Noise Filtering in Autonomous Emergency Braking Systems with Sensor Fusions

論文
IA-04-0012

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執行期間：104.1.1 ～ 104.12.31

中華民國 一百零四年 七月 九日
Noise Filtering in Autonomous Emergency Braking Systems with Sensor Fusions

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Abstract

This paper discusses noise filtering in an autonomous emergency braking (AEB) system with a sensor fusion between a millimeter wave (MMW) radar and a camera. Three kinds of noise, namely twice harmonic noise, ground noise, and specular reflection noise, are then filtered. The former is caused by the reflection of a radar wave between a target object and the MMW radar; therefore, one of the sensing distances would be twice as longer as one of others. An object featuring this characteristic is treated as the noise and filtered. Next, detecting a ground metal as the target object generates the second noise with a focus of car-like objects. That is, an object—with the sensing distance from the MMW radar being smaller than that from the camera by a threshold value—is taken as the ground metal noise and ignored. Moreover, the third noise happens when there is a radar wave reflection between an object and its surroundings. While one focuses on standard derivation (SD) of a difference between the real and estimated object position from an object tracker, the specular reflection noise naturally reveals high SD. An object revealing this characteristic is hence removed from sensing data. Verification results indicate that the surroundings filtered by the proposed mechanisms are simplified such that the AEB system catches the right target object with its sensing distance being within [5, 50] (m) and our car speed lying within [10, 50] (km/h).

Introduction

Car accidents are commonly induced by distraction in car driving. This gives rise to the requirement of safety systems, such as autonomous emergency braking (AEB) systems [1] and forward collision warning mechanisms. In particular, Euro NCAP has announced that the assessment program must include AEB technologies since 2014 [2-3].

The AEB system normally consists of several parts, including an object sensing module, a data processor, a driver warning module, and a braking control device. The former is quite different between different types of AEB systems while the others are the same between such types. For example, a city safety system, a kind of AEB mechanisms suitable for low speed driving, mainly aims at the collision avoidance between cars and pedestrians [4-5]. To guarantee the detection of the pedestrian, such systems commonly apply cameras as the desired object sensor. However, the camera may fail in the object detection because of lacking visibility.

Fusing multi sensors in the object detection improves this disadvantage [6-8]. In addition to the city safety system, the sensor fusion is also implemented in another kind of safety system, an inter-urban system for high speed driving, which mostly adopts radars [9] or lidars to detect objects. Although the AEB system has been stabilized by applying the sensor fusion method, it may still work incorrectly if a noise signal is focused as the target object in AEB strategies (i.e., the AEB mechanism is activated by this noise). As a result, car accidents may be induced via the unexpected AEB operation.

This motivates us to design a noise filtering manner in the AEB system with a sensor fusion. Three kinds of noise are considered in this paper: the twice harmonic noise, ground noise, and specular reflection noise. Corresponding filters are constructed by investigating the causes of these three disturbances, respectively. The launching point of this paper is that applying the designed filters in AEB systems further simplifies the sensor data and avoids unexpected braking operations.

System Description and Problem Definition

AEB System Description

![Figure 1. Architecture of the proposed AEB system.](image)

<table>
<thead>
<tr>
<th>Device</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMW radar</td>
<td>Maximal sensing distance: 327.64 m</td>
</tr>
<tr>
<td></td>
<td>Sensing period: 64 ms.</td>
</tr>
<tr>
<td></td>
<td>Sensing angle: ±10 degree</td>
</tr>
<tr>
<td>Camera</td>
<td>Sensing distance range: 5-50 m</td>
</tr>
<tr>
<td>MCU</td>
<td>Chip mode: dsPIC30F6010A.</td>
</tr>
</tbody>
</table>
Figure 1 shows the proposed AEB system, including a camera, a MMW radar, a car signal provider, a MCU/DSP board, a warning module, and a braking actuator. Table I lists their hardware specification. Furthermore, in the beginning of the AEB procedure, the MMW radar detects objects and transmits results to MCU, which classifies the obstacles into those in front of the driving car and the others. The obstacle data, such as the position and moving speed, of the former are then sent to DSP for further sensor fusions with the camera image. In the fusion process, one applies DSP to identify that whether the objects located in the received radar positions are cars or not. After the identification, DSP returns the sensing distance from the camera of the nearest car-like object to MCU based on the pixel analysis; it simultaneously signals the location of the nearest car to MCU via a flag. The time to collision (TTC) with respect to this car is computed by using MCU. If TTC is smaller than a predefined value, MCU enables the warning module to signal users to stop cars with a buzzer and a warning image. If the user does not stop the car while approaching the front vehicle, the AEB system will automatically stops cars by activating the braking actuator. This completes the AEB task.

