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Contributions to improving the adaptability of radar sensor systems in the automotive field

Doctoral Thesis - Abstract

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The PhD thesis aims to develop methods and techniques for the automatic compensation of mounting errors and those induced by vehicle bumpers for radar sensors used in the automotive industry. These things are critical to improving the accuracy and reliability of driver assistance systems and autonomous driving functions. Radar sensors are critical to modern vehicles, providing vital information about the surrounding environment. Incorrect mounting and angular distortions caused by the bumper can lead to significant errors in measurements, affecting the performance of active safety systems.

The thesis proposes innovative solutions for the critical problems encountered by the automotive industry in the use of radar sensors. The developed automatic compensation methods can become standards in the design and implementation of vehicle radar systems, thus contributing to technological progress and improving road safety. Radar functionalities require very good accuracy in azimuth and elevation, but these attributes are much more easily affected by the environment than other attributes, since the automotive radar is mounted behind a bumper. The bumper causes angular measurement errors due to its physical properties: shape, material, color, thickness.

These measurement errors will degrade system performance, leading to local angular distortions.

Another type of angular (global) distortions are caused by sensor mounting errors in azimuth and elevation at the factory, or in the case of minor accidents that result in misalignment of the radar sensors with respect to the mounting angle. The angular self-calibration of sensors is a very important topic in the automotive field, due to the negative impact on functionality in its absence. There are offline calibration methods, which are carried out in the automotive customer's production plant or in service (End Of Line Calibration). These involve placing the vehicle in a well-determined set-up together with various reference objects, whose attributes such as position and azimuth and elevation angles are well known, respecting tight tolerances. These methods are disadvantageous both financially and in terms of the time required to perform the calibration of a vehicle.

Other methods of calibrating mounting angles in azimuth and elevation can also be obtained in a controlled environment but with fewer restrictions, using data from other automotive systems, such as Lidar and cameras. The main advantage of these methods is to provide an initial elevation mount angle calibration if the radar does not support elevation angle measurement. However, a big disadvantage of these methods is the fact that they only provide an initial calibration of the mounting angles, not providing long-term compensation.

Online azimuth mounting error compensation methods can be based on a reference consisting of a static object parallel (street or highway edges) to the driving direction of the vehicle or based on data fusion from multiple sensors. To compensate for local angular distortions in azimuth, there are different offline methods based either on simulations that include knowledge of the bumper properties, or on methods that require receiving a signal from a target with a known angle.

For automotive radars, these types of offline calibration present great difficulties, due to the need to calibrate the sensors after mounting them behind the bumper, as well as the related cost of allocating a special space for the setup. These types of corrections should ideally be automatic, taking into account both radar wear and the wear and tear of the bumper properties over time. There are automatic local offset compensation methods for MIMO (Multiple-Input and Multiple Output) radars, but they require a special setup and present difficulties in adapting for SIMO (Single-Input and Multiple Output) radars, as well as a feasible method for radars SIMO, which generates a correction table by performing a regression of the bias error function. A disadvantage of this solution is the incorporation of the Monte Carlo Markov Chain (MCMC) method in performing the regression of the error function, due to the high computing power.

The original contributions of this PhD thesis include the introduction of new methods for evaluating mounting errors in azimuth and elevation, compensating for bumper effects on the azimuth surveyor, and detecting angular distortions in azimuth caused by meteorological phenomena, for radar systems mounted on cars.

The method of compensating the angular offsets in azimuth, caused by the influence of the integration of the radar sensor in the vehicle, provides an automatically adjustable calibration process, adaptable to any vehicle, which can accurately compensate offsets, and which can generate statistics that characterize and evaluate the obtained correction curve.

A method to compensate for the azimuth mounting error when the errors caused by the integration of the sensor in the vehicle have not been compensated proposes to divide a wide angular range into more sectors and calculate the mounting error for each sector separately, so that based on some statistical processes the best sector is chosen in order to provide an automatically adjustable calibration process, adaptable to any vehicle, that can accurately compensate for offsets and that can generate statistics characterizing and evaluating the correction angles obtained for each sector. For the calculation of elevation mounting error, three distinct methods are presented as original contributions. One method uses stationary reference structures made of metal or concrete, such as the edge of the street, structures that have an approximately constant height with increasing longitudinal distance from the vehicle.

The other two alternative methods to the previous one for unsupervised online calibration, in the context of vertical alignment of an automotive radar, are based both on the calculation of a reference height from stationary targets at a short distance, extrapolating the reference height for targets at a greater distance, and the use of ground clutter targets, having as reference the distance of the sensor from the ground.

A method was also proposed for the simultaneous calculation of compensation values for mounting errors in azimuth and elevation, being based on the use of stationary targets using tuples of three targets each to solve equations with two unknowns, these being the mounting corrections in azimuth and elevation. These values are approximated with a modified Levenberg-Marquardt method in which we proposed the use of an update step based on the RMSProp method, but keeping the influence of the parameter λ that can make the transition from a gradient descent algorithm and the Gauss-Newton method. This together with the application of confidence regions provides fast convergence of high accuracy. Finally, a method for improving the adaptivity of radar sensors in the context of the detection of angular distortions caused by the accumulation of snow or ice on the vehicle bumper was proposed, marking a final personal contribution.

The detector is based on a modified version of the local error compensation method using the vehicle speed and the measured azimuth angle. For the purpose of angular distortion detection, the detector calculates various properties and characteristics of the correction table at the end of each plausibility cycle.

The proposed methods have a particular practical relevance, being already partially used for the latest generation radar systems, developed and produced by the Forvia-Hella company, installed in the latest generation cars of many major car manufacturers. This research makes a significant contribution to the field of automotive radar technologies, providing a solid framework for future developments and innovations in this sector.