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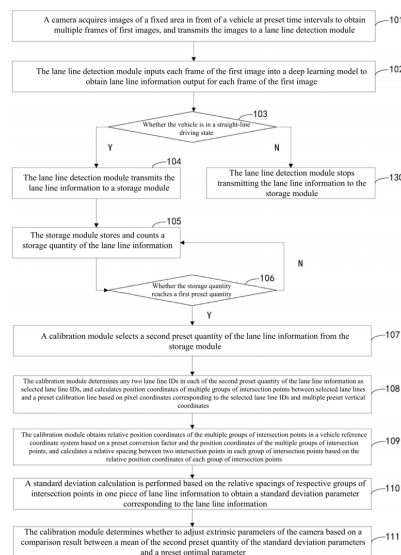
Claims 2 pages, Description 6 pages, Drawings 3 pages

(54) Title

Dynamic Calibration Method for Camera Extrinsic Parameters

(57) Abstract

The present invention relates to a dynamic calibration method for camera extrinsic parameters, comprising: performing, by a camera, image acquisition at preset time intervals to obtain multiple frames of first images; inputting, by a lane line detection module, each frame of the first image into a deep learning model to obtain lane line information; when a vehicle is in a straight-line driving state, transmitting the lane line information to a storage module; when the quantity of the lane line information reaches a first preset quantity, selecting, by a calibration module, a second preset quantity of the lane line information; determining selected lane line IDs, and calculating position coordinates of multiple groups of intersection points between selected lane lines and a preset calibration line; obtaining relative position coordinates based on a preset conversion factor and the position coordinates, and calculating a relative spacing between two intersection points in each group of intersection points; obtaining a standard deviation parameter based on the relative spacings of respective groups of intersection points; and determining whether to adjust extrinsic parameters of the camera based on a comparison result between a mean of the second preset quantity of the standard deviation parameters and a preset optimal parameter.



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1. A dynamic calibration method for camera extrinsic parameters, characterized by comprising: acquiring, by a camera, images of a fixed area in front of a vehicle at preset time intervals to obtain multiple frames of first images, and transmitting the images to a lane line detection module, wherein each frame of the first image has an image ID;

inputting, by the lane line detection module, each frame of the first image into a deep learning model to obtain lane line information output for each frame of the first image, wherein the lane line information comprises the image ID, a lane line ID of each lane line, and pixel coordinates corresponding to the lane line ID;

determining whether the vehicle is in a straight-line driving state;

when the vehicle is in the straight-line driving state, transmitting, by the lane line detection module, the lane line information to a storage module; when the quantity of the lane line information in the storage module reaches a first preset quantity, selecting, by a calibration module, a second preset quantity of the lane line information from the storage module, wherein the second preset quantity is less than the first preset quantity;

determining, by the calibration module, any two lane line IDs in each of the second preset quantity of the lane line information as selected lane line IDs, and calculating position coordinates of multiple groups of intersection points between selected lane lines and a preset calibration line based on pixel coordinates corresponding to the selected lane line IDs and multiple preset vertical coordinates, wherein each group of intersection points comprises two intersection points formed between one preset vertical coordinate and two lane lines corresponding to the selected lane line IDs;

obtaining, by the calibration module, relative position coordinates of the multiple groups of intersection points in a vehicle reference coordinate system based on a preset conversion factor and the position coordinates of the multiple groups of intersection points, and calculating a relative spacing between two intersection points in each group of intersection points based on the relative position coordinates of each group of intersection points; performing a standard deviation calculation based on the relative spacings of respective groups of intersection points in one piece of lane line information to obtain a standard deviation parameter corresponding to the lane line information, wherein the standard deviation parameter has a corresponding image ID; and

determining, by the calibration module, whether to adjust extrinsic parameters of the camera based on a comparison result between a mean of the second preset quantity of the standard deviation parameters and a preset optimal parameter,

wherein when the mean of the standard deviation parameters is not equal to the preset optimal parameter, the calibration module adjusts the extrinsic parameters using a gradient descent method or a grid search method to obtain adjusted extrinsic parameters; and

the calibration module performs multiplication calculation based on preset camera intrinsic parameters and the adjusted extrinsic parameters, assigns a calculation result to the preset conversion factor, and executes the dynamic calibration method for camera extrinsic parameters again.

