

Sensor Type and Calibration Techniques on Multisensor Fusion and Their Application in Self-Driving Cars

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Abstract. The technology of multi-sensor fusion has had a significant influence on the sphere of self-driving vehicles. This paper commences by giving the roles of different sensors; the two most common sensors are radar and camera. It then goes on to tell about sensor calibration methods, and lastly gives information about the use of sensor fusion technology. The research concludes that Multisensor fusion is capable of bringing out the benefits and information of many sensors and coming up with the most optimal result. The sensor fusion allows vehicle brands to mature their autonomous driving technologies. It also contributes greatly to the accuracy of the perception and the environmental modeling of the cars, as well as showing significant improvements in cost reduction and scalability. Nevertheless, it has issues with this technology, especially sensor heterogeneity and alignment of spatiotemporal data, which have been a big problem.

Keywords: Multi-sensor fusion technology, Radar, Camera, Pinhole model, Calculating methods.

1 Introduction

Autonomous driving technology has a good market potential in the technology era. The technology puts high requirements on the obstacle avoidance and navigation/localization of vehicles. Multi-sensor fusion technology is one of the strong solutions to this challenge [1]. The multi-sensor technology is the fusion process that entails the gathering of raw data about the environment or targets by using various sensor types (radar, cameras, LiDAR, inertial navigation units, and so on). This is then followed by filtering algorithms to eliminate random noise that came about either by the sensors themselves or by the environment. Lastly, the technology carries out temporal and spatial calibration, and it deals with the time spatial alignment between data as collected by several sensors. This is done by filtering invalid data due to sensor failure or extreme environmental conditions.

The Kalman filter is a recursive optimum estimation algorithm that is grounded on linear system state equations (i.e., an algorithm that is always optimal in estimating system state, using noisy observation information, recursively determined). This algorithm is conceptually straightforward to change the estimate by taking the outcome of the last moment and the present observation [2-4]. As an example, in the recently suggested pure vision fusion solution of Tesla,

the FSD system. This system is based on eight cameras and neural networks that combine multiple frame time-related data and BEV (Bird's Eye View) features. This solution can enable Tesla to have numerous opinions that can improve the perception of the environment around the vehicle. Therefore, the multi-task neural network design of FSD can be more refined to meet the safety decision making needs of complex driving environments, as the multi-task neural network is capable of executing multiple tasks at once, such as object detection and semantic segmentation. This solution allows Tesla cars to circumvent the problems of path deviation in the foremost way when they are controlled and is able to combat negative factors [5].

An autonomous driving paper is a series of research and reviews based on minimizing the positive and negative aspects of autonomous driving as an optimization of the fusion algorithm, focusing on maintaining balanced performance and accuracy and the fault tolerance of the system, along with the necessity to balance the need to satisfy the real-time performance criteria of the system and its ability to ensure quality performance. It defines the concepts of Multisensor fusion technology first, and in light of this definition, extends further into the study of sensor types and the method of calibration. The following paper will also seek to give an overview of Multisensor fusion technology of obstacle avoidance of self-driving cars, as well as vehicle navigation/localization, and develop a systematic theoretical knowledge. Theoretically, it aims at the optimization of sensor configuration schemes and fusion mechanisms towards autonomous driving. Building theoretical frameworks of sensor arrangements, which combine redundancy and cost efficiency, and enhancing the algorithmic rationale of multi-modal data fusion, the following work will contribute to the advancement of knowledge on how autonomous driving perception systems operate.

2 Technology Multisensor fusion Tech Principles and Characteristics

2.1 The principles of Multisensor fusion Tech are outlined through

Multi-sensor fusion technology combines gadgets on varied concepts and dimensions to awaken as a team to enable one or more effects. One such example is infrared cameras, millimeter-wave radar, and lidar, which interact in the vehicle environmental perception to improve road safety in driving [1, 6]. The success that they take relies on the optimization of the algorithms. The conventional Kalman filtering (KF) and extended Kalman filtering (EKF) algorithms are mostly employed to remove noisy sensor data. The two algorithms are used in the localization and tracking tasks of targets in autonomous driving [7].

