On the Use of Low-Cost Radars and Machine Learning for In-Vehicle Passenger Detection

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Abstract

In this paper, we use a low-cost low-power mm-wave frequency modulated continuous wave (FMCW) radar for in-vehicle occupant monitoring. We propose an algorithm to identify occupied seats. Instead of using a high-resolution radar which increases the cost and area, we integrate machine learning algorithms with the results of covariance-based angle of arrival estimation capon beamformer.

1 Introduction

Human monitoring plays an important role for several applications. Most of the existing occupancy detection methods were applied for building automation control, public safety and intelligent transportation [1]. However, in automotive safety technologies, the ability to identify if a seat is occupied by a passenger or not is rapidly gaining importance. The most commonly available seat-occupancy monitoring sensors are mechanical sensors, mechanical sensors may fail to distinguish between humans and objects placed over the seat and, thus, are prone to false alarms. Different limitations also apply to camera vision [2], infrared (IR) [3] and acoustic sensors, which suffer from obstructed line-of sight conditions. Furthermore, camera-based systems and IR sensors are sensitive to illumination levels and sunlight. Radar sensors provide a promising approach to overcome the problems of dead spots and dependency of environmental conditions in conventional occupancy sensors.
We used FMCW radar [4] to count the number of passengers in a vehicle as well as to identify their seat numbers. Increasing the resolution of radar requires a large number of transmitters and receivers would result in higher system cost and more operational complexity. Hence it is desirable to achieve accurate occupancy detection with low-resolution radars.
In this paper, we applied machine learning on the data from non-expensive FMCW MIMO radar to accurately provide information about the passenger (s) presence and location within the vehicle. Based on the attributes obtained from range-azimuth maps, using capon beamforming algorithm, we trained RF, KNN and SVM classifiers to identify occupied seats in a vehicle.

2 System Design

The range FFT is applied on the received chirp samples. At the receiver, the signal is collected and assigned to a virtual channel such that each channel contains the data transmitted and received from and to a unique pair of transceiver which is done in stationary clutter removal stage together with removing the average of each range bin. Then, capon filter was applied to estimate the angle of arrival spectrum of each range. By putting them in a matrix, range-azimuth map will be constructed and is delivered to ML section to perform classification.

3 Experimental Results

Using mm-wave FMCW radar, our measurements were conducted in a minivan with three rows and seven seats. Our main purpose was to count the number of passengers in the second and the third rows in addition to know their positions; i.e., to identify the seat numbers which are occupied by passengers. Therefore, we had 32 possible situations (25) for five seats in the vehicle. To achieve the specific performance of the radar with a visibility range of approximately 2 m and the resolution of 4 cm, the chirp duration was 62 ms with an idle time of 250 ms, the slope frequency was 60 MHz and the sweeping bandwidth was 3.6 GHz. During recordings, passengers were allowed to freely move their hands, talk to each other, and work with their phones. We applied SVM, KNN and RF to classify the capon filter output for five seats. Applying principle component analysis, the size of features was reduced without information loss. A grid search with 5-fold cross validation was employed to search for the best hyperparameters that will increase the prediction accuracy of the classifiers. However, to identify passengers with this limitation, we applied machine learning. In order to obtain dataset, we recorded 73,209 frames of 32 possible situations of five seats. We had five seats in our vehicle under test, and we used machine learning algorithm five times. For instance, for seat 3, our goal was to identify if seat 3 is occupied or not, leading to a binary class, 0 or 1. Therefore, we labelled all our dataset as "1" when someone was sitting in seat 3, otherwise the label was "0". We repeated this procedure for all five seats, second and third rows, and ran the classifier for each seat. Fig. 2 illustrates the results of our proposed method based on machine learning classifiers.

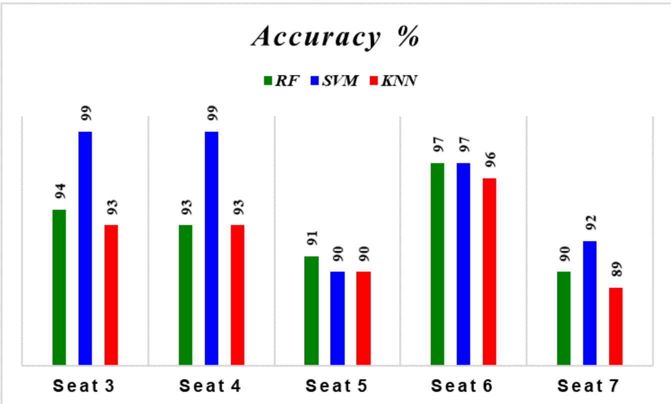

Fig. 1: Accuracy of different classifiers for method for five seats (RF:Random Forest, KNN: K-nearest neighborhood, SVM: support vector machine)

4 Conclusion

In this paper, we investigated the in-vehicle occupancy detection with a mm-wave FMCW radar. Also, we addressed the low angular resolution which limits the visual perception of the occupant location. However, with the utilization of a machine learning classifier, a high detection accuracy was obtained across multiple possible scenarios.

References

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