2. The dynamic calibration method for camera extrinsic parameters according to claim 1, wherein after the calibration module determines whether to adjust the extrinsic parameters of the camera based on the comparison result between the mean of the second preset quantity of the standard deviation parameters and the preset optimal parameter, the method further comprises:

when the mean of the standard deviation parameters is equal to a preset value, determining, by the calibration module, that the preset conversion factor remains unchanged.

3. The dynamic calibration method for camera extrinsic parameters according to claim 2, wherein after the camera acquires the images of the fixed area in front of the vehicle at the preset time intervals to obtain the multiple frames of first images, the dynamic calibration method further comprises:

transmitting, by the camera, the multiple frames of first images to a target detection module; and

performing, by the target detection module, recognition processing on the first images based on machine vision technology or artificial neural network technology to obtain target information, and transmitting the target information to the calibration module, wherein the target information comprises a target ID and pixel coordinates corresponding to the target ID.

4. The dynamic calibration method for camera extrinsic parameters according to claim 3, characterized by further comprising:

obtaining, by the calibration module, relative position coordinates of a target based on the

conversion factor and pixel coordinates of the target.

5. The dynamic calibration method for camera extrinsic parameters according to claim 1, wherein the determining whether the vehicle is in the straight-line driving state specifically comprises:

acquiring, by the lane line detection module, a vehicle speed and a steering wheel angle from a controller of the vehicle, and determining whether the vehicle is in the straight-line driving state based on the vehicle speed and the steering wheel angle.

6. The dynamic calibration method for camera extrinsic parameters according to claim 5, wherein when the vehicle speed is less than a preset vehicle speed and/or the steering wheel angle is greater than or equal to a preset angle, the lane line detection module determines that the vehicle is not in the straight-line driving state and stops transmitting the lane line information to the storage module; and

when the vehicle speed is greater than or equal to the preset vehicle speed and the steering wheel angle is less than the preset angle, the lane line detection module determines that the vehicle is in the straight-line driving state.

7. The dynamic calibration method for camera extrinsic parameters according to claim 1, wherein after the lane line detection module transmits the lane line information to the storage module, the dynamic calibration method further comprises:

storing and counting, by the storage module, a storage quantity of the lane line information, and determining whether the storage quantity reaches the first preset quantity.

DYNAMIC CALIBRATION METHOD FOR CAMERA EXTRINSIC PARAMETERS

TECHNICAL FIELD

[0001] The present invention relates to the technical field of autonomous driving, and in particular to a dynamic calibration method for camera extrinsic parameters.

BACKGROUND

[0002] In recent years, autonomous vehicles have been widely applied in multiple scenarios such as intelligent transportation, logistics distribution, and cleaning operations. Cameras, as a primary sensor of autonomous vehicles, are commonly used to detect obstacle positions during vehicle driving, and the accuracy of detected obstacle positions is directly related to camera extrinsic parameters.

[0003] Current camera extrinsic parameter calibration is mainly divided into two categories.

[0004] The first category relies on specific calibration plates or calibration objects. Therefore, manual arrangement of calibration scenarios is required, and the calibrated extrinsic parameters are a set of fixed parameters. When the vehicle experiences bumps, this set of fixed parameters from extrinsic parameter calibration become inapplicable.

[0005] The second category utilizes vanishing points or parallel lane lines for extrinsic parameter calibration. Although such calibration category has relatively low requirements for calibration scenarios, a set of parameters obtained from a single calibration of extrinsic parameters are likewise fixed values, which are unsuitable for target position perception during vehicle bumps.

[0006] As a result, existing camera extrinsic parameters for autonomous vehicles are all calibrated data obtained when the vehicle is on smooth roads. Once the vehicle encounters bumps or slopes during vehicle driving, the accuracy of target positions in the vehicle reference coordinate system that are obtained based on the fixed extrinsic parameters becomes degraded, and consequently, the safety factor of the autonomous vehicle is reduced.