2.2 Properties of Multi-Sensor Fusion Technology

This attribute underscores the fact that sensors work together using different detection principles, and their application in various cases and the information that they retrieve is varied. Therefore, the combination of these sensors can result in the fact that information acquired in various sources can be used to support each other, allowing for a clearer picture of the current environment. Multi-sensor fusion technology also involves consecutive detection of the same target or area by all the sensors, permitting the output of information by different sensors to be cross-validated. This minimizes the potential of error and improves the consistency of results [8]. Fusion is classified into three levels in the layered processing, namely data fusion, feature

fusion and decision fusion. The essence of the algorithm that makes multi-sensor fusion possible in that regard is known as the Kalman filter where it is applied to the estimation of the state of dynamic targets [9]. The functionalities and distribution of each sensor are depicted in Figure 1.

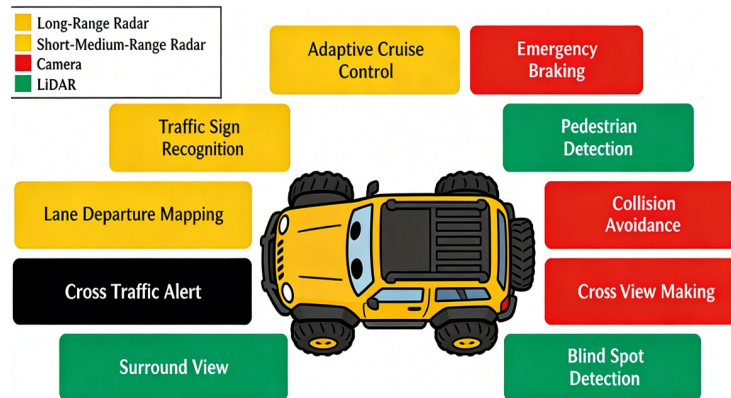


Figure. 1. depicts the functions and distribution of other sensors [5].

3. Sensor Categories in Multisensor Fusion Technology

3.1 Camera

The principle of the camera can be explained as the optical characteristics of the surrounding since light becomes visible on a material of photosensitivity by means of a lens attached to the sensor and, thus creating pictures of the surroundings with light as their source. The sensor under discussion is not very expensive, although it offers a lot of support to the self-driving system. In mathematics, to provide an example, stereo cameras have been used to emulate animal vision where the disparity in the baseline of the sensors is used to generate depth maps with epipolar geometry. Fisheye cameras prove to be very useful in densely populated vehicle scenes as the four-camera range offers an all-around view to the vehicle without any blind spots. [1, 5]. To conclude, cameras are one of the widely used technologies that are capable of enhancing image quality and identifying road lanes, traffic lines, and road signs. Path planning to self-driving entails a vital role of cameras [5, 8].

3.2 Radar

One of the most important sensors in this technology is radar. As the sphere of autonomous vehicle research and associated businesses evolves at an extremely high rate, the demand in the market for lidar and millimeter-wave radar has grown considerably [5]. Some of the extreme environments that radar can withstand include speed and distance of the vehicle and targets, which it directly measures. Such a sensor is of great benefit to the effectiveness of accomplishing autonomous driving objectives. Lidar is very sensitive to fog and rain, gives high-resolution point clouds, and is commonly applied to work in heavily hostile conditions.

Millimeter-wave Radar. Millimeter-wave radar employs electromagnetic waves that have frequencies within a lower frequency ranging between 30 Hz and a higher frequency limit of

300 Hz to determine the relative position of the vehicle to the road, together with the distance between the vehicle and the target. Millimeter-wave radar works on the principle of time delaying of reflected waves, and it uses the Doppler effect to make the determination of the target velocity possible [1]. The benefit that comes with the use of this radar is that it can still work in low-light conditions, but it can still scan the immediate environment. This feature enables self-driving systems to operate during low-light conditions like tunnels [1, 5]. Nevertheless, the weaknesses of this radar can be pointed out. It is only able to sense larger objects and distant objects, whereas having serious errors in sensing small or close objects near to the target vehicle [1].

