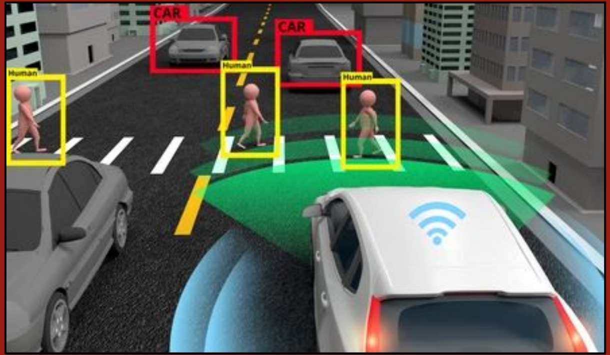
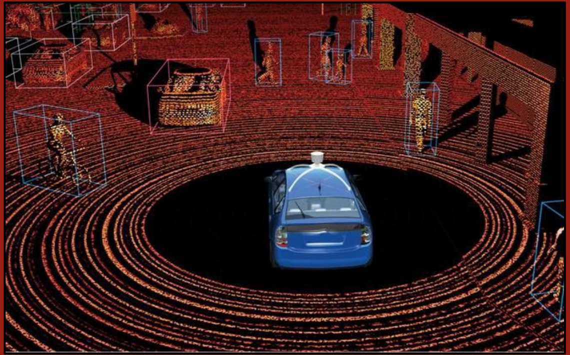
Pedestrian Detection and Sensor Fusion





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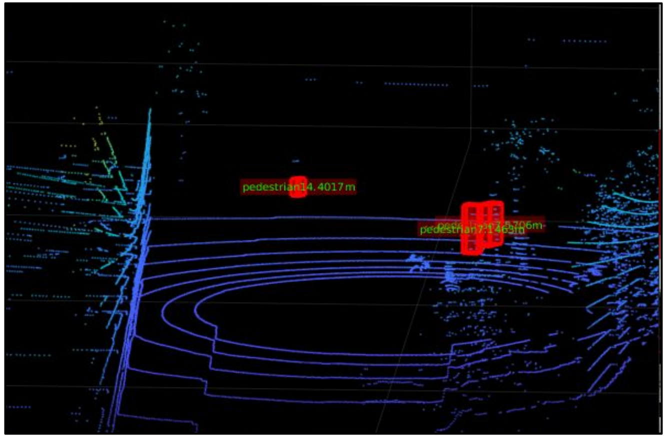
Overview

1. Detection and Fusion Goal
2. Technology
3. Data Collection
4. Detection: YOLOv5
5. Sensor Fusion
    a. LiDAR and RGB
    b. LiDAR and IR
    c. RGB and IR
6. Limitations/ Challenges
7. Questions

Detection + Fusion Goal

- **Problem:** All sensors have individual strengths and weaknesses



- **Goal:** Combine the strengths of different sensors to increase the efficiency and accuracy of detecting objects at any moment in any environment

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Technology

Velodyne VLP 16 LiDAR

- Extremely accurate distance and position measurements

Ouster OS1 LiDAR

- Lots of noise
- Not reliable for object detection
- Higher cost: computation and price

Teledyne FLIR ADK IR Camera

- Can often get a picture when RGB can't
- Lower resolution image
- Detection not as efficient