SUMMARY

[0007] An objective of the present invention is to provide a dynamic calibration method for camera extrinsic parameters in view of the deficiencies in the prior art, which can achieve initial extrinsic parameter calibration when the vehicle is offline, and can also perform real-time dynamic camera extrinsic parameter calibration when the vehicle is driving. Particularly in cases of vehicle bumps or slope driving, it can automatically correct parameters from extrinsic parameter calibration of cameras, improve the positional accuracy of visually detected targets, and thus enhance the safety factor of vehicle driving.

[0008] To achieve the above objective, the present invention provides a dynamic calibration method for camera extrinsic parameters, the dynamic calibration method comprising:

[0009] acquiring, by a camera, images of a fixed area in front of a vehicle at preset time intervals to obtain multiple frames of first images, and transmitting the images to a lane line detection module, wherein each frame of the first image has an image ID;

[0010] inputting, by the lane line detection module, each frame of the first image into a deep learning model to obtain lane line information output for each frame of the first image, wherein the lane line information comprises the image ID, a lane line ID of each lane line, and pixel coordinates corresponding to the lane line ID;

[0011] determining whether the vehicle is in a straight-line driving state;

[0012] when the vehicle is in the straight-line driving state, transmitting, by the lane line detection module, the lane line information to a storage module; when the quantity of the lane line information in the storage module reaches a first preset quantity, selecting, by a calibration module, a second preset quantity of the lane line information from the storage module, wherein the second preset quantity is less than the first preset quantity;

[0013] determining, by the calibration module, any two lane line IDs in each of the second preset quantity of the lane line information as selected lane line IDs, and calculating position coordinates of multiple groups of intersection points between selected lane lines and a preset calibration line based on pixel coordinates corresponding to the selected lane line IDs and multiple preset vertical coordinates, wherein each group of intersection points comprises two intersection points formed between one preset vertical coordinate and two lane lines corresponding to the selected lane line IDs;

[0014] obtaining, by the calibration module, relative position coordinates of the multiple groups of intersection points in a vehicle reference coordinate system based on a preset conversion factor and the position coordinates of the multiple groups of intersection points, and calculating a relative spacing between two intersection points in each group of intersection points based on the relative position coordinates of each group of intersection points; performing a standard deviation calculation based on the relative spacings of respective groups of intersection points in one piece of lane line information to obtain a standard deviation parameter corresponding to the lane line information, wherein the standard deviation parameter has a corresponding image ID; and

[0015] determining, by the calibration module, whether to adjust extrinsic parameters of the camera based on a comparison result between a mean of the second preset quantity of the standard deviation parameters and a preset optimal parameter,

[0016] wherein when the mean of the standard deviation parameters is not equal to the preset optimal parameter, the calibration module adjusts the extrinsic parameters using a gradient descent method or a grid search method to obtain adjusted extrinsic parameters; and

[0017] the calibration module performs multiplication calculation based on preset camera intrinsic parameters and the adjusted extrinsic parameters, assigns a calculation result to the preset conversion factor, and executes the dynamic calibration method for camera extrinsic parameters again.

[0018] Preferably, after the calibration module determines whether to adjust the extrinsic parameters of the camera based on the comparison result between the mean of the second preset quantity of the standard deviation parameters and the preset optimal parameter, the method further comprises:

[0019] when the mean of the standard deviation parameters is equal to a preset value, determining, by the calibration module, that the preset conversion factor remains unchanged.

[0020] Further preferably, after the camera acquires the images of the fixed area in front of the vehicle at the preset time intervals to obtain the multiple frames of first images, the dynamic calibration method further comprises:

[0021] transmitting, by the camera, the multiple frames of first images to a target detection module; and

[0022] performing, by the target detection module, recognition processing on the first images based on machine vision technology or artificial neural network technology to obtain target information, and transmitting the target information to the calibration module, wherein the target information comprises a target ID and pixel coordinates corresponding to the target ID.

[0023] Further preferably, the dynamic calibration method further comprises:

[0024] obtaining, by the calibration module, relative position coordinates of a target based on the conversion factor and pixel coordinates of the target.