Lidar. The other sensor with distance measurement technology is the Lidar [1, 8]. The principle of lidar is that one should release a pulse of laser and then identify the delay between the emission pulse and the reflected radiation of the surrounding objects, and accurate relative distances can be computed with high precision [1, 5]. Lidar is able to produce 3D images of high definition with precision in measurements [1, 5, 10,11]. As an illustration, the scan data of a 3D lidar sensor consists of the x, y position of the scenes and the obstacles of the environment, as well as the intensity of the scans. The 64-beam and 128-beam lidar sensors are usually used in autonomous driving to generate high-resolution lidar images [5]. Currently, 3D rotating lidar has become more common in autonomous driving since the information taken by this system gives comparatively precise 3D space features of the surroundings around autonomous cars.

4. Sensor Fusion and Calibration Research

4.1 Sensor Calibration Methods

The sensor calibration methods entail the images and position data of the surrounding environment as recorded by the detection sensor, and this data allows the autonomous driving system sensors to view the direction and position of target vehicles in the real-world environment. Calibration has proved to be quite useful in sensor fusion systems, which have played a major role in providing increased environmental perception and accurate vehicle localisation [5]. Calibration methods can be divided into external calibration, internal calibration, and temporal calibration. Internal calibration is the one that is especially essential because it helps to estimate a number of certain values that are unique to each sensor.

4.2 Calibration of the Pinhole Camera Model.

The pinhole camera is a popular model used in calibration methods and is based on the simplicity of the basic camera [5, 10]. This model is made up of a completely enclosed chamber that has a pinhole in the middle. It aims at letting light from the object detected get through this hole to create an image on the wall opposite the camera [5]. Its principle and structure are depicted in Figure 2.

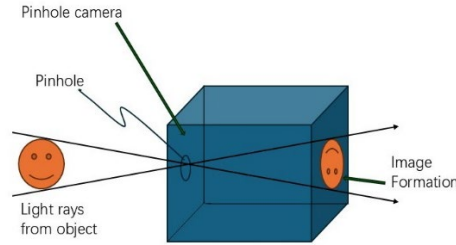


Figure.2. The establishing principle and imaging working of a pinhole camera [5].

The establishment principle and imaging working of a pinhole camera are demonstrated in figure 2 [5]. This model is applied in the area of mathematics, where the coordinate systems of two-dimensional images and 3D images, and the method of calibration of cameras is achieved through a perspective approach [5, 10]. In the calibration stage, a 3 column 4 row matrix of rotation and translation transformations R , t is used to ensure that the points in the world coordinate system are transformed to points in the camera three dimensional coordinate system. In this model, the internal parameters of the sensor are also utilized in transforming the three-dimensional coordinates into the image's two-dimensional coordinates (x, y) [5]. Figure 3 illustrates the process which is specific.

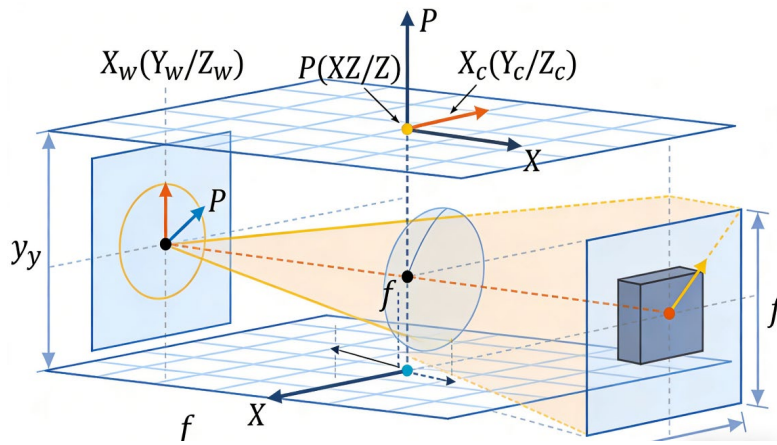


Figure. 3. The principle of imaging of the pinhole model [5].