Problem Statement

The AEB system equipped with the MMW radar inevitably detects a noise signal; it may decelerate the car due to the appearance of this noise object. A car accident would occur accordingly. For example, a car accident has happened in Japan in 2013 due to the unexpected brake via AEB systems. In this case, the MMW radar suddenly detected a noise signal in front of the driving vehicle. The AEB module immediately braked the car to avoid the collision with this pseudo obstacle. Due to this unexpected operation, a following car bumped into the braked vehicle. To avoid this kind of accident, we have to construct noise filters in AEB systems so that the AEB mechanism should not be activated by the noise signals. The considered problem is hence defined as that how to identify the noise signals from the MMW radar and filter them in a systematical manner.

Main Results

Noise Definition and Filtering Strategy

Three kinds of noise, such as the twice harmonic noise, ground noise, and specular reflection noise, are considered in this paper. Let us next introduce them in details.

Twice Harmonic Noise

The harmonic noise is resulted from the reflection of a radar wave between a target object and the MMW radar. As shown in Fig. 2, the radar wave may reflect between the front car and radar for one more time in the case of Fig. 2(b) than that in Fig. 2(a). Because the MMW radar evaluates the sensing distance based on the time interval between the transmitting and receiving of the radar wave, the sensing distance corresponding to the noise signal would be twice as longer as one of others due to the additional wave reflection. An example is displayed in Fig. 3, in which the point A is a noise signal. This motivates us to capture the noise signal based on the comparison of the sensing distances between objects; however, the existence of the measuring disturbance complicates this identification.

To deal with the effect of the measuring noise on fluctuation of coordinate values, one discusses the standard derivation of the coordinate values for a static object. Given the standard derivation
and the averaging coordinate value \( \bar{x}_y/\bar{y}_x \) for x-axis/y-axis, the static object’s x-axis/y-axis value will lie within the range \( [\bar{x}_y - 3\varepsilon_y, \bar{x}_y + 3\varepsilon_y] / [\bar{y}_x - 3\varepsilon_x, \bar{y}_x + 3\varepsilon_x] \) with a probability 0.997. In other words, the object \((x_1, y_1)\) is regarded as the twice harmonic noise and filtered if there is an object \((x_2, y_2)\) satisfying \(|x_2 - x_1| \leq 3\varepsilon_x\) and \(|y_1 - 2y_2| \leq 3\varepsilon_y\). Objects holding these two inequalities are ignored.

**Ground Noise**

The AEB system may automatically brake the moving car by suddenly catching a front ground metal, like the detected objects illustrated in Fig. 4, while the driver is actually not threatened by the metal. Conversely, suddenly decelerating the driving car largely threatens the user by inducing a car accident. Hence, the AEB mechanism should not be activated by such ground metals. This explains why we treat ground metal signals as disturbances and filter them.

![Figure 4. Example of detecting ground metals as the front objects.](image)

The ground noise can be identified by comparing all the sensing distances from the MMW radar and the camera, respectively, where the sensing distance of the object in front of the car is derived based on the sensor fusion of the MMW radar data and the camera image. Precisely speaking, one determines whether the nearest front obstacle located at its corresponding radar position is car-like or not by catching the characteristic in vision space. Two kinds of characteristic are considered next—one is the symmetric feature and the other is the shadow property. The former is investigated by catching the boundary shape of the considered object and searching for its symmetrical axis. The latter is recognized by adopting following equation and Sobel boundary detection. The analysis of the shadow property is accomplished by searching for the boundary image of the object shadow. For the object showing the detected shadow, its sensing distance is derived as

\[
d_2 = \frac{H_c e_p}{v_0} - d_1
\]

where \( v_0 \) is the height of the image center in image, \( H_c \) means the height the camera located in real world, \( e_p \) states the camera focal length, \( d_1 \) denotes the distance from the camera to the car’s front bumper, and other parameters are as defined in Fig. 5.