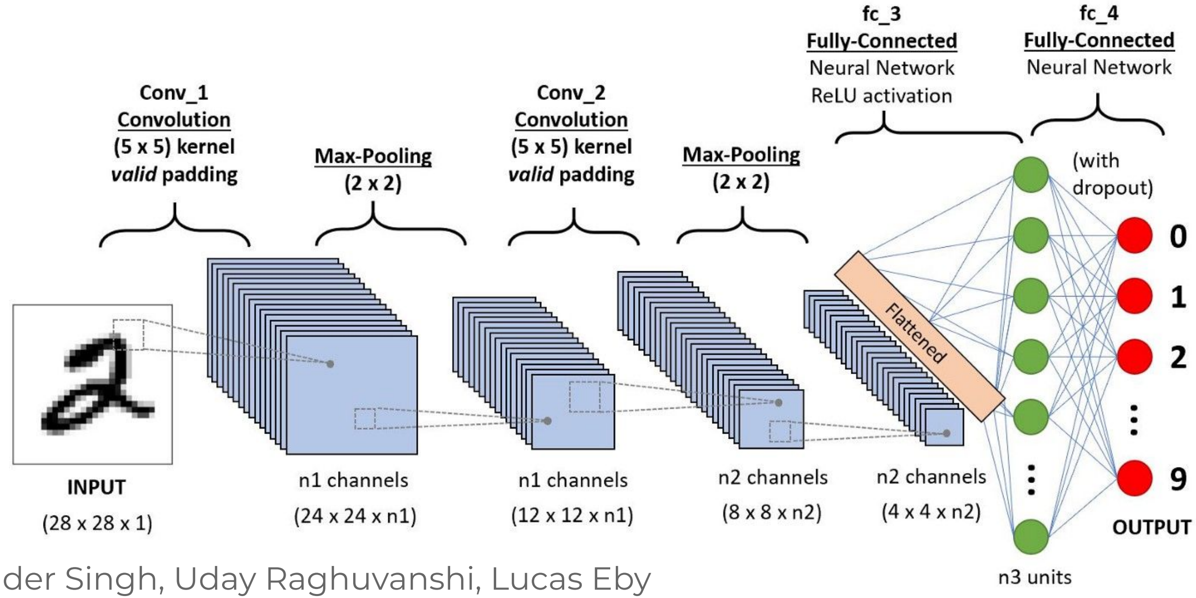
Teledyne FLIR BlackflyS 5MP Camera

- High resolution
- Very effective in right environment
- Low cost
- Performs poorly in non-ideal conditions

- Software
  - MATLAB
  - Python

Convolutional Neural Networks(CNN)

- Cameras are relatively cheap and have high resolution
- Layers are made up of filters that can detect "patterns"
- BUT the size of the object is not guaranteed to be constant



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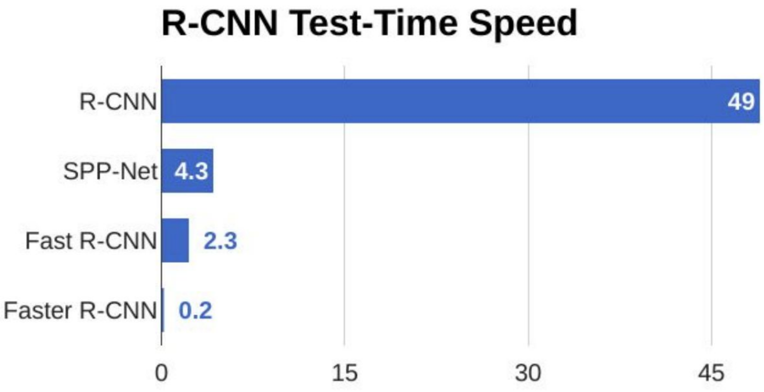
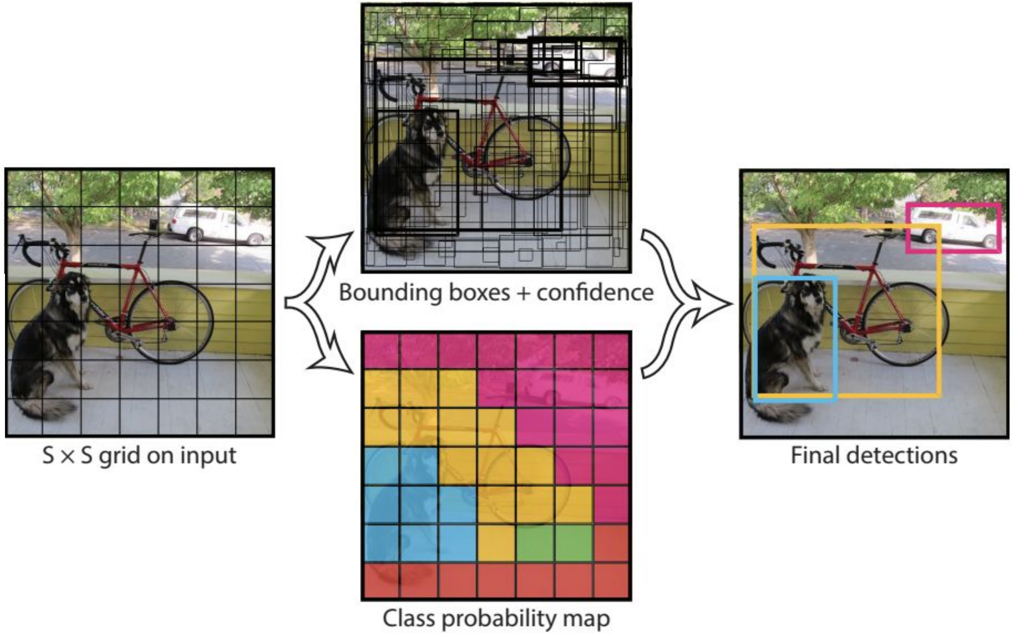
You Only Look Once (YOLO)

