Mono-Camera based Localizarion Model

(Autonomous Vehicle Localization Using Onboard Sensors and HD-Geolocated Maps [MATLAB Project #20] - Spring 2024 Semester).

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Under Supervision of:

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 $Frames \ are \ stored \ in \ the \ folders D: \ GP-Github \land Autonomous-Vehicle-Localization-Using-Onboars-Sensor- and -HD-Geolocalization-Using-Onboars-Sensor- and -HD-Geolocalization-Using-Onboars- Sensor- and -HD-Geolocalization- using-Onboars- using-Onb$

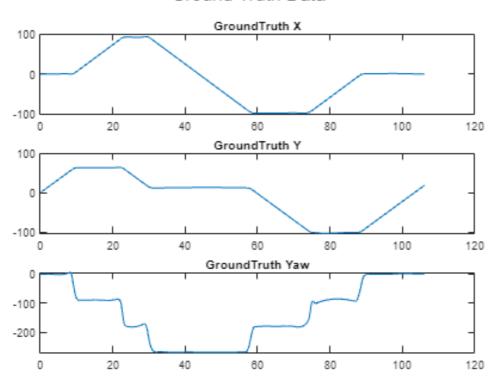
```
%Visualize groundtruth X, Y, and Yaw data.
timeVector = refPosesX(:,1); %Which is also consists of 500 element with deltaT
= 0.21245(sec.)
refX = refPosesX(:,2)+17.5109; %Plot X data starting from X(0) = 0
refY = refPosesY(:,2)+11.1966; %Plot Y data starting from Y(0) = 0
refYaw = refPosesT(:,2)-89.6327; %Plot Yaw data starting from Yaw(0) = 0
figure;

%Creating subplots
subplot(3, 1, 1);
plot(timeVector, refX);
title('GroundTruth X');

subplot(3, 1, 2);
plot(timeVector, refY);
title('GroundTruth Y');
```

```
plot(timeVector, refYaw);
title('GroundTruth Yaw');
sgtitle('Ground Truth Data');
```

Ground Truth Data



```
%Absolute Velocity calculations
distanceX = refPosesX(:,2); %X_distance
distanceY = refPosesY(:,2); %Y_distance

%Calculating the velocity using differentiation
dt = diff(timeVector);
ddX = diff(distanceX);
ddY = diff(distanceY);

Vx = [ddX(1) ./ dt(1); ddX ./ dt]; %Velocity in X_direction
Vy = [ddY(1) ./ dt(1); ddY ./ dt]; %Velocity in Y_direction

Vabs = (sqrt(Vx.^2 + Vy.^2)); %Absolute Velocity
SF = Vabs/frameRate; %Scale Factor
```

```
%Creating cameraParams intrinsics
focalLength = [fx fy];
principalPoint = [cx cy];
cameraParams = cameraIntrinsics(focalLength, principalPoint, imageSize);
```

Front Camera Localizarion Model (On the Roof of the Vehicle)

```
%Store Front Camera frames in vector
```



```
%Loop for saving front camera estimates
camXF = zeros(numel(jpgFilesF),1);
camYF = zeros(numel(jpgFilesF),1);
camYawF = zeros(numel(jpgFilesF),1);
camYawF(1) = deg2rad(refYaw(1));
```

```
figure;
for i = 1:numel(jpgFilesF) - 1
    grayFrame1F = grayVectorF{i};
    grayFrame2F = grayVectorF{i+1};
    %Detect and match features
    points1F = detectKAZEFeatures(grayFrame1F);
    points2F = detectKAZEFeatures(grayFrame2F);
    [features1F, points1F] = extractFeatures(grayFrame1F, points1F);
    [features2F, points2F] = extractFeatures(grayFrame2F, points2F);
    indexPairs = matchFeatures(features1F, features2F);
    matchedPoints1F = points1F(indexPairs(:, 1), :);
    matchedPoints2F = points2F(indexPairs(:, 2), :);
    %Estimate Essential matrix
    [eMatrix, inliers] = estimateEssentialMatrix(matchedPoints1F,
matchedPoints2F, cameraParams);
    %Select inlier points
    inlierPoints1F = matchedPoints1F(inliers);
    inlierPoints2F = matchedPoints2F(inliers);
    %Estimate relative camera pose
    relPoseF = estrelpose(eMatrix, cameraParams, inlierPoints1F, inlierPoints2F);
    RotF = relPoseF.R;
    tF = relPoseF.Translation;
    %Visualize matched features
    showMatchedFeatures(grayFrame1F, grayFrame2F, inlierPoints1F,
inlierPoints2F, 'montage');
    disp(['Matched Features in front frame ', num2str(i-1)]);
    eulerAngles = rotm2eul(RotF, 'XYZ');
    camYawF(i+1) = camYawF(i) - eulerAngles(2);
    camYF(i+1) = camYF(i) + tF(3)*cos(deg2rad(refYaw(i)))*SF(i) -
tF(1)*cos((pi/2) - (deg2rad(refYaw(i))))*SF(i);
    camXF(i+1) = camXF(i) - tF(3)*sin(deg2rad(refYaw(i)))*SF(i) + tF(1)*sin(pi/2)
-(deg2rad(refYaw(i))))*SF(i);
    %Visualization of the matched Features
    if(i==1)
        fprintf('Out of 500 Front Camera Frames, Processing the matching Frame
No.: ');
    end
    fprintf('\b\b\b\b\b\d', i);
    showMatchedFeatures(grayFrame1F, grayFrame2F, inlierPoints1FEss,
inlierPoints2FEss, 'montage');
end
```