![Figure 5. Parameters in the sensing distance computation.](image)

Since the ground metal is not a car-like object, the camera could not evaluate its sensing distance upon (2); instead, it would catch another car-like one as the target of calculating the sensing distance. The object signal—with the sensing distance from the MMW radar being smaller than that from the camera by a threshold value—is therefore treated as the ground metal noise and filtered. Notice that this threshold value is evaluated as larger than the maximum of theoretically sensing errors from the camera with respect to the real distance range 5-50 m.

**Specular Reflection Noise**

![Figure 6. Example of the specular reflection noise, (a) camera view and (b) object positions from radar.](image)

The specular reflection noise occurs when there is a random radar wave reflection between an object and its surrounding devices. This
gives rise to two characteristics: i) the MMW radar would detect an obstacle position which corresponds to nothing in real world; and ii) the specular reflection noise reveals high SD while we focus on the SD of a difference between the detected and estimated object position from an object tracker, established by using extrapolation method. Furthermore, Fig. 6 shows an example of the specular reflection noise. Compared to the camera view in Fig. 6(a), one can find that a noise object appears in Fig. 6(b) because of its unreasonable position, which corresponds to the inside of a building in Fig. 6(a).

Instead of manually determining the appearance of the considered noise by a comparison between radar positions and the camera view, how to recognize this noise in a systematically manner is worth of further attention. The current noise can be identified by studying the SD of the difference between sensed and estimated locations. An object revealing the SD larger than others by a threshold value is considered as the noise and filtered. Let us explain how to perform the specular reflection noise filtering in this way by introducing an example.

Similar to the scenario in Fig. 3(a), we conducted object detections and computed the mentioned SD, as displayed in Fig. 7, in which the MMW radar sensed six objects and transmitted their positions to MCU by using controller area network (CAN) with ID 0x290-0x295. It can be observed that the object form ID 0x294 features a quite larger SD value than others in Fig. 7. How to mathematically identify this property is still unsolved.

The considered problem is solved by three steps: i) organize the SD values \(SD_1-SD_6\) as \(SD_{value} = [SD_1, SD_2, SD_3, SD_4, SD_5, SD_6]\) where \(SD_i\) denotes the SD for the \(i\)-th object, \(SD_i \leq SD_{i+1}\), and \(i = 1-5\); ii) find the SD of \(SD_{value}\); and iii) treat the object featuring \(SD_{i+1}\), which is larger than \(SD_{SD_i}\) by a predefined value, as the noise signal where \(SD_{SD_i}\) represents the SD generated from \(SD_1-SD_i\), and this threshold value is selected by experience. The obstacles guaranteeing the above feature should be ignored except the nearest car-like object in front of the MMW radar.

**Experimental Results**

This section gives three case studies of filtering the twice harmonic noise, ground noise, and specular reflection noise. After the verification of the proposed filters, the advantage of simplifying the surroundings around the driving car equipped with the MMW radar was significantly addressed by conducting an on-line test of the AEB mechanism in real world.

**Twice Harmonic Noise Filtering**

An experiment of filtering the twice harmonic noise was conducted with a similar scenario in Fig. 3(a), in which there is a static car in front of the vehicle equipped with the AEB system using the MMW radar and camera. Experimental results are as shown in Fig. 8, in which a noise signal obviously appears at the location (-0.5, 12) (m) in Fig. 8(a). After the filtering operation in the proposed manner, this twice harmonic noise has been ignored, as well as what displayed in Fig. 8(b). This indicates that the AEB system supporting the proposed filters was capable of removing the twice harmonic noise from the sensor data.