The principle of imaging of the pinhole model is as shown in Figure 3 [5]. The most famous approach of Zhang successfully employs this technique as well as is the most widespread camera calibration technology in the market. The camera matrix is estimated in this method through the use of the relationships between the calibration points which are seen on at least 2 planar pattern and their matching points at various orientations. The ROS open-source camera calibration package is based on OpenCV and offers easily available scripts, and the planar patterns are used as calibration objects. It is capable of calibration of monocular, stereo and fisheye cameras and provides numerous core calibration outcomes including intrinsic and distortion parameters [5].

5. Sensor Fusion Technology Application

5.1 Overview of Sensor Fusion

The self driving technology and autonomous ground unmanned vehicles. integrity depends on sound sensor fusion. Sensor fusion is mainly based on combining data gathered by using more than one sensory mode. This method does not just minimize uncertainties in detection as well as address the drawbacks of each of the sensors working independently, but also builds a complete model that can provide an accurate perception of the surrounding environment in a variety of conditions. To illustrate the point, the integration of cameras and radar will allow taking high-resolution photos and essential data at the same time, including a relative speed of the obstacles located in the field of view. This model allows autonomous systems to better perceive their environment and increase their ability to stay steady in use because full-capability autonomous systems utilize the strengths of various sensors [5, 11].

5.2. Sensor Fusion Technology

Some typical sensor systems are camera-lidar, camera-lidar-radar. The most popular of them is the Camera-Radar (CR) sensor combination. This pair is able to give high-quality images and also identify the distance and speed of the obstacles surrounding the vehicle in question [5]. Tesla in practical applications, has largely used the CR sensor combination to sense the environment and the things that are around the target car.

The main innovation of this combination is the opportunity of getting the 360 surround view with the use of 8 cameras (a front camera covers a range of 250 meters), and 1 forward millimeter-wave radar. Hardware-wise, the CR combination creates a complementary division of labor, high-resolution visual realization and all-weather distance and speed measurement with radar, striking a balance between performance, cost, and the computations. This is the best sensor arrangement and allocation of functions [5]. The radar equipment is able to see through tricky conditions like rain and dust, which offers backup in environmental flexibility with the visual system. This is compatible with the data closed-loop at Tesla so that the scenario data could be collected by means of shadow mode and driving optimization of the fusion algorithms in an iterative way [1, 5].

This sensor combination can precisely report the vehicles, pedestrians, and obstacles in structured road settings and testing locations, like highways cruising and the urban ring roads. It has the ability to provide consistent relating speed and range data that allows it to be used in automatic following and changing lanes. It is in such circumstances that the FSD Beta reports a lane changing and ramp merging success rate of above 95 percent [5]. Such a combination illustrates that Multisensor fusion is able to decrease the uncertainty of individual sensors and it is the vision and radar that promote the strengths of each other with the benefits of one sensor greatly outweighing the benefits of another type of sensor and in turn in the complex environment, perception remains steady with the help of Multisensor fusion [5]. In this combination however the radar has poor angular resolution and identification rate of small near objects. It can cause fusion false matches, and the movement filtering logic of the stationary target may lead to false misses of the still obstacles, which are hazardous [5].

6. Conclusion

The focus of this paper is a review of multisensor fusion technology, which explains the kind of sensors as well as research and use of other sensors in the fusion technology of self-driving cars. Environmental perception is attained by combining information from various sensors, like radar and cameras, and filtering it using noise reduction and spatiotemporal calibration. The research concludes that the strength of this fusion technology is that it utilizes the compatibility and redundancy effect of data, which improves the accuracy and reliability of perceptions due to the ability of hierarchical processing. Among them, sensor calibration is a main requirement of an autonomous driving obstacle avoidance technology. Camera models like the pinhole one have methods of calibration to secure the accuracy of positioning by conversion of coordinates. The study is aimed at providing a point of balance between real-time performance and accuracy, along with the system fault tolerance, which would provide technical support to self-driving vehicles, which can detect obstacles and make avoidance maneuvers.

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