- A CNN that only uses a single propagation through a neural network to detect objects
- Made up of:
  1. Residual blocks
  2. Bounding box regression
  3. Intersection over union





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IR vs RGB

Collected Night Data

Provided Day Data

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Data Collection Checklist

- Make sure the required sensors are clean.
- Check whether all the ros drivers are running.
- Check whether your rosbag record command has all the topics you need.
- Make sure that the LiDARs are turned on by checking the display console in the front center of car.
- Rostopic echo all the topics once you start recording to ensure you have incoming data and visualize in parallel with Rviz.
- Make sure the car's hdd has enough space to store your rosbags.
- Before you drive, make sure the car has enough fuel to run
- Be patient while using the keyboard (very important).
- Try your best to not crash the car (most important)

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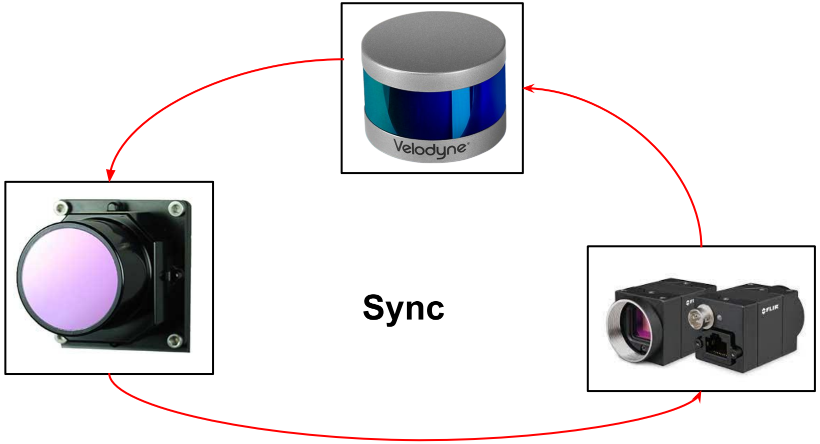
Sensor Fusion

1. **Time Syncing**

   Output rate of the sensors:

   - RGB Camera: 8Hz
   - IR Camera: 30Hz
   - Velodyne VLP16 LiDAR: 10Hz
   - Ouster OS1 LiDAR: 10Hz




```
camera = select(bag,'Topic','/camera_array/cam0/image_raw');
lidar = select(bag,'Topic','/ns1/velodyne_points');
ir = select(bag,'Topic','/boson_camera_array/cam_right/image_raw');


cameraMsgs = readMessages(camera);
lidarMsgs = readMessages(lidar);
irMsgs = readMessages(ir);

ts1 = timeseries(camera);
ts2 = timeseries(lidar);
ts3 = timeseries(ir);

t1 = ts1.Time;
t2 = ts2.Time;
t3 = ts3.Time;

k = 1;
k2 = 1;

if size(t2,1) > size(t1,1)
    for i = 1:size(t1,1)
        [val,indx] = min(abs(t1(i) - t2));
        if val <= 0.1
            idx(k,:) = [i indx];
            k = k + 1;
        end
    end
else
    for i = 1:size(t2,1)
        [val,indx] = min(abs(t2(i) - t1));
        if val <= 0.1
            idx(k,:) = [indx i];
            k = k + 1;
        end
```

