Machine Learning Approach for Vehicle Classification in Automotive Radar

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Abstract: *In this paper, we propose machine learning based approach for vehicle classification for automotive radar. We present the conventional Fuzzy based technique and its limitations. An approach to address the issues using machine learning techniques: logistic regression and Support Vector Machine (SVM) is presented and the results are shown using the real world radar data.*
Keywords: *Emergency Brake Assist (EBA), Object Classifier*

1. Introduction

In the modern day world of road fatalities Continental's radar is one of the world leaders in using automotive radar technology to save lives. The objective is to minimize fatalities with the use of multiple sensors: camera, lidar, radar etc. In this paper, we discuss the approach that adds intelligence to the vehicle with use of radar. In order to achieve this challenging goal for radar, other than obstacle detection or objects at distance, additional knowledge of something about the type of the object helps in a better decision making.

Proper classification of the class (Ex: Truck, Car, Pedestrian, etc.) is a key feature to be determined for semi and highly autonomous 'safe' driving. For example a truck has lesser maneuverability than a car which needs to be taken into account while acting on a given situation on the road.

The classification information is used for Emergency Break Assist (EBA) functionality which autonomously can break the vehicle when a confident obstacle is detected on the lane of the ego vehicle. Any radar hardware that meets the design criteria to have appropriate range resolution, velocity resolution and azimuth resolution will be able to apply the below approach to develop classifier.

2. Methodology

The radar transmits multiple pulses [1] and collects reflections from environment. The detections in the environment are appropriately associated [2] to create objects. The objects associated with detections are used as input to the object dimension classifier. The classifier is trained offline using an exhaustive labeled data collected in the field. The radar field data is collected using the vehicle fitted with automotive radar. The field data is a diverse data set obtained in different scenarios: highway, city, rainy, foggy, snow, with traffic, tunnels, subway etc. The classifier algorithm design involves following steps:

1. Collect radar recordings from the field with different types of objects car, truck, bus, van, etc.
2. Label the objects collected from the field
3. Train the classifier algorithm to learn the features of the object.
4. Use the trained classifier co-efficient to classify objects.

The advantage of this approach is that with the new recordings available with more data, offline training can be performed again to learn from the new data. This can be used to either further improve the algorithm or to add additional class.

The paper is organized as: the definition of the classification problem, conventional Fuzzy Logic Approach, and the machine learning approach used namely a) Logistic Regression and b) Support Vector Machine. The main objective of the paper is to analyze and compare the performance of the algorithms. The algorithms are introduced conceptually, however the details are ignored for sake of completeness so as to focus on solving the classification problem at hand. The development and details of the algorithms are available in [3] [4].

Classification Problem

The classification problem at hand using the parameters of the radar objects is categorize them as any one of the below four classes:

a. Small (Pedestrian, Bicycle, Motorcycle)
b. Car
c. Van
d. Truck

Feature Analysis of radar data

Data extracted from radar sensors is analyzed for unique features or signatures. With the visualization of the Radar object attributes Length, Width and RCS (Radar Cross Section), it is seen that objects can potentially be classified as the objects are well separated in these feature dimension. This features can be used for training the machine learning classifier.

The Length, width and RCS of the bigger object like Truck will be higher and for smaller objects these values will be in the lower range. The features of the object depends on the range of the object from the ego vehicle, so range is also taken as feature. In this paper, we have chosen those features that has significant effect on the classification accuracy. However, there is a trade-off between the number of features, computational complexity and classifier accuracy. The Machine Learning algorithm will learn properties of these attributes from different training samples.

FUZZY LOGIC APPROACH

Fuzzy Logics classifiers are rule based classifiers. A fuzzy classifier consists of four main parts: fuzzifier, rules, inference engine, and defuzzifier [5]. In Fuzzy classifier, Radar object attributes are converted into fuzzy set using linguistic variables, fuzzy linguistic terms and membership functions.

