Development of Machine learning algorithms for Radar based Automotive applications

-by Santhana Raj
-Mar 2020
Synopsis

PathPartner – Company Introduction
Automotive Radar capabilities of PathPartner
Requirement and Use case
Problems with radar based classification
Project approach
Machine Learning Toolbox
Training & Testing
New challenges & Re-Design
Final Development
Executive Overview

CORPORATE OVERVIEW

- Incorporated in 2006 as embedded multimedia systems organization later on changed the vision to Intelligent system
- HQ in Bangalore, India. R&D centre in Bangalore, India and Bay Area, USA. Sales presence in India, USA, Japan, Europe & China
- Focus verticals: Automotive, Internet of Things & Digital Media Products
- Key offerings: Embedded systems, Multimedia, Imaging, Connectivity, Machine intelligence
- Credentials: 13+ years, 100+ customers, 300+ projects

PATHPARTNER IN AUTOMOTIVE

- Leveraging competencies in embedded systems, multimedia, imaging, & embedded vision, Automotive vertical established in the year 2011
- Started with multimedia adjacencies such as infotainment and gradually grew as an expert in automotive offerings across infotainment, ADAS, digital cockpit and connected services
- Strategic growth through partnerships with key automotive IC majors – TI, NVIDIA, Qualcomm, NXP, STM, Renesas, Cadence, Synopsys
- Delivered accelerated solutions to automotive tier-1s across the globe – US, Germany, Japan
- Follow ISO 26262 compliant processes
Automotive Radar Offerings

Complete firmware and software development for radar systems

- **Radar algorithm pipeline**
  - Algorithm design | Algorithm consulting | Porting & Optimization | Tuning | Testing

- **Sensor fusion**
  - Radar | Camera | Lidar

- **BSP & System software**
  - Board bring-up | Sensor integration | Comm Stacks (LVDS, CSI2, CAN, Ethernet)

- **System Integration & Applications**
  - Integration with other systems | Use-case specific app development

- **Functional safety**
  - ISO 26262 Part 6 (MISRA-C, Static Analysis, Code Coverage)

**Automotive Use-cases**

- Object detection & tracking | Blind Spot Monitoring | Surround view | Park Assist
- Occupancy detection | Gesture recognition | Vibration Monitoring
PathPartner Radar SDK

PathPartner offers end to end algorithm package for radar application across various domain. We expertise in all formats (LRR, MRR and SRR) of radar application. PathPartner possesses expertise to deliver the algorithm pipeline to any different board for custom integration.

<table>
<thead>
<tr>
<th>Range &amp; Doppler Estimation</th>
<th>Threshold</th>
<th>Direction of Arrival</th>
<th>Clustering</th>
<th>Tracking</th>
<th>Classification</th>
<th>PC Tool UI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Considering the complexities and performance, FFTs are the best for range and doppler estimation</td>
<td>Adaptive threshold algorithms are required especially in radar use case for effective noise removal</td>
<td>Considering the limited number of antennas in automotive use cases, Super resolution algorithms with increased accuracy is mandatory</td>
<td>A proper algorithm is high required for grouping of detection points to objects in the noisy radar environment</td>
<td>Non linear tracking algorithm is necessitated by</td>
<td>Depending of use cases, classification can very from simple decision tree to classify static clutter objects to complex Random Forest classifier for pedestrian classification</td>
<td>Special features of display UI to ease the developers and testing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>To avoid miss detection due to occlusion</td>
<td>To track any object continuously across the RoI</td>
<td>Detection area selection, ADC data capture and analysis, point cloud data capture and replay etc.,</td>
</tr>
</tbody>
</table>

Our custom algorithms give better results in extreme conditions compared to any off the shelf algorithms. Our algorithm pipeline are sensor fusion ready, where in they can be used with imaging sensor too.

- **High accuracy**
- **Optimized**
- **Ready to integrate**

Please contact PathPartner for full details of the algorithms supported in Radar SDK.
Approaches to High Performance Radar Solutions

**FFT**
- Zoom FFT can produce high accurate range and doppler detections.
- FFT is performed with highly optimised intrinsic DSP libraries or on Hardware accelerators.

**Threshold**
- CFAR is an adaptive thresholding technique which sets the threshold based on nearby data.
- CFAR-OS implementation has both algorithm level optimisation and intrinsic optimisation.

**DoA**
- Super resolution DoA algorithms has the advantage of accuracy, resolution and noise immunity even with limited antennas.
- DoA algorithms require high level of optimisation to compensate for the heavy computation requirement.

**Clustering**
- Modified DBSCAN with effective density calculation algorithm can remove clutter points from active objects.
- DBSCAN is implemented with optimisation on both memory and computation.

**Tracking**
- A cluster point is considered valid only if it is present for more than 2 consecutive frames.
- Non linear tracking performs well in case of highly noisy inputs.