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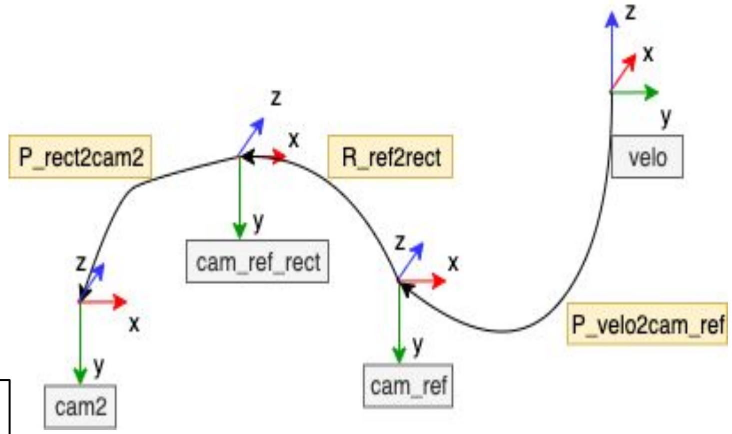
2. Transformations

- Lidar to Camera
  1. Find Camera intrinsics (yaml)
  2. Get available frames from ROS
  3. Calculate the transformation matrix using getTransform
- Camera to Lidar- invert(LidarToCamera)




```
%Transformations
frames = bag.AvailableFrames;
gettf= getTransform(bag,frames{21},frames{4});% cam_0_optical_frame and vlp_16 port (frame 18,os_sensor for Ouster)
tf = gettf.Transform;
ros_quat = tf.Rotation;
quat = [ros_quat.X ros_quat.Y ros_quat.Z ros_quat.W];
rotm = quat2rotm(quat);

ros_trans = tf.Translation;
trans_RGB = [ros_trans.X ros_trans.Y ros_trans.Z];
trans_IR = [-0.8 -0.23 0];
tform = rigid3d(rotm, trans_RGB); %RGB transformation matrix
tform=rigid3d(rotm,trans_IR);% IR transformation matrix
```

Finding transformation matrices

```
% IR Intrinsics
focalLength_IR = 2*[5.24888150200348832e+02, 5.21776791343664968e+02];
principalPoint_IR = 2*[3.25596989785447420e+02, 3.25596989785447420e+02];
%RGB Intrinsics
focalLength_RGB = [1888.4451558202136, 1888.4000949073984];
principalPoint_RGB = [613.1897651359767, 482.1189409211585];
```

Camera Intrinsics

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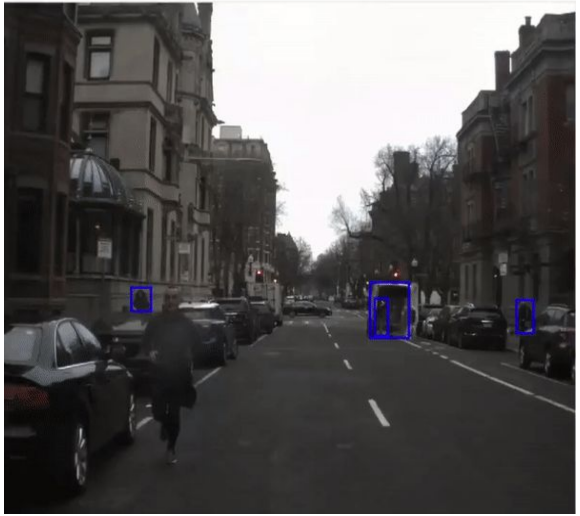
3. Projecting bounding boxes on RGB/IR Image

- Extract bounding boxes location from YOLO
- Pre-process the data to get only person class
- Normalize YOLO coordinates
- Convert relative coordinates to pixel coordinates

```
fileID = fopen(labels_loc,'r');
formatSpec = '%f';
A = fscanf(fileID,formatSpec);
k = 1;
clusterpoints = [];
if length(A)>=5
    for i = 1:5:length(A)
        if A(i)==0
            x_center= A(i+1,1)*w;
            y_center= A(i+2,1)*h;
            width= A(i+3,1)*w;
            height= A(i+4,1)*h;
            xLeft = x_center - width/2;
            yLeft = y_center - width/2;
            xBottom = x_center - height/2;
            yBottom = y_center - height/2;
            bbox = [xLeft, yBottom, width, height];
            figure(1)
            hold on
```



Code **Results**

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4. Segment 3D point cloud data on 2D RGB/IR image

- Downsample ? No !
- Pre-Process ? Yes !