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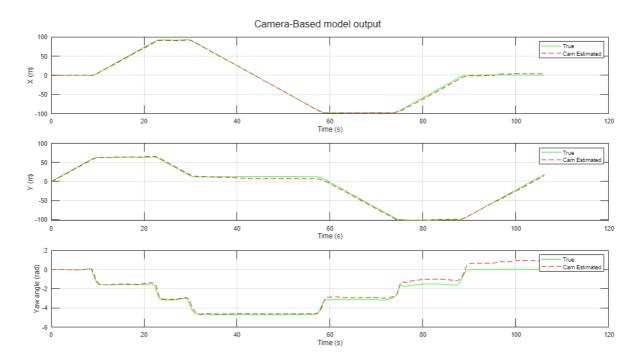
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Matched Features in front frame 498
```



```
%Plot ground truth vs. Front camera estimation
figure;
figure('Position', [50, 50, 2000, 1000]); % [left bottom width height]
subplot(3, 1, 1);
plot(timeVector, refX, 'g');
hold on;
plot(timeVector, camXF, 'r--');
xlabel('Time (s)');
ylabel('X (m)');
legend('True', 'Cam Estimated');
grid on;
subplot(3, 1, 2);
plot(timeVector, refY, 'g');
hold on;
plot(timeVector, camYF, 'r--');
xlabel('Time (s)');
ylabel('Y (m)');
legend('True', 'Cam Estimated');
grid on;
```

```
subplot(3, 1, 3);
plot(timeVector, deg2rad(refYaw), 'g');
hold on;
plot(timeVector, camYawF, 'r--');
xlabel('Time (s)');
ylabel('Yaw angle (rad)');
legend('True', 'Cam Estimated');
grid on;
sgtitle('Camera-Based model output');
```

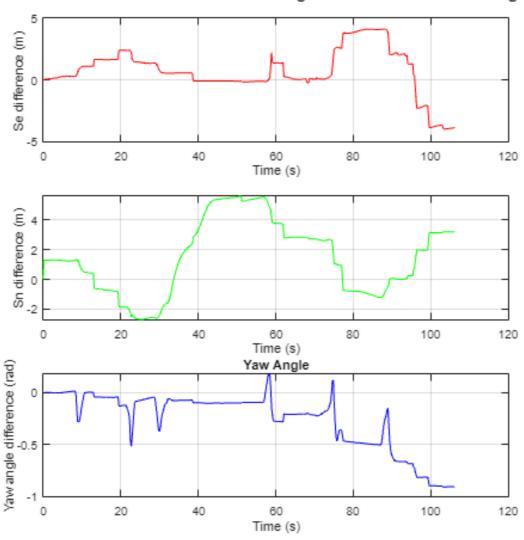