Fuzzy rule base is constructed to control the output variable. A fuzzy rule is a simple IF-THEN rule with condition and conclusion. Rules are defined for each Radar attributes and output of the each attributes rules are combined together to get the final classification output.

The fuzzy rule-based classifiers suffer from combinatorial explosion of the number of rules [6]. The main reason is that the classifier is trained by partitioning of the data space along each feature [7]. A careful pay-off between accuracy and transparency must be made. The system is not learning anything from the data and manual tuning is required when new feature or rule is defined. This results in re-designing the fuzzy system when additional data is available.

The following two Machine Learning approaches addresses the issues of fuzzy based approach and has better scalability in terms of algorithm improvement when new data is available.

A) LOGISTIC REGRESSION METHOD

Logistic Regression is basically a linear binary classifier [3]. This classifier fits linear boundary on the training data using gradient decent algorithms.

$$y = \theta_0 + \theta_1 x_1 + \theta_2 x_2 \ldots + \theta_K x_K$$

Where β = [θ_0 $\theta_1 \ldots$ θ_K] is the optimum co-efficient learned through training samples that would classify the different classes and $x_1, x_2, \ldots x_K$ are different features (Ex: Length, RCS, etc). If we take all the K features, we will be learning K-dimension co-efficient. In most practical cases, all the features might not be required. There are methods which can be used to decide on the major features. Since this is beyond the scope of the paper, it's not discussed further. More information is available in [3].

Logit or sigmoid model is used to map projection values to 0-1 probability scale

$$log \frac{p(x)}{1 - p(x)} = \theta_0 + \beta X$$

$$p(x) = \frac{1}{1 + e^{-x}}$$

Here we have used One Vs All method for training multi class objects. Each time one class will be taken as positive class and all other considered to be negative class, this will be done for all the classes, we will get 4 set of coefficients for each class. Dimension of the coefficients would be feature dimension plus bias. Accuracy of the algorithm depends on the data which will be learned, if the data is linearly separable in its feature dimension then classification accuracy will be good.

Gradient decent algorithm is used to estimate the parameters. And it will be mapped to 0 to 1 probability values using softmax function $p(x)$.

Total extracted labeled data is divided into testing (70%) and training (30%) sets randomly. Training set is the data with label which will be used to train the data and the test set is like the field data which will be used for testing the model accuracy, this will be repeated five times and each time model accuracy will calculated, Then the trained model is used for classify the test data from the field.

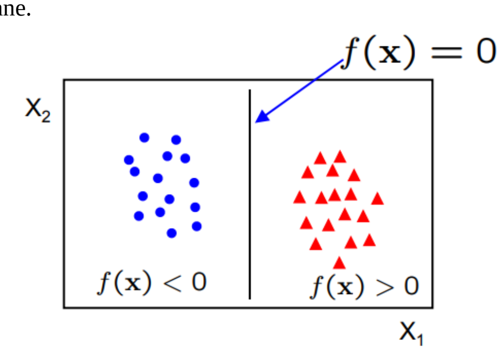
B) SUPPORT VECTOR MACHINE (SVM) METHOD

Support vector machine is basically a linear binary classifier, which learns the line (plane in K dimension) which separates the classes by maximizing the margin [3]. In Figure 1, a linear binary classifier is shown as an example in 2 Dimension for visualization. However, SVM can be used to classify cloud of points in K-dimension based on K different features.

A linear classifier has the form

$$f(X) = W^T X + b$$

Where W is the set of co-efficients and X as the input K dimensional features. The result is a (K-1) dimension hyper plane.



One vs All method is used to solve the multi class problem, Radar object attributes were fed to the support vector machine to learn the decision boundaries. Hyper plane is learned from the training data, since the SVM is computationally heavy the training time is higher.

3. Testing of the Algorithm

The co-efficients learned in the off-line training process can be verified by embedded the classification algorithm in the radar signal chain. A lab validation on the performance of the algorithm can be performed by using the field recordings and verifying the classification. Once the algorithm, and coefficients are validated for their performance, the algorithm can be scaled-up for production in radar software.

