t):
    data = []
    for i in t:
        if i < 1:
            data.append(80)
        elif i > 9:
            data.append(20)
        else:
            data.append(80 - 60 / 8 * (i - 1))
    return np.array(data)

# Graph sensor reading for 45 degree plate moving from 80cm to 20cm␣
↪(80cm_to_20cm_45deg_CCW_metal_plate)
```

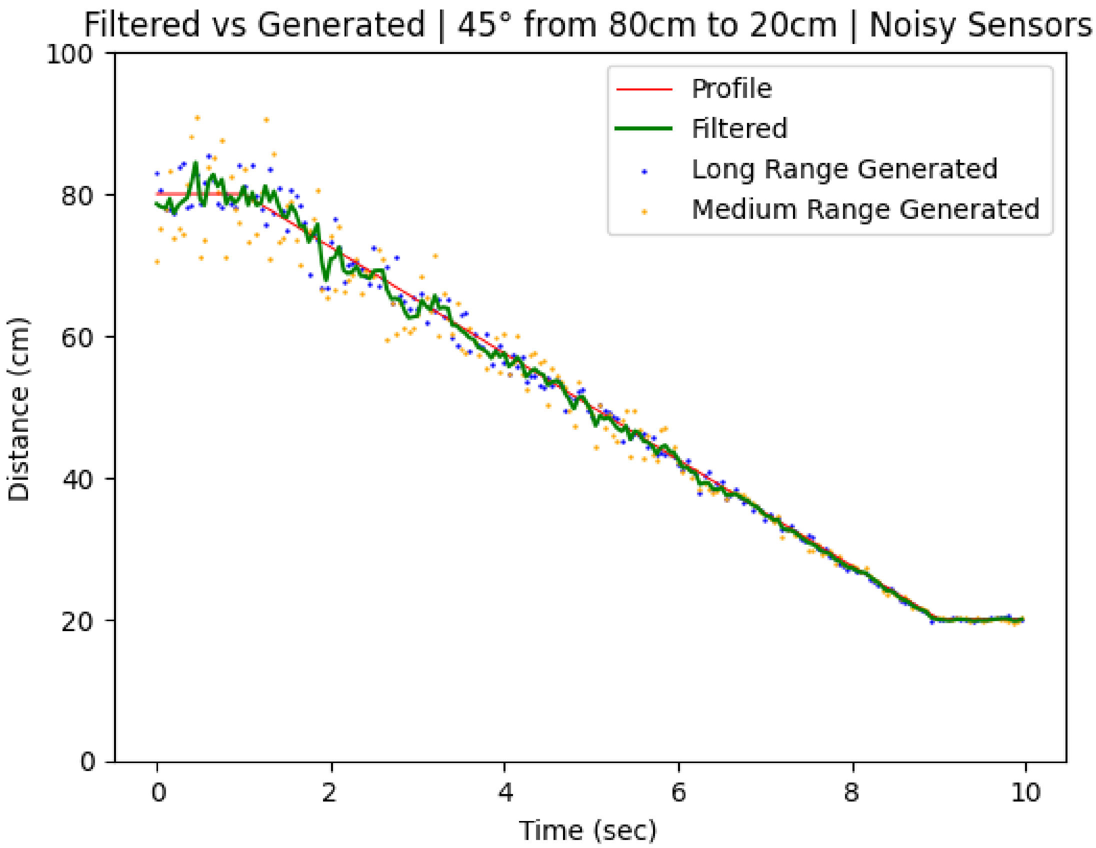
```
plate_45deg_80to20 = p5["80_to_20_45deg_CCW_metal_plate"]
calculate_and_gen_graphs(
    title = "45° from 80cm to 20cm",
    file="Part5_80to20_45deg",
    data=plate_45deg_80to20,
    profile=movement_profile
)
```

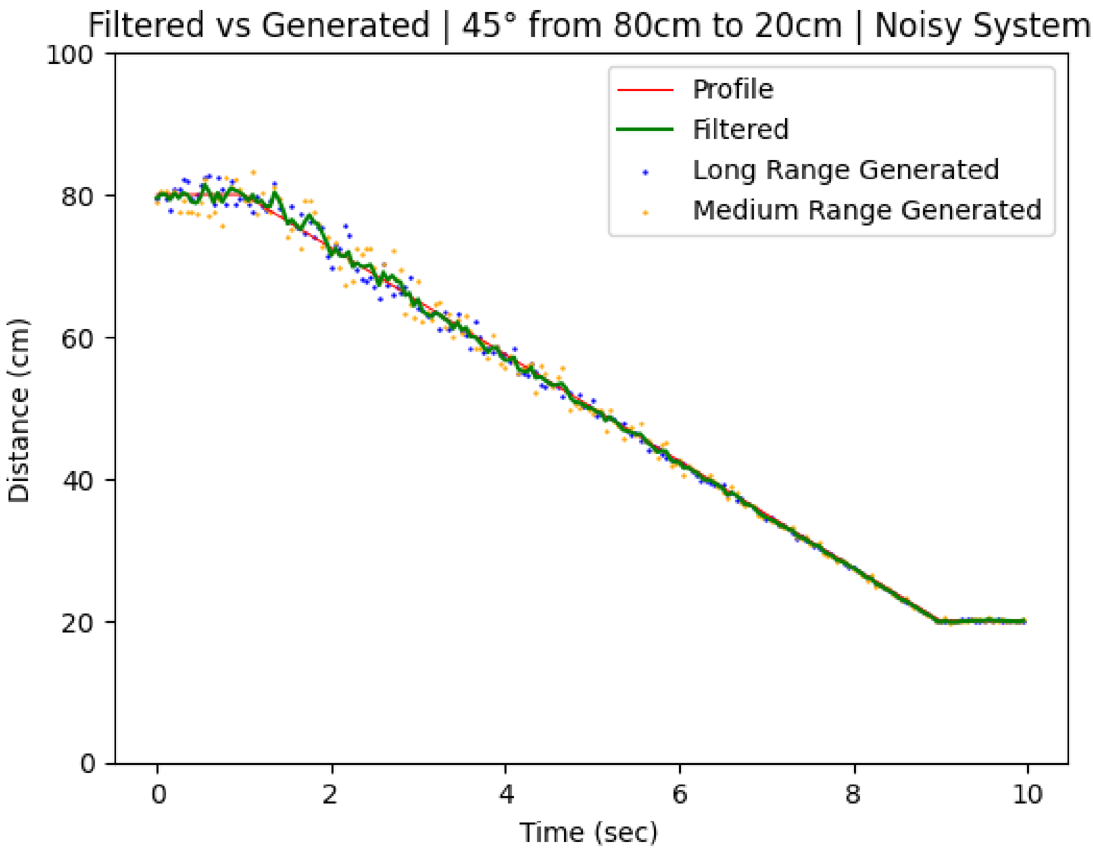



Filtered vs Generated | 45° from 80cm to 20cm
Distance (cm)
Time (sec)