➔ Extract lidar points inside the 2D bbox

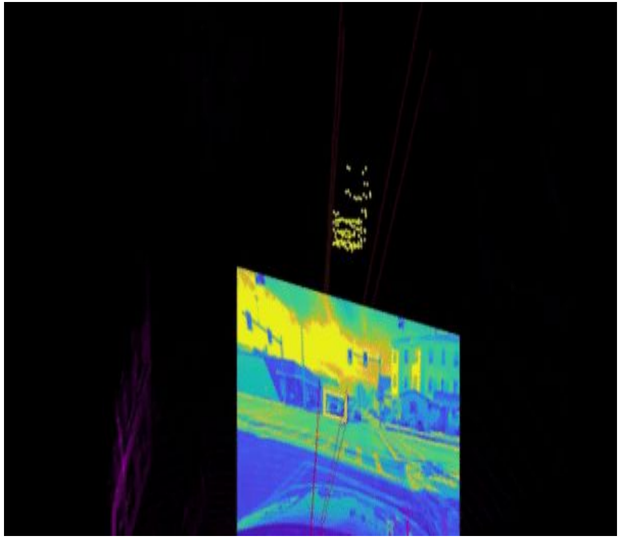
Pre-Process

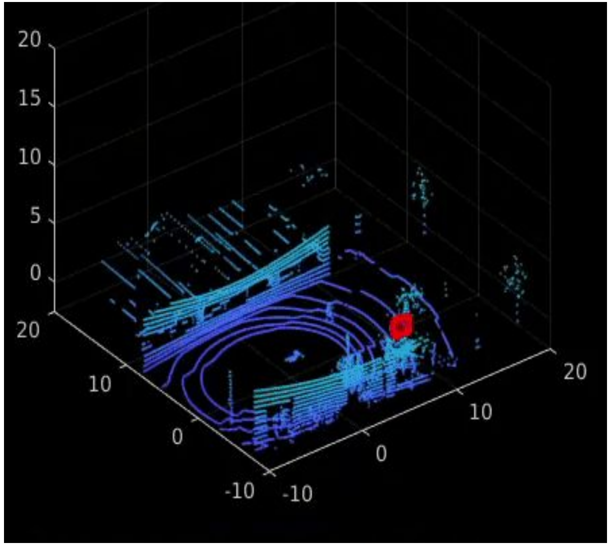
```
for j = 1:length(imPts)
    if imPts(j,1)<=xLeft+width &&  imPts(j,1)>=xLeft
        if imPts(j,2)<=yBottom+height &&  imPts(j,2)>=yBottom
            clusterpoints(k, 1) = imPts(j,1);
            clusterpoints(k, 2) = imPts(j,2);
            k = k+1;
        end
    end
end
```

Result

5. Adding 3D bounding boxes in point cloud data

- Find transformation from camera frame to lidar frame [invert(LidarToCamera)]
- Define Cluster Threshold
- Transform corners of 2D bboxes to 3D lines (Frustum Flaring)
- Segment into various clusters based on Euclidean distance





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6. Calculating distance of pedestrians from car

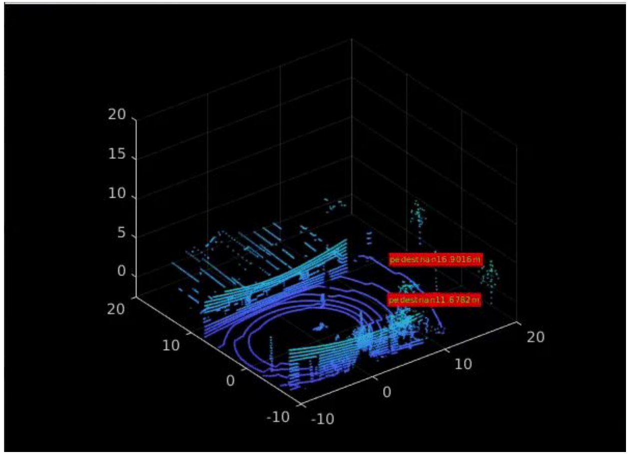
- Extracting the coordinates of 3D bounding boxes.
- Keeping only distances of interest
- Calculating distance from LiDAR
- Using the distances in autonomous driving