```
%Front Camera based error evaluation
%Calculating Error between Front Camera and ground truth
XDiffCamF = refX - camXF;
YDiffCamF = refY - camYF;
YawDiffCamF = deg2rad(refYaw) - camYawF;
%Graphing error
figure;
figure('Position', [50, 50, 600, 600]); %left bottom width height
subplot(3, 1, 1);
plot(timeVector, XDiffCamF, 'r');
xlabel('Time (s)');
ylabel('Se difference (m)');
grid on;
subplot(3, 1, 2);
plot(timeVector, YDiffCamF, 'g');
xlabel('Time (s)');
ylabel('Sn difference (m)');
grid on;
subplot(3, 1, 3);
```

```
plot(timeVector, YawDiffCamF, 'b');
xlabel('Time (s)');
ylabel('Yaw angle difference (rad)');
title('Yaw Angle')
grid on;

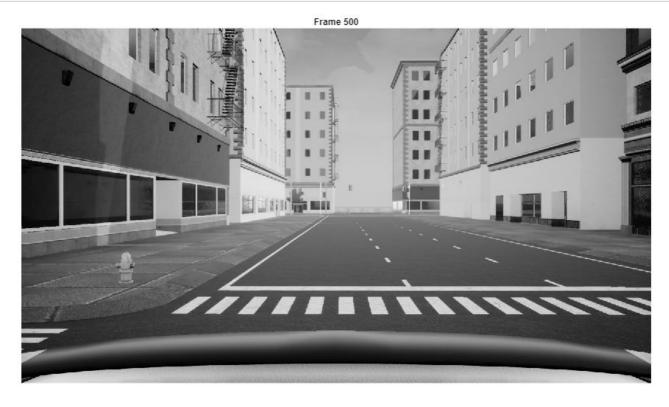
sgtitle('Camera-Based model Evaluation Consedring Front Camera data Vs ground
truth');
```

era-Based model Evaluation Consedring Front Camera data Vs ground



Back Camera Localizarion Model (On the Roof of the Vehicle with offset in (X = -0.04m & Yaw = 180))

```
%Store the back camera frames in vector
grayFolderPathB
= 'D:\GP-Github\Autonomous-Vehicle-Localization-Using-Onboars-Sensor-and-HD-
Geolocated-Maps-Project-Solution\MonoCamera_based_Localization\MonoCameraB';
%The Back images folder path
jpgFilesB = dir(fullfile(grayFolderPathB, '*.jpg'));
```



```
%Loop for saving the back camera estimates
camXB = zeros(numel(jpgFilesB),1);
camYB = zeros(numel(jpgFilesB),1);
camYawB = zeros(numel(jpgFilesB),1);
camYawB(1) = deg2rad(refYaw(1));