[0025] Preferably, the determining whether the vehicle is in the straight-line driving state specifically comprises:

[0026] acquiring, by the lane line detection module, a vehicle speed and a steering wheel angle from a controller of the vehicle, and determining whether the vehicle is in the straight-line driving state based on the vehicle speed and the steering wheel angle.

[0027] Further preferably, when the vehicle speed is less than a preset vehicle speed and/or the steering wheel angle is greater than or equal to a preset angle, the lane line detection module determines that the vehicle is not in the straight-line driving state and stops transmitting the lane line information to the storage module; and

[0028] when the vehicle speed is greater than or equal to the preset vehicle speed and the steering wheel angle is less than the preset angle, the lane line detection module determines that the vehicle is in the straight-line driving state.

[0029] Preferably, after the lane line detection module transmits the lane line information to the storage module, the dynamic calibration method further comprises:

[0030] storing and counting, by the storage module, a storage quantity of the lane line information, and determining whether the storage quantity reaches the first preset quantity.

[0031] The dynamic calibration method for camera extrinsic parameters provided in the present invention can achieve initial extrinsic parameter calibration when the vehicle is offline, and can also perform real-time dynamic camera extrinsic parameter calibration when the vehicle is driving. Particularly in cases of vehicle bumps or slope driving, it can automatically correct parameters from extrinsic parameter calibration of cameras, improve the positional accuracy of visually detected targets, and thus enhance the safety factor of vehicle driving.

BRIEF DESCRIPTION OF THE DRAWINGS

[0032] FIG. 1 is a flowchart of a dynamic calibration method for camera extrinsic parameters according to an embodiment of the present invention;

[0033] FIG. 2 is a schematic diagram of lane lines in an image coordinate system according to an embodiment of the present invention;

[0034] FIG. 3 is a schematic diagram of calibration lines in the image coordinate system according to an embodiment of the present invention;

[0035] FIG. 4 is a schematic diagram of calibration lines in a vehicle reference coordinate system according to an embodiment of the present invention; and

[0036] FIG. 5 is a schematic diagram of targets in the vehicle reference coordinate system according to an embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

[0037] The technical solution of the present invention will be further described in detail below with reference to the accompanying drawings and embodiments.

[0038] The dynamic calibration method for camera extrinsic parameters provided in the present invention can achieve initial extrinsic parameter calibration when the vehicle is offline, and can also perform real-time dynamic camera extrinsic parameter calibration when the vehicle is driving. Particularly in cases of vehicle bumps or slope driving, it can automatically correct parameters from extrinsic parameter calibration of cameras, improve the positional accuracy of visually detected targets, and thus enhance the safety factor of vehicle driving.

[0039] To facilitate understanding of the technical solution of the present invention, a pixel coordinate system, a vehicle reference coordinate system and camera extrinsic parameters mentioned below are first explained.

[0040] The pixel coordinate system is a two-dimensional coordinate system with pixels as units, with a first pixel point at the top left of an image as an origin, a horizontal rightward direction as a u-axis, and a vertical downward direction as a v-axis.

[0041] In embodiments of the present invention, the established vehicle reference coordinate system takes a projection of a center point of a vehicle's rear axle on the ground as an origin, a vertical upward direction from the ground as a z-axis, the vehicle's forward direction as an x-axis, and a direction perpendicular to the x-axis pointing to the left side of the vehicle as a y-axis.

[0042] The camera extrinsic parameters include a rotation matrix and a translation matrix. The rotation matrix includes three rotation parameters for the x, y, and z axes, and the translation matrix includes three translation parameters for the x, y, and z axes. In the embodiments of the present invention, dynamically calibrated camera extrinsic parameters specifically refer to the aforementioned three rotation parameters and three translation parameters.

[0043] The rotation matrix describes the direction of coordinate axes of the vehicle reference coordinate system relative to camera coordinate axes, and the translation matrix describes the position of a spatial origin in a camera coordinate system. The rotation matrix and the translation matrix jointly describe how to convert points from the vehicle reference coordinate system to the camera coordinate system.