**Classification**
- Embedded classifiers like SVM and Random Forest with intrinsic optimisation provide promising results.
- Micro Doppler feature based classification of pedestrian.
Main Objective: Development of Radar based object classification

Scope of project: To design and develop a classifier based on radar point cloud detection. Two sub sections, namely:

- Detection of objects with considerably small RCS
- Classification of Human (VRUs) from other objects

Application: Detection of Vulnerable Road Users in urban environment is necessary for level 3 and above autonomous vehicles. Radar based VRU classification system can perform better than camera in no light/fog/snow conditions. It can at worst assist or provide redundant information to camera based system.
Automotive Radar is gaining importance nowadays as camera based systems can't meet all the requirements for autonomous driving.

Advantages like visibility at night, very long distance viewing, good performance in bad weather conditions etc are major plus for radar.

Major advancements are already done wrt Military systems to detect aeroplanes and ballistic missiles.

Applications not restricted to automobile, but from Drones, UAVs, Robotic systems, satellite imagery etc.,

Classification using Automotive Radar and human detection is a challenging area.
Automotive Frequencies

24 GHz
- Smaller Bandwidth (200 MHz)
- Interference with radio astronomy, satellite services etc.,
- Will be phased out in Europe by 2022

77 GHz
- Larger Bandwidth (4GHz)
- higher frequency : Smaller antenna (1/3rd)
- More Attenuation by atmosphere
Current State of the art: Mostly Camera is used for classification applications in automotive. This has issues in unfavorable environment conditions, cost and privacy

Project Objective: Radar based VRU detection can overcome all these problems and provide efficient solution for this purpose
- Frequency Modulated-Continuous Wave Radars
- The waveform is sinusoidal with linearly increasing frequency in time
- It can be Sawtooth or Triangular
- Triangular waveform has the advantage to distinguish multiple objects with unambiguous velocity.
- Sawtooth is generally used as it is easier to generate with simple hardware.
Hardware & Pipeline

- Radar Hardware supported at PP
  - Texas Instruments’ AWR1243, AWR1443, AWR1642, AWR1843, IWR1443, IWR1642, IWR1843, IWR6843
  - NXP’s TEF810x
  - Infineon’s BGT60TR13C

- PathPartner provides Radar Signal Processing algorithms that are
  - RF frontend agnostic
  - Partner SoC Agnostic
  - OS agnostic
  - Frequency band Agnostic (79GHz or 60GHz)

General Radar algorithm processing pipeline is provided below.

The classification block is introduced right after Clustering or Tracking.
Classification

- Various types of Classification methods. No single method is an universal solution.
- Based on the complexity of the application and the required accuracy of classification, the method is chosen.
- No of features determine the dimensionality – Higher the dimension, more difficult to properly classify
Automotive solution depends mostly on camera to perform the classification. No commercial only - Radar based classification is available in the market

Major issues:
- Detections
  - No of detection is low
  - No direct relevance to shape or size of the object
- Embedded implementation
- Moving radar sensor

Solvable????
Project Approach

The confidence to solve the current radar problems in classification comes from:

- Better RSP algorithms and PathPartner's accessibility to them. This includes super resolution DOA, hybrid clustering and tracking, noise immune CFAR etc.,
- Embedded implementation requires a simple classifier which mandates a strong feature set
- Classifier with low memory footprint and complexity
Machine Learning toolbox
Feature Selection & Extraction

- From the grouped radar object, various features can be extracted, which are fed to classification module.
- Feature selection helps in identifying the features which better represent the variance in the dataset with respect to classification parameters.
- Inbuilt analysis methods can be done to determine how good the feature set is and rank the features based on maximum contribution to classification and lesser repetition of same information.
- Feature Extraction is to combine multiple features in a way to reduce the final numbers of features. It helps in overcoming the “Curse of Dimensionality.”
- Its requirement depends on the no of features selected after Feature Selection step and the classification method’s accuracy and ability to handle multiple features.

<table>
<thead>
<tr>
<th>Functionality</th>
<th>Matlab in built commands</th>
<th>Toolbox</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature Selection</td>
<td><code>fscmrmr</code> <code>fscnca</code></td>
<td>Statistics and Machine Learning Toolbox</td>
</tr>
<tr>
<td>Feature Extraction</td>
<td><code>rica</code> <code>pca</code></td>
<td>Statistics and Machine Learning Toolbox</td>
</tr>
<tr>
<td>Visualization</td>
<td><code>tsne</code></td>
<td>Statistics and Machine Learning Toolbox</td>
</tr>
</tbody>
</table>
Exhaustive 21 features were collected from literature and previous experiences.
Feature selection analysis removed many repeating and redundant features.

Features like Density, number of detections and detection area, provide almost same and redundant info wrt classification.

Final list of 16 features were decided to be used.