figure;
for i = 1:numel(jpgFilesB) - 1

grayFrameB1 = grayVectorB{i};
grayFrameB2 = grayVectorB{i+1};
```

```
%Detect and match features
    pointsB1 = detectKAZEFeatures(grayFrameB1);
    pointsB2 = detectKAZEFeatures(grayFrameB2);
    [featuresB1, pointsB1] = extractFeatures(grayFrameB1, pointsB1);
    [featuresB2, pointsB2] = extractFeatures(grayFrameB2, pointsB2);
    indexPairs = matchFeatures(featuresB1, featuresB2);
    matchedPointsB1 = pointsB1(indexPairs(:, 1), :);
    matchedPointsB2 = pointsB2(indexPairs(:, 2), :);
    %Estimate Essential matrix
    [eMatrix, inliers] = estimateEssentialMatrix(matchedPointsB1,
matchedPointsB2, cameraParams);
    % Select inlier points
    inlierPointsB1 = matchedPointsB1(inliers);
    inlierPointsB2 = matchedPointsB2(inliers);
    %Estimate relative camera pose
    relPoseB = estrelpose(eMatrix, cameraParams, inlierPointsB1, inlierPointsB2);
    RotB = relPoseB.R;
    tB = relPoseB.Translation;
    eulerAngles = rotm2eul(RotB, 'XYZ');
    camYawB(i+1) = camYawB(i) - eulerAngles(2);
    camYB(i+1) = camYB(i) + tB(3)*cos(deg2rad(refYaw(i))+pi)*SF(i) - tB(1)*cos(-
pi/2 -(deg2rad(refYaw(i))))*SF(i);
    camXB(i+1) = camXB(i) - tB(3)*sin(deg2rad(refYaw(i))+pi)*SF(i) + tB(1)*sin(-
pi/2 -(deg2rad(refYaw(i))))*SF(i);
    %Visualization of the matched Features
    if(i==1)
        fprintf('Out of 500 Back Camera Frames, Processing the matching Frame
No.: ');
    end
    fprintf('\b\b\b\b\b\d', i);
    showMatchedFeatures(grayFrameB1, grayFrameB2, inlierPointsB1,
inlierPointsB2, 'montage');
end
Matched Features in Back frame 0
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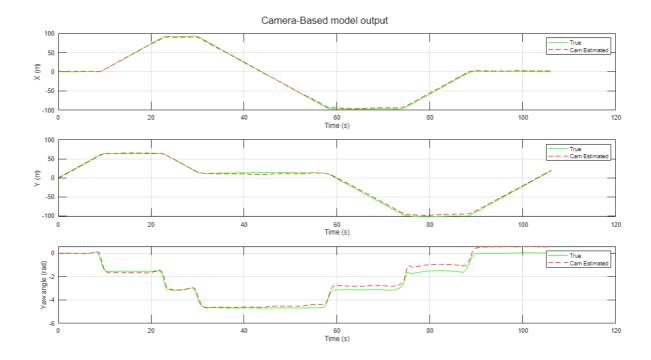
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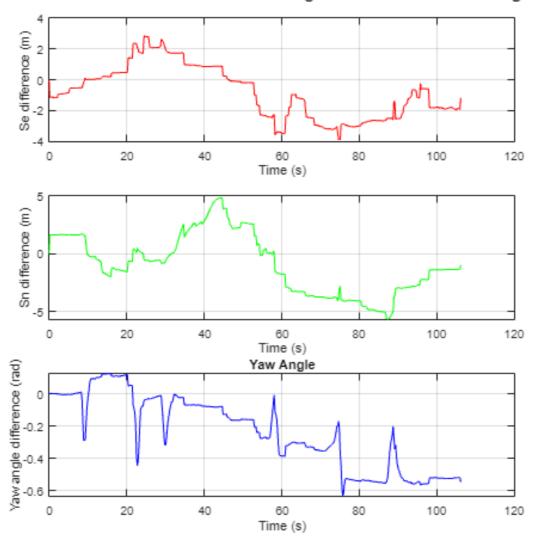


```
%Plot ground truth vs. back camera estimation
figure;
figure('Position', [50, 50, 2000, 1000]);
subplot(3, 1, 1);
plot(timeVector, refX, 'g');
hold on;
plot(timeVector, camXB, 'r--');
xlabel('Time (s)');
ylabel('X (m)');
legend('True', 'Cam Estimated');
grid on;
subplot(3, 1, 2);
plot(timeVector, refY, 'g');
hold on;
plot(timeVector, camYB, 'r--');
xlabel('Time (s)');
ylabel('Y (m)');
legend('True', 'Cam Estimated');
grid on;
subplot(3, 1, 3);
plot(timeVector, deg2rad(refYaw), 'g');
hold on;
plot(timeVector, camYawB, 'r--');
xlabel('Time (s)');
ylabel('Yaw angle (rad)');
legend('True', 'Cam Estimated');
grid on;
sgtitle('Camera-Based model output');
```



```
%Back Camera based error evaluation
%Calculating Error between Back Camera and ground truth
XDiffCamB = refX - camXB;
YDiffCamB = refY - camYB;
YawDiffCamB = deg2rad(refYaw) - camYawB;
%Graphing error
figure;
figure('Position', [50, 50, 600, 600]); % [left bottom width height]
subplot(3, 1, 1);
plot(timeVector, XDiffCamB, 'r');
xlabel('Time (s)');
ylabel('Se difference (m)');
grid on;
subplot(3, 1, 2);
plot(timeVector, YDiffCamB, 'g');
xlabel('Time (s)');
ylabel('Sn difference (m)');
grid on;
subplot(3, 1, 3);
plot(timeVector, YawDiffCamB, 'b');
xlabel('Time (s)');
ylabel('Yaw angle difference (rad)');
title('Yaw Angle')
grid on;
sgtitle('Camera-Based model Evaluation Consedring Back Camera data as ground
truth');
```