[0044] FIG. 1 is a flowchart of a dynamic calibration method for camera extrinsic parameters according to an embodiment of the present invention. The technical solution of the present invention is described in detail below with reference to FIG. 1.

[0045] Step 101: a camera acquires images of a fixed area in front of a vehicle at preset time intervals to obtain multiple frames of first images, and transmits the images to a lane line detection module.

[0046] Specifically, the camera is disposed at the center of the front end of the vehicle to ensure that a lens of the camera faces directly ahead of the vehicle, that is, along a y-axis in a vehicle coordinate system. The translation of the camera relative to the origin in the vehicle reference coordinate system can be obtained with a scale and based on the vehicle model. The camera acquires the images of the fixed area in front of the vehicle at the preset time intervals, and the first image acquired at each time point is regarded as one frame of the first image. Each frame of the first image has an image ID.

[0047] Step 102: the lane line detection module inputs each frame of the first image into a deep learning model to obtain lane line information output for each frame of the first image.

[0048] Specifically, each frame of the first image is input into a trained deep learning model, and the deep learning model performs recognition and semantic segmentation on each frame of the first image to obtain lane line information. The lane line information includes the image ID, a lane line ID of each lane line, and pixel coordinates corresponding to the lane line ID. That is to say, one piece of lane line information corresponds to one frame of the first image, and each lane line information contains multiple lane lines.

[0049] FIG. 2 is a schematic diagram of lane lines in an image coordinate system according to an embodiment of the present invention. As shown, each lane line consists of discrete points.

[0050] Step 103: whether the vehicle is in a straight-line driving state is determined.

[0051] Specifically, the lane line detection module acquires a vehicle speed and a steering wheel angle from a controller of the vehicle, and determines whether the vehicle is in the straight-line driving state based on the vehicle speed and the steering wheel angle.

[0052] When the vehicle speed is less than a preset vehicle speed and/or the steering wheel angle is greater than or equal to a preset angle, the lane line detection module determines that the vehicle is not in the straight-line driving state and executes step 130; and when the vehicle speed is greater than or equal to the preset vehicle speed and the steering wheel angle is less than the preset angle, the lane line detection module determines that the vehicle is in the straight-line driving state and executes step 104.

[0053] Step 130: the lane line detection module stops transmitting the lane line information to a storage module.

[0054] Specifically, when the vehicle is not in the straight-line driving state, camera extrinsic parameters are not dynamically calibrated.

[0055] Step 104: the lane detection module transmits the lane line information to the storage module.

[0056] Specifically, when the vehicle is in the straight-line driving state, the camera extrinsic parameters are dynamically calibrated based on the lane line information detected by the lane line detection module.

[0057] Step 105: the storage module stores and counts a storage quantity of the lane line information.

[0058] Specifically, the storage module is a fixed-size cache space. When the cache space is exceeded, the storage module deletes a fixed quantity of the earliest stored lane line information to free up the cache space.

[0059] Step 106: whether the storage quantity reaches a first preset quantity is determined.

[0060] When the quantity of the lane line information in the storage module reaches the first preset quantity, step 107 is executed. When the quantity of the lane line information in the storage module does not reach the first preset quantity, step 105 is re-executed.

[0061] Step 107: a calibration module selects a second preset quantity of the lane line information from the storage module.

[0062] Specifically, the calibration module randomly selects the second preset quantity of the lane line information to reduce the impact of a certain abnormal frame of the lane line information on the camera extrinsic parameters. The second preset quantity is less than the first preset quantity.

[0063] Step 108: the calibration module determines any two lane line IDs in each of the second preset quantity of the lane line information as selected lane line IDs, and calculates position coordinates of multiple groups of intersection points between selected lane lines and a preset calibration line based on pixel coordinates corresponding to the selected lane line IDs and multiple preset vertical coordinates.

[0064] Specifically, a difference between every two adjacent preset vertical coordinates is a fixed value. The fixed value can be changed as needed. Each lane line information contains multiple lane line IDs. The calibration module selects any two lane line IDs in each lane line information as the selected lane line IDs and determines a group of corresponding intersection points on the two selected lane lines based on the multiple preset vertical coordinates. Each group of intersection points includes two intersection points between one preset vertical coordinate and two lane lines corresponding to the selected lane line IDs.