Code

```
bboxLidar = bboxCameraToLidar(bbox,pc,intrinsics,invert(tform),'ClusterThreshold',1);
bbox=[floor(xLeft), floor(yBottom), floor(width), floor(height)];
dist_x=bboxLidar(:,1);
dist_y=bboxLidar(:,2);
dist_z=bboxLidar(:,3);
if isempty(dist_x)==false
    dist=sqrt(dist_x^2+dist_y^2+dist_z^2)-2;
    labels="pedestrian"+dist+"m";
    figure(1)
    hold on
    showShape('rectangle',bbox,'color','yellow','Label',labels)

    figure(2)
    hold on
    showShape('cuboid',bboxLidar,'Opacity',0.5,'Color','red', ...
        'Label',labels,'LabelTextColor','green','LabelFontSize',7,'LabelOpacity',0.3)

end
```



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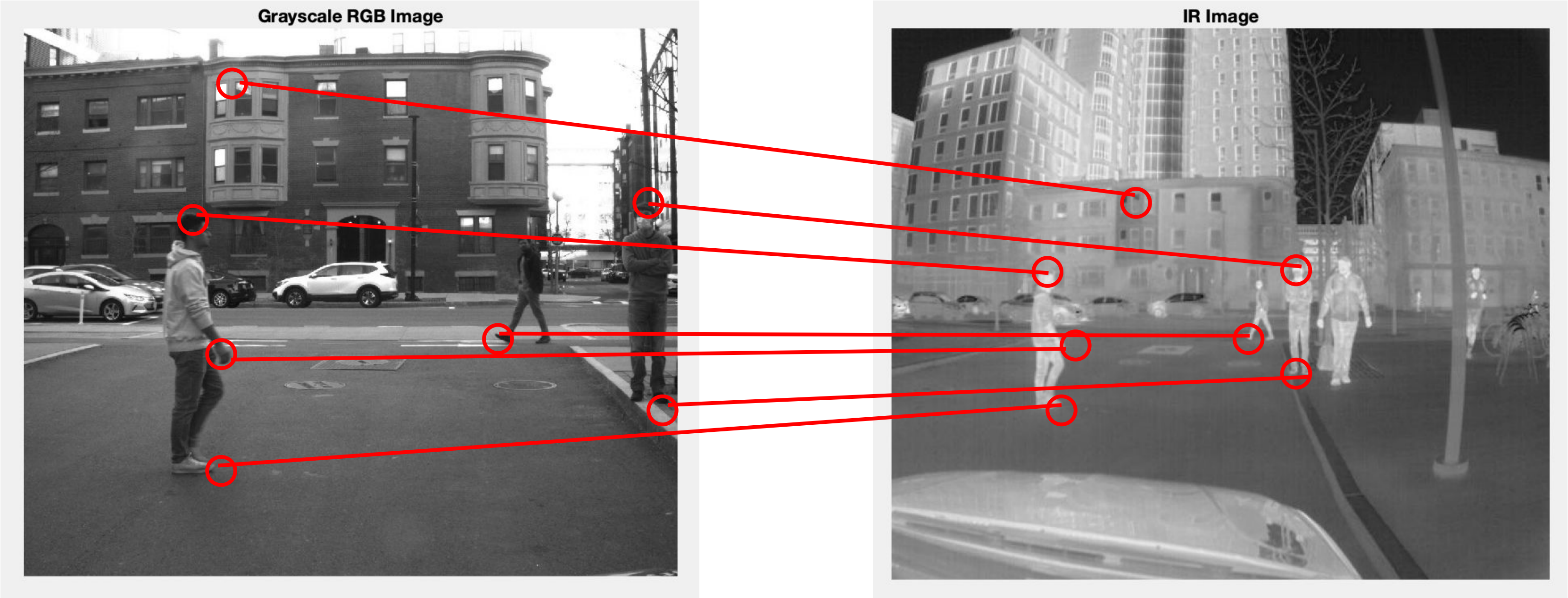
Sensor Fusion