4. Important Outcomes

Machine Learning algorithm will make the system to identify the subject vehicle in front of the ego vehicle based on the dimensions. Vehicles can be categorized into different classes [3] based on its dimensions like small object, car, pedestrian, truck etc. In this study, we have used SVM (linear & non-linear) and logistic regression. With training, it is found that logistic regression takes lesser time and has lesser computational load for real-time implementation. The classification of four different classes namely: small, car, truck and large objects is shown in the Figure 1. It can be seen that the posterior probability of each of the class is correct atleast 90% (yellow region) of the time. This information is useful for EBA.

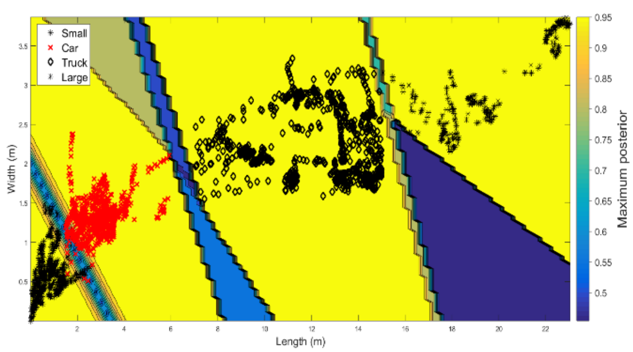


Figure 1 Vehicle Classification based on dimension: length, width and RCS (not shown in figure) using Logistic Regression

The percentage accuracy of each of classification algorithm namely: Fuzzy Logic, Logistic Regression and SVM is shown in Figure 2 with 3 fold validation (i.e., done three times for different sample set of test data). It can be seen that the accuracy of fuzzy logic is only about 60% which is due to the rules that couldn't include all the features of the data. Alternatively, the performance of logistic regression and SVM is around 80% and their accuracy is comparable. Depending on the application, complexity, training time the developer has the freedom to choose logistic regression or SVM.

5. Conclusion

Machine Learning algorithm will give intelligence to the system to identify the object in front of the ego vehicle, which will help in understanding the surrounding without any human interventions. The ego vehicle will be able to understand the surrounding and act accordingly. Since the RADAR sensor is less susceptible on environmental conditions like low light, fog, rain. Identification of the subject vehicle will be more accurate on different environmental conditions than the camera sensor based vehicle classification. Though it's time-consuming to generate the classifier co-efficients (which is one time), the classifier has manifold improvement in radar intelligence and the safety of the passenger.

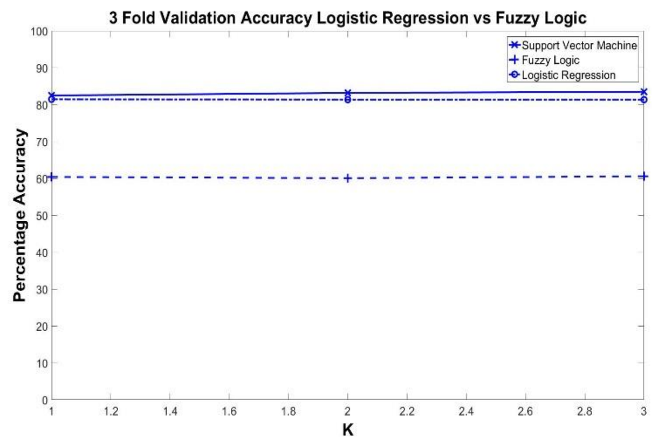


Figure 2 Comparison of the performance of Fuzzy Logic, Logistic Regression and SVM

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Sujith KS joined Continental AG Bangalore in 2106, is responsible for developing Machine Learning algorithm for radar sensors He has exposure in computer vision, image processing and had his internship at Tata Consultancy Services Lab. He has his Masters (Digital Signal Processing) from Indian Institute of Space science and Technology, Trivandrum in 2016 and Bachelors in Electronics and Communication Engineering from Cochin University in 2013.