era-Based model Evaluation Consedring Back Camera data as ground



<u>Left Camera Localizarion Model (On the Roof of the Vehicle</u> with offset in (Y = -0.06m & Yaw = 90))

```
grayVectorL{i} = imread(filePathL);
end
```



```
%Loop for saving left camera estimates
camXL = zeros(numel(jpgFilesL),1);
camYL = zeros(numel(jpgFilesL),1);
camYawL = zeros(numel(jpgFilesL),1);
camYawL(1) = deg2rad(refYaw(1));
figure;
for i = 1:numel(jpgFilesL) - 1

    grayFrame1L = grayVectorL{i};
    grayFrame2L = grayVectorL{i+1};

%Detect and match features
points1L = detectKAZEFeatures(grayFrame1L);
points2L = detectKAZEFeatures(grayFrame2L);

[features1L, points1L] = extractFeatures(grayFrame1L, points1L);
[features2L, points2L] = extractFeatures(grayFrame2L, points2L);
```

```
indexPairs = matchFeatures(features1L, features2L);
    matchedPoints1L = points1L(indexPairs(:, 1), :);
    matchedPoints2L = points2L(indexPairs(:, 2), :);
    %Estimate Essential matrix
    [eMatrix, inliers] = estimateEssentialMatrix(matchedPoints1L,
matchedPoints2L, cameraParams);
    %Select inlier points
    inlierPoints1L = matchedPoints1L(inliers);
    inlierPoints2L = matchedPoints2L(inliers);
    %Estimate relative camera pose
    relPoseL = estrelpose(eMatrix, cameraParams, inlierPoints1L, inlierPoints2L);
    RotL = relPoseL.R;
    tL = relPoseL.Translation;
    eulerAngles = rotm2eul(RotL, 'XYZ');
    camYawL(i+1) = camYawL(i) - eulerAngles(2);
    camYL(i+1) = camYL(i) + tL(3)*cos(deg2rad(refYaw(i))-pi/2)*SF(i) -
tL(1)*cos(pi-(deg2rad(refYaw(i))))*SF(i);
    camXL(i+1) = camXL(i) + tL(3)*sin(deg2rad(refYaw(i))-pi/2)*SF(i) -
tL(1)*sin(pi-(deg2rad(refYaw(i))))*SF(i);
    %Visualization of the matched Features
        fprintf('Out of 500 Left Camera Frames, Processing the matching Frame
No.: ');
    fprintf('\b\b\b\b\b\d', i);
    showMatchedFeatures(grayFrame1L, grayFrame2L, inlierPoints1L,
inlierPoints2L, 'montage');
end
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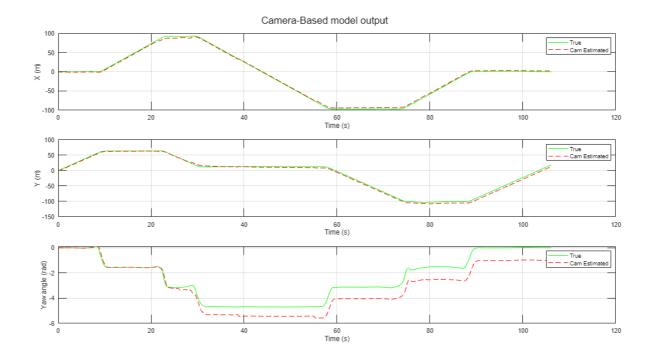
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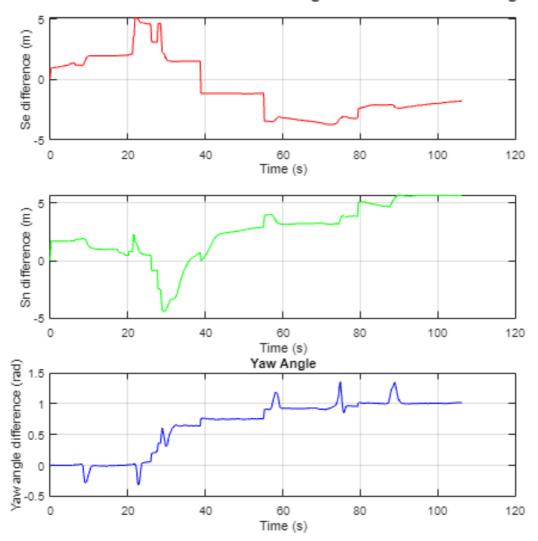