Fusing RGB and IR



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Sensor Fusion

Fusing RGB and IR

Read and Convert

```
ir_im = imread('/Users/lukedavidson/Desktop/ir_im_box2.png');
rgb_im = imread('/Users/lukedavidson/Desktop/rgb_im_box2.png');
rgb_to_gray = rgb2gray(rgb_im);
```

Resize

```
size_rgb = size(rgb_to_gray);
ir_im_resize = imresize(ir_im,size_rgb);
```

Create TF

```
movingPoints = [765 853; 593 889; 699 647; 661 389; 527 579; 605 697];
fixedPoints = [499 735; 399 743; 461 619; 447 479; 381 577; 419 643];
tform = fitgeotrans(movingPoints,fixedPoints,'projective');
```

Transform and Display

```
rgb_warped = imwarp(rgb_im,tform);
rgb_warped_translated = imtranslate(rgb_warped,[155,220],"OutputView","full");
figure
imshow(ir_im_resize)
alpha(0.4)
hold on
imshow(rgb_warped_translated)
alpha(0.4)
title('Projective Transformation')
```

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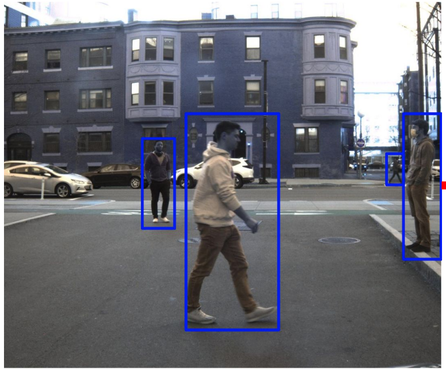
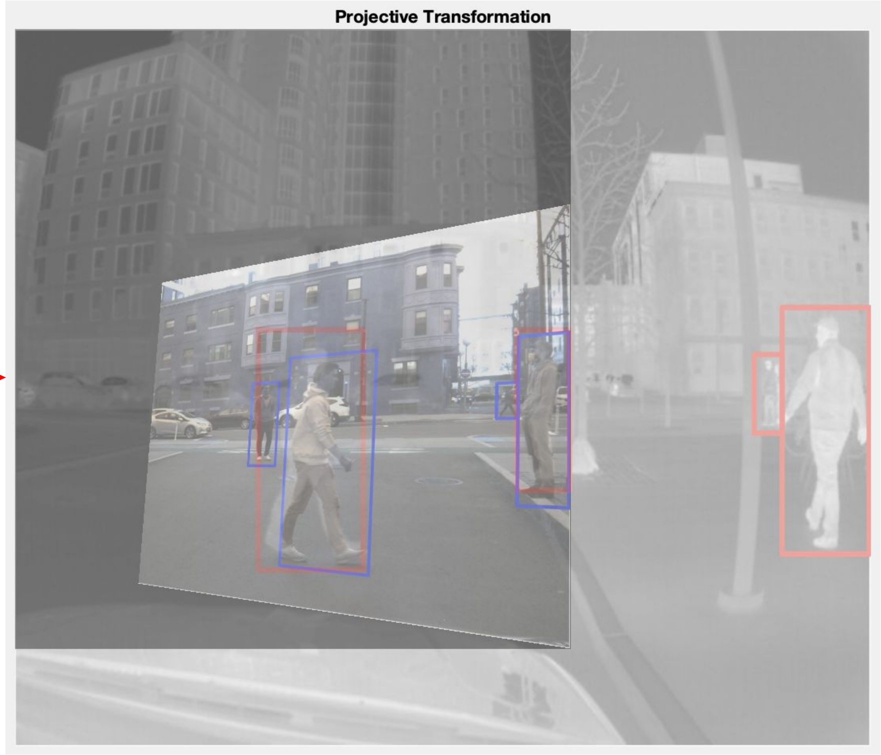
Sensor Fusion





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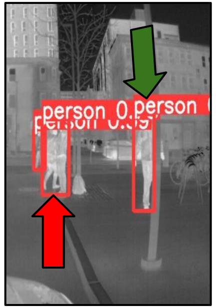
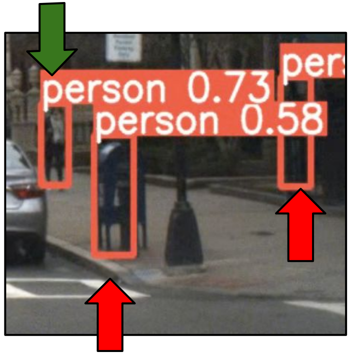
Limitations/Challenges