Profile
Filtered
Long Range Generated
Medium Range Generated
0
20
40
60
80
100
0
2
4
6
8
10

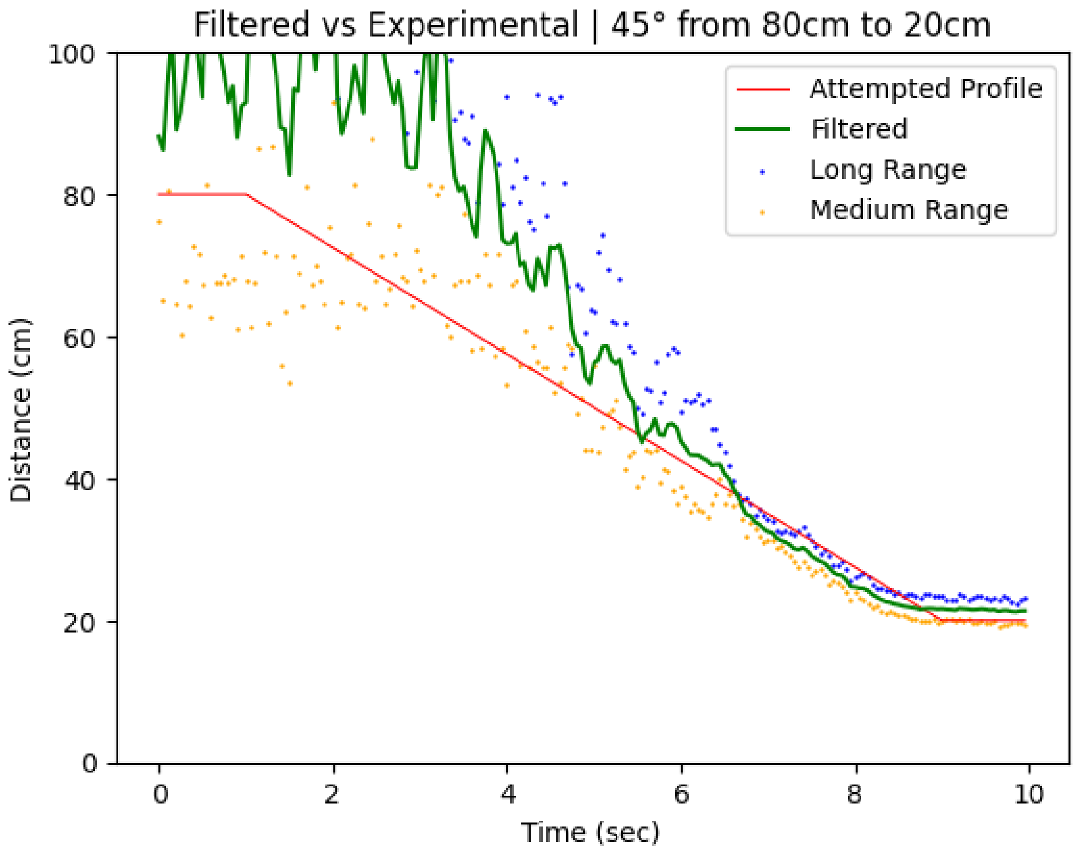


Filtered vs Generated | 45° from 80cm to 20cm | Bad State Estimate
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10


Filtered vs Generated | 45° from 80cm to 20cm | Noisy Sensors
Profile
Filtered
Long Range Generated
Medium Range Generated
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10



Title	R^2
Default	0.999149
Bad State Est.	0.986741
Noisy Sensors	0.996861
Noisy System	0.999015



Filtered vs Experimental | 45° from 80cm to 20cm
Attempted Profile
Filtered
Long Range
Medium Range
Distance (cm)
Time (sec)
0
20
40
60
80
100
0
2
4
6
8
10