![Figure 8. Verification of the twice harmonic noise filter, (a) results without filtering and (b) results with noise filtering.](image)

**Ground Noise Filtering**

An experiment was performed with a scenario in Fig. 9(a), in which a box stuck with metal tapes is taken as the ground metal, and a static car was parked in front of the box. As mentioned previously, the camera system computed the sensing distance by focusing on this static car instead of the ground metal while the ground metal was the nearest object. The sensing distance from the camera is hence larger than that from MMW radar in Fig. 9(a) by 6 m, which is larger than the threshold value 5 m, which was determined upon a concern that the maximum of theoretically sensing errors from the camera with respect to the real distance range 5-50 m is 5 m. A ground metal noise hence showed on (-0.5, 9.5) (m) in Fig. 9(b) according to the proposed methodology. Experimental results in Fig. 9(c) state that the ground metal was successfully removed from the sensor data after the application of the designed filter.

![Figure 9. (a) Sensing distance from radars and cameras, (b) Sensing distance from cameras, and (c) Sensing distance from radars.](image)
Three noise filters are shown in Fig. 9. Figure 10 reveals that the AEB system performing the designed methodology and the optimal one.

The remaining noise was not filtered due to the cause that the threshold value was determined as 0.7, which was not the optimal one. This simplifies the radar data in AEB strategies and reveals that the AEB system performing the designed methodology was capable of filtering the specular reflection noise.

**Specular Reflection Noise Filtering**

The proposed filter for the specular reflection noise was verified with a scenario in Fig. 10(a), where a static vehicle was in front of the driving car. In the surroundings of Fig. 10(a), raw data from the MMW radar are as displayed in Fig. 10(b), where tow static objects are detected, and three specular reflection disturbances show up at (4, 30) (m), (4, 42) (m), and (4, 50) (m) because one cannot find the corresponding objects in Fig. 10(a) on these three locations (they are in the outside of the wall). Furthermore, after the performance of the filtering strategy, it can be observed that two of the noise signals disappear in Fig. 10(c). The remaining noise was not filtered due to the cause that the threshold value was determined as 0.7, which was not the optimal one. This simplifies the radar data in AEB strategies and reveals that the AEB system performing the designed methodology was capable of filtering the specular reflection noise.

**Conclusions**

This paper has investigated noise filtering in an autonomous emergency braking (AEB) system with a sensor fusion between a millimeter wave (MMW) radar and a camera. Three noise filters are proposed to avoid unexpected operations of the AEB system caused by the sudden appearance of the noise signal; they work for twice harmonic, ground metal, and specular reflection noise, respectively. By discussing the cause of such noise, the filter for the first noise is constructed by the comparison of the sensing position from radars, the one for the second disturbance is developed based on the computation of standard derivation values, and the other is designed in a sensor fusion manner. With the aid of the proposed methodology, possibility of activating AEB systems by detecting noise has been reduced by simplifying the sensing data.

**References**


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Figure 9. Verification of the ground metal noise filter, (a) a scenario, (b) results without filtering, and (b) results with noise filtering.

Figure 10. Verification of the specular reflection noise filter, (a) a scenario, (b) results without filtering, and (b) results with noise filtering.

Figure 11. Object detection from MMW radar, (a) raw data and (b) filtered results.

**On-line Verification of Noise Filters**

To emphasize the ability of simplifying the radar data in the AEB mechanism upon the proposed methods, an on-line experiment was conducted on an urban road. Experimental results are as illustrated in Fig. 11, in which Fig. 11(a) displays the raw data from the MMW radar and Fig. 11(b) shows the filtered ones with the blue car representing an alarming signature. From Fig. 11, it can be observed that one of detected objects in Fig. 11(a) has been removed from results in Fig. 11(b). The remaining one was the target car. This implies that the detected environment was simplified such that the AEB system could easily catch the target vehicle. Moreover, given total 92 target cars suffered in the on-line experiment, 75% of objects focused by the AEB system without filters were real cars; however, 89% of objects focused by the AEB system were real cars after the application of the proposed filters. Performing filtering thus enhances the preciseness of catching front cars.


**Acknowledgments**

This work was supported by Department Industrial Technology, Ministry of Economic Affairs, Taiwan, R.O.C under grant 104-EC-17-A-23-0803.