1. Velodyne vs Ouster- Having better LiDAR increases cost.
2. YOLO is not perfect
   - False positives
   - False Negatives
   - Single box for multiple pedestrians
3. Parameters required for calibration
   - Data set had older calibration values

Ouster

Velodyne





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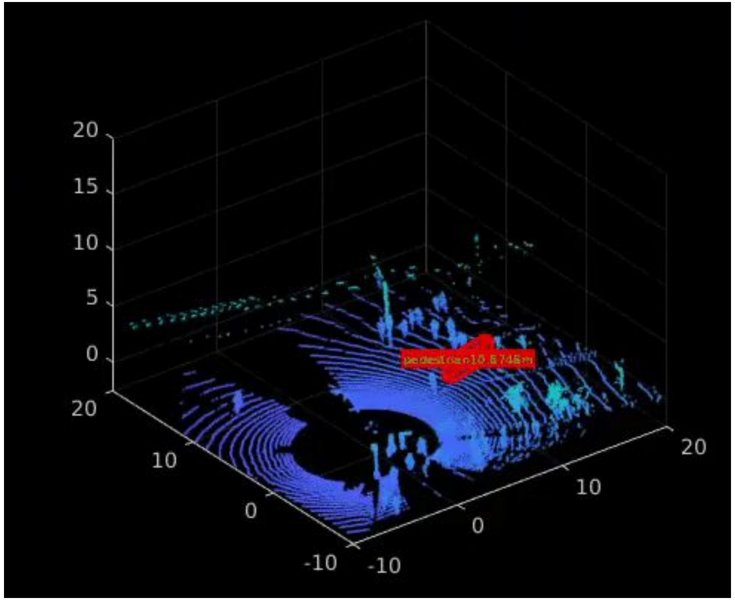
Final Outcome (RGB)



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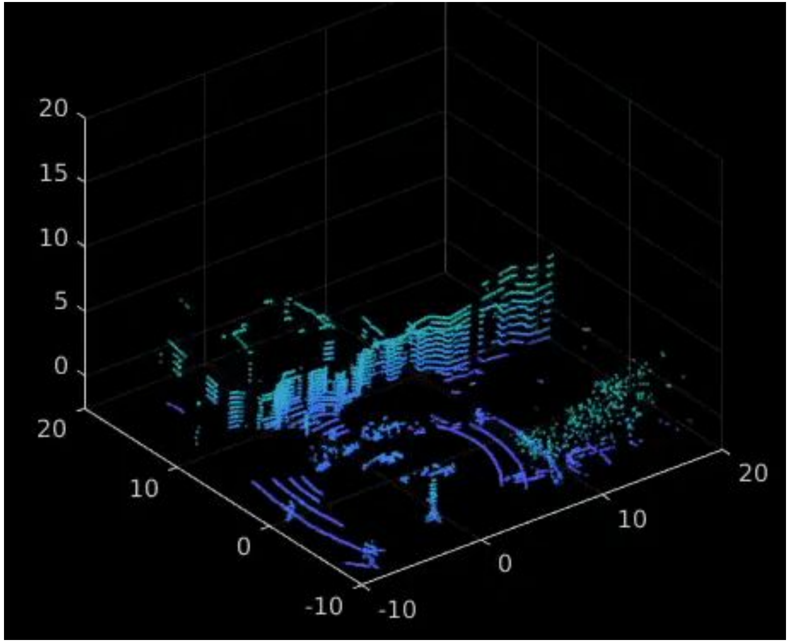
Final Outcome (IR)



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Conclusion

- We were able to get a rough transformation between IR and Velodyne Lidar
- We were able to detect the poses of pedestrians up until about 15 meters with high precision
- We had about 85-90% accuracy with YOLO
- If we had more time in the future we would:
  - Calibrate the velodyne and ouster as well as the RGB and IR cameras together
  - Add path prediction to each pedestrian

Questions?

Works Cited

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