Grouped into three board categories
  - Micro-Doppler based
  - Geometry based
  - RCS based

Sample Feature set

<table>
<thead>
<tr>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
</tr>
<tr>
<td>Acceleration</td>
</tr>
<tr>
<td>Reflectivity</td>
</tr>
<tr>
<td>No of scattering centres</td>
</tr>
<tr>
<td>Velocity profile centroid</td>
</tr>
<tr>
<td>Relative displacement</td>
</tr>
<tr>
<td>Velocity profile dispersion</td>
</tr>
<tr>
<td>Total instantaneous energy</td>
</tr>
<tr>
<td>Total time varying energy</td>
</tr>
<tr>
<td>Multi channel integration</td>
</tr>
<tr>
<td>Multi channel derivative</td>
</tr>
<tr>
<td>Temporal derivative</td>
</tr>
</tbody>
</table>
Feature Comparison – ML app

Predictions: model 1.11

Predictions: model 1.11
ML algorithms used in literature for Radar Classification:
- Neural Network -> People detection in doppler radars
- Decision tree -> military radar
- SVM-> VRU detection
- Random Forest -> Soli for gesture
- Ensemble bagged trees ->

Characteristics of dataset:
- Limited training data
- Non linear process

Constraints:
- Limited memory in embedded hardware : 300kB
- Less complexity as real time performance is required -> 5 to 10 fps
ML app – Cubic SVM results

Predictions: model 1

Model: Cubic SVM

Accuracy: 97.5%

Total training time: 12.656 sec

Features: 3036 features
# New Challenges

<table>
<thead>
<tr>
<th>Expected challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Response time</td>
</tr>
<tr>
<td>• The classifier took about 5-8s to classify a human.</td>
</tr>
<tr>
<td>• This is not a acceptable real time implementation.</td>
</tr>
<tr>
<td>• The algorithm was running at 3 fps and the classifier took about 15 frames to classify</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unexpected challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Motorcycle</td>
</tr>
<tr>
<td>• Motorcycle was mostly detected as human. This was because the reflectivity and some characteristics where from the human sitting on the motorcycle.</td>
</tr>
<tr>
<td>• Sensor movement</td>
</tr>
<tr>
<td>• When sensor is mounted in a car and the car is moving, the classifier accuracy goes for a toss. This is because the relative velocity is on a different band than stationary sensor</td>
</tr>
</tbody>
</table>
Solution & Re Design

Response time
- Improved frame time to 5fps
- Created new set of features which are moving averaged values of previous set of feature

Motorcycle
- New data capture and re training

Sensor Movement
- Remove any feature with mean value as a parameter, especially from velocity
- New data capture and re training

Company Confidential
Faster Development time

Verify and validate increase in accuracy, precision and Recall with:

- Every new dataset
- Selection of new features -> moving average values
- Improvement of old features -> velocity mean removal
- Inclusion of new features -> ego velocity
- Retrain and reload data

Data capture
- Real data capture from embedded
- Only features set is stored

Re train
- Load data & re train in Matlab
- Analyse proposed feature set options quickly

Load data
- Load classifier parameters into embedded
- Ready for next round of testing

Activity would usually take 3-5 months for this level of confidence to be developed. Took about 1 month time using Matlab’s ML toolbox.
Any change in Classifier takes about only 1 hour of effort which includes:

- 40 minutes for data capture
- 5 minutes to retrain classifier
- 10 minutes to reload code

Provide an Automotive ready classifier within a very short time.
Confusion Matrix

Model 1.11

<table>
<thead>
<tr>
<th>True Class</th>
<th>Predicted Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>4178</td>
</tr>
<tr>
<td>1</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td>14082</td>
</tr>
</tbody>
</table>

Company Confidential
ROC curve

Model 1.11

True positive rate: 0.99977
False positive rate: 0.88203

AUC = 1.00

What is the ROC curve?
Changes made in Feature set:
- Velocity Segmented energy: energy in certain velocity bands
- Removed mean velocity and mean angle as features
- Moving average features: Included 18 current frame features and moving average of those 18 features
- Normalized all features before Classification

Changes made in Classifier:
- RBF based SVM classifier: to improve non linear response
- Implementation of only predict feature to reduce computation

Results:
- Accuracy: 99%
- True positive Rate: 99.97
ML app results

Predictions: model 1.11

Accuracy: 99.0%

Training time: 22.65 s

Model Type: KNN

Validation: 5-fold Cross-Validation
Vulnerable Road Users detection

Future Work:
- Classify objects into multiple sections like human, bicycle, car and trucks
- Determine intention of human on pathway: Stationary or walking

Application use cases:
- Blind Spot detection in trucks
- Classification in multi radar Surround View
- Park Assist use cases
- Interior Sensing
- People detection & Tracking in Security scenarios
- People counting and Fall detection in medical scenarios
PathPartner in other verticals

<table>
<thead>
<tr>
<th>Automotive</th>
<th>Intelligent Devices</th>
<th>Digital Media Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADAS</td>
<td>Connected cameras</td>
<td>Next gen audio system</td>
</tr>
<tr>
<td>Infotainment</td>
<td>IOT &amp; medical devices</td>
<td>Broadcast &amp; video centric solution</td>
</tr>
</tbody>
</table>

**Engagement models**

- Turnkey
- Resource augmentation
- Fixed price – milestone based
- Time and material
- Onsite
- Offshore
- Hybrid
- ODCs