[0065] FIG. 3 is a schematic diagram of calibration lines in an image coordinate system according to an embodiment of the present invention; and FIG. 4 is a schematic diagram of calibration lines in a vehicle reference coordinate system according to an embodiment of the present invention. In FIG. 3, there are multiple groups of intersection points between two selected lane lines and multiple vertical coordinates. When converted to the vehicle coordinate system, the multiple groups of intersection points are represented in FIG. 4 as A_1A_2 , B_1B_2 , C_1C_2 , D_1D_2 , E_1E_2 , and F_1F_2 , respectively.

[0066] Step 109: the calibration module obtains relative position coordinates of the multiple groups of intersection points in the vehicle reference coordinate system based on a preset conversion factor and the position coordinates of the multiple groups of intersection points, and calculates a relative spacing between two intersection points in each group of intersection points based on the relative position coordinates of each group of intersection points.

[0067] Specifically, in the image coordinate system, the two selected lane lines are not parallel. To determine whether the two selected lane lines are parallel, it is necessary to convert the multiple groups of intersection points obtained in the previous step into the vehicle reference coordinate system, and then the relative spacing between two intersection points in each group of intersection points is calculated based on the relative positional coordinates in the vehicle reference coordinate system.

[0068] The formula for conversion from the vehicle reference coordinate system to the pixel coordinate system is as follows:

$$\mathbf{z}_c \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = K \begin{bmatrix} R & T \end{bmatrix} \begin{bmatrix} x_\omega \\ g_\omega \\ z_\omega \\ 1 \end{bmatrix} \quad (\text{Formula 1})$$

[0070] Conversion factor $q = Z_c / (K[R \ T])$ (Formula 2)

[0071] where Z_c is a scale factor, K is an intrinsic parameter matrix of the camera, R is a rotation matrix, and T is a translation matrix.

[0072] Step 110: A standard deviation calculation is performed based on the relative spacings of respective groups of intersection points in one piece of lane line information to obtain a standard deviation parameter corresponding to the lane line information.

[0073] Specifically, the standard deviation calculation is performed based on the relative spacings of respective groups of intersection points in one piece of lane line information to determine whether two selected lane lines in the lane line information are parallel. The standard deviation parameter has a corresponding image ID.

[0074] The formula for calculating the standard deviation parameter is as follows:

$$\bar{D} = [D(A_1, A_2) + D(B_1, B_2) + D(C_1, C_2) + D(D_1, D_2) + D(E_1, E_2) + D(F_1, F_2)] / 6 \quad (\text{Formula 3})$$

$$\text{COST} = \sqrt{\left\{ \left[D(A_1, A_2) - \bar{D} \right]^2 + \left[D(B_1, B_2) - \bar{D} \right]^2 + \left[D(C_1, C_2) - \bar{D} \right]^2 + \left[D(D_1, D_2) - \bar{D} \right]^2 + \left[D(E_1, E_2) - \bar{D} \right]^2 + \left[D(F_1, F_2) - \bar{D} \right]^2 \right\} / 6} \quad (\text{Formula 4})$$

[0077] where $D(A_1, A_2)$, $D(B_1, B_2)$, $D(C_1, C_2)$, $D(D_1, D_2)$, $D(E_1, E_2)$, and $D(F_1, F_2)$ are the relative spacings of respective groups of intersection points, respectively, \bar{D} is a mean of the six relative spacings, and COST is a standard deviation of the six relative spacings.

[0078] Step 111: the calibration module determines whether to adjust extrinsic parameters of the camera based on a comparison result between a mean of the second preset quantity of the standard deviation parameters and a preset optimal parameter.

[0079] Specifically, when the relative spacings of respective groups of intersection points in one piece of lane line information are the same, it is determined that the two selected lane lines are parallel to each other, and accordingly, the standard deviation parameter is 0. In other words, as long as the standard deviation parameter is not 0, it indicates that the two selected lane lines are not parallel.

[0080] The calibration module performs mean calculation on the second quantity of standard deviation parameters, compares a calculated result with an optimal parameter, and determines whether the extrinsic parameters of the camera need to be adjusted according to a comparison result. The optimal parameter may be 0 or an interval.

[0081] When the mean of the standard deviation parameters is not equal to the preset optimal parameter, the calibration module adjusts the extrinsic parameters using a gradient descent method or a grid search method to obtain adjusted extrinsic parameters. The calibration module performs multiplication calculation based on preset camera intrinsic parameters and the adjusted extrinsic parameters, assigns a calculation result to the preset conversion factor, and executes the dynamic calibration method for camera extrinsic parameters again.

[0082] The gradient descent method finds minimum values by descending against the direction of the standard deviation parameter gradient. Both the step size and maximum number of iterations for gradient descent can be configured as required. Ultimately, minimum values in different directions are obtained through iterative cycles of gradient descent. The minimum value in each direction corresponds to one of the camera extrinsic parameters, thereby yielding adjusted camera extrinsic parameters.

[0083] The grid search method calculates corresponding COSTs for all combinations of extrinsic parameters according to preset extrinsic parameter variable step sizes and upper and lower adjustment thresholds, and then selects a set of combined camera extrinsic parameters with an optimal calculation result as adjusted extrinsic parameters.

[0084] When the mean of the standard deviation parameters is equal to a preset value, it indicates that the camera extrinsic parameters at this time are consistent with a current driving state of the vehicle, and the calibration module determines that the preset conversion factor remains unchanged.

[0085] After the conversion factor is determined, pixel coordinates of a target in the image coordinate system can be converted to relative position coordinates of the target in the vehicle reference coordinate system, so that the position of the target relative to the vehicle can be obtained, thereby achieving more accurate vehicle obstacle avoidance or route planning.

[0086] Specifically, the camera transmits the multiple frames of first images to a target detection module. The target detection module performs recognition processing on the first images according to machine vision technology or artificial neural network technology to obtain target information, and transmits the target information to the calibration module. The target information includes a target ID and pixel coordinates corresponding to the target ID. The calibration module obtains the relative position coordinates of the target according to the conversion factor and the pixel coordinates of the target.

[0087] FIG. 5 is a schematic diagram of targets in the vehicle reference coordinate system according to an embodiment of the present invention. The relative position coordinates of the target are the coordinates of the target relative to the vehicle in the vehicle reference coordinate system. The target may be understood as other vehicles, pedestrians, or other obstacles on the road that affect the driving of the vehicle.

[0088] The dynamic calibration method for camera extrinsic parameters provided in the present invention can achieve initial extrinsic parameter calibration when the vehicle is offline, and can also perform real-time dynamic camera extrinsic parameter calibration when the vehicle is driving. Particularly in cases of vehicle bumps or slope driving, it can automatically correct parameters from extrinsic parameter calibration of cameras, improve the positional accuracy of visually detected targets, and thus enhance the safety factor of vehicle driving.

[0089] Those skilled in the art should further appreciate that the units and method steps of each example described in connection with the embodiments disclosed herein can be implemented in electronic hardware, computer software, or a combination of the two. To clearly illustrate the interchangeability of hardware and software, the composition and steps of each example have been generally described in terms of function in the foregoing description. Whether these functions are executed in hardware or software depends on specific applications and design constraints of the technical solution. Skilled technicians may implement the described functionality using different methods suited to specific applications, but such implementation shall not be construed as falling outside the scope of the present invention.

[0090] The methods or the steps of the methods described in connection with the embodiments disclosed herein may be implemented in hardware, software modules executed by a processor, or a combination of the two. The software module may reside in random access memory (RAM), memory, read-only memory (ROM), electrically programmable ROM, electrically erasable programmable ROM, registers, hard disks, removable disks, CD-ROMs, or any other form of storage media known in the art.

[0091] The specific implementations described above further elucidate the objective, technical solution, and beneficial effects of the present invention. It should be understood that the foregoing descriptions are merely specific implementations of the present invention and are not intended to limit the scope of protection of the present invention. Any modifications, equivalent substitutions, improvements, etc. made within the spirit and principles of the present invention shall be included within the scope of protection of the present invention.