```
%Plot ground truth vs. left camera estimation
figure;
figure('Position', [50, 50, 2000, 1000]);
subplot(3, 1, 1);
plot(timeVector, refX, 'g');
hold on;
plot(timeVector, camXL, 'r--');
xlabel('Time (s)');
ylabel('X (m)');
legend('True', 'Cam Estimated');
grid on;
subplot(3, 1, 2);
plot(timeVector, refY, 'g');
hold on;
plot(timeVector, camYL, 'r--');
xlabel('Time (s)');
ylabel('Y (m)');
legend('True', 'Cam Estimated');
grid on;
subplot(3, 1, 3);
plot(timeVector, deg2rad(refYaw), 'g');
hold on;
plot(timeVector, camYawL, 'r--');
xlabel('Time (s)');
ylabel('Yaw angle (rad)');
legend('True', 'Cam Estimated');
grid on;
sgtitle('Camera-Based model output');
```



```
%Left Camera based error evaluation
%Calculating Error between Left Camera and ground truth
XDiffCamL = refX - camXL;
YDiffCamL = refY - camYL;
YawDiffCamL = deg2rad(refYaw) - camYawL;
%Graphing error
figure;
figure('Position', [50, 50, 600, 600]); % [left bottom width height]
subplot(3, 1, 1);
plot(timeVector, XDiffCamL, 'r');
xlabel('Time (s)');
ylabel('Se difference (m)');
grid on;
subplot(3, 1, 2);
plot(timeVector, YDiffCamL, 'g');
xlabel('Time (s)');
ylabel('Sn difference (m)');
grid on;
subplot(3, 1, 3);
plot(timeVector, YawDiffCamL, 'b');
xlabel('Time (s)');
ylabel('Yaw angle difference (rad)');
title('Yaw Angle')
grid on;
sgtitle('Camera-Based model Evaluation Consedring Left Camera data as ground
truth');
```

iera-Based model Evaluation Consedring Left Camera data as ground



Right Camera Localizarion Model (On the Roof of the Vehicle with offset in (Y = 0.06m & Yaw = -90))

```
grayVectorR{i} = imread(filePathR);
end
```



```
%Loop for saving right camera estimates
camXR = zeros(numel(jpgFilesR),1);
camYR = zeros(numel(jpgFilesR),1);
camYawR = zeros(numel(jpgFilesR),1);
camYawR(1) = deg2rad(refYaw(1));
figure;

for i = 1:numel(jpgFilesR) - 1

    grayFrame1R = grayVectorR{i};
    grayFrame2R = grayVectorR{i+1};

    %Detect and match features
    points1R = detectKAZEFeatures(grayFrame1R);
    points2R = detectKAZEFeatures(grayFrame2R);

[features1R, points1R] = extractFeatures(grayFrame1R, points1R);
    [features2R, points2R] = extractFeatures(grayFrame2R, points2R);
```

```
indexPairs = matchFeatures(features1R, features2R);
    matchedPoints1R = points1R(indexPairs(:, 1), :);
    matchedPoints2R = points2R(indexPairs(:, 2), :);
    %Estimate Essential matrix
    [eMatrix, inliers] = estimateEssentialMatrix(matchedPoints1R,
matchedPoints2R, cameraParams);
    %Select inlier points
    inlierPoints1R = matchedPoints1R(inliers);
    inlierPoints2R = matchedPoints2R(inliers);
    %Estimate relative camera pose
    relPoseR = estrelpose(eMatrix, cameraParams, inlierPoints1R, inlierPoints2R);
    RotR = relPoseR.R;
    tR = relPoseR.Translation;
    eulerAngles = rotm2eul(RotR, 'XYZ');
    camYawR(i+1) = camYawR(i) - eulerAngles(2);
    camYR(i+1) = camYR(i) + tR(3)*cos(deg2rad(refYaw(i))+pi/2)*SF(i) -
tR(1)*cos(-(deg2rad(refYaw(i))))*SF(i);
    camXR(i+1) = camXR(i) + tR(3)*sin(deg2rad(refYaw(i))+pi/2)*SF(i) -
tR(1)*sin(-(deg2rad(refYaw(i))))*SF(i);
    %Visualization of the matched Features
    if(i==1)
        fprintf('Out of 500 Left Camera Frames, Processing the matching Frame
No.: ');
    end
    fprintf('\b\b\b\b\b\d', i);
    showMatchedFeatures(grayFrame1R, grayFrame2R, inlierPoints1R,
inlierPoints2R, 'montage');
end
Matched Features in Right frame 0
```

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Matched Features in Right frame 1
Matched Features in Right frame 2
Matched Features in Right frame 3
Matched Features in Right frame 4
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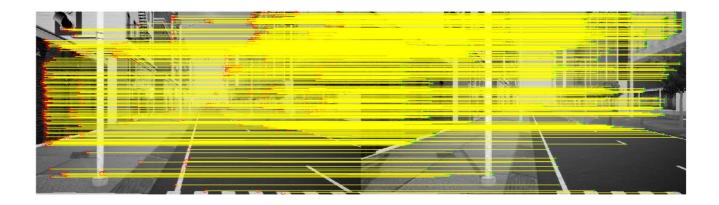
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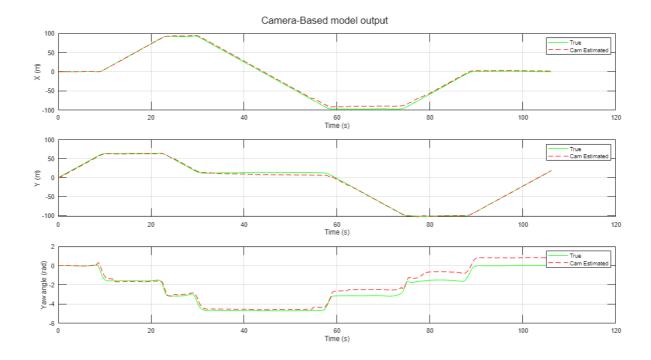
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Matched Features in Right frame 480
Matched Features in Right frame 481
Matched Features in Right frame 482
Matched Features in Right frame 483
Matched Features in Right frame 484
Matched Features in Right frame 485
Matched Features in Right frame 486
Matched Features in Right frame 487
Matched Features in Right frame 488
Matched Features in Right frame 489
Matched Features in Right frame 490
Matched Features in Right frame 491
Matched Features in Right frame 492
Matched Features in Right frame 493
Matched Features in Right frame 494
Matched Features in Right frame 495
Matched Features in Right frame 496
Matched Features in Right frame 497
```



Matched Features in Right frame 498

```
% 11. Plot ground truth vs. camera estimation
figure('Position', [50, 50, 2000, 1000]); % [left bottom width height]
subplot(3, 1, 1);
plot(timeVector, refX, 'g');
hold on;
plot(timeVector, camXR, 'r--');
xlabel('Time (s)');
ylabel('X (m)');
legend('True', 'Cam Estimated');
grid on;
subplot(3, 1, 2);
plot(timeVector, refY, 'g');
hold on;
plot(timeVector, camYR, 'r--');
xlabel('Time (s)');
ylabel('Y (m)');
legend('True', 'Cam Estimated');
grid on;
subplot(3, 1, 3);
plot(timeVector, deg2rad(refYaw), 'g');
hold on;
plot(timeVector, camYawR, 'r--');
xlabel('Time (s)');
ylabel('Yaw angle (rad)');
legend('True', 'Cam Estimated');
grid on;
sgtitle('Camera-Based model output');
```



```
%Right Camera based error evaluation
%Calculating Error between Right Camera and ground truth
XDiffCamR = refX - camXR;
YDiffCamR = refY - camYR;
YawDiffCamR = deg2rad(refYaw) - camYawR;
%Graphing error
figure;
figure('Position', [50, 50, 600, 600]);
subplot(3, 1, 1);
plot(timeVector, XDiffCamR, 'r');
xlabel('Time (s)');
ylabel('Se difference (m)');
grid on;
subplot(3, 1, 2);
plot(timeVector, YDiffCamR, 'g');
xlabel('Time (s)');
ylabel('Sn difference (m)');
grid on;
subplot(3, 1, 3);
plot(timeVector, YawDiffCamR, 'b');
xlabel('Time (s)');
ylabel('Yaw angle difference (rad)');
title('Yaw Angle')
grid on;
sgtitle('Camera-Based model Evaluation Consedring Right Camera data as ground
truth');
```

era-Based model Evaluation Consedring Right Camera data as ground