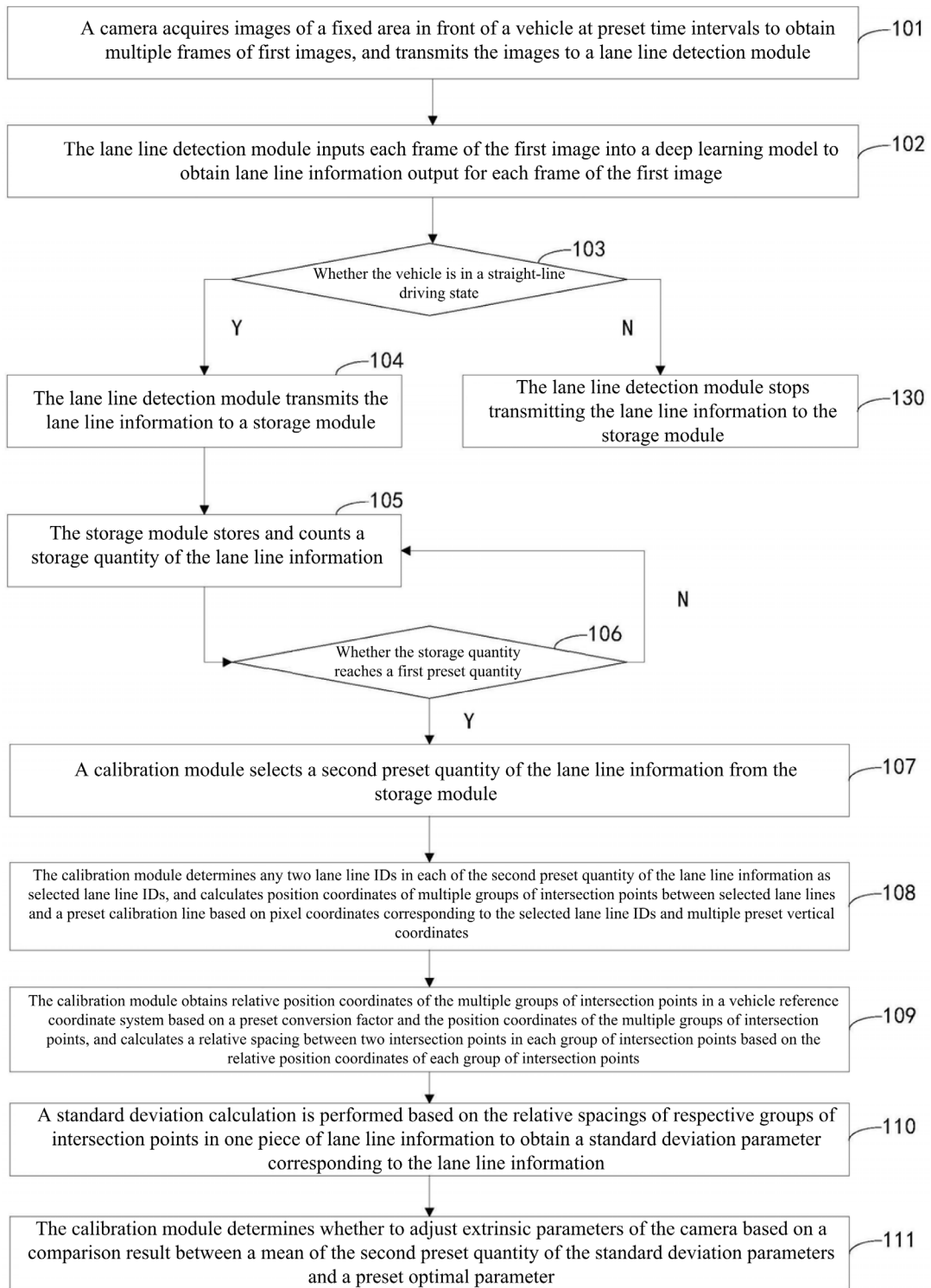


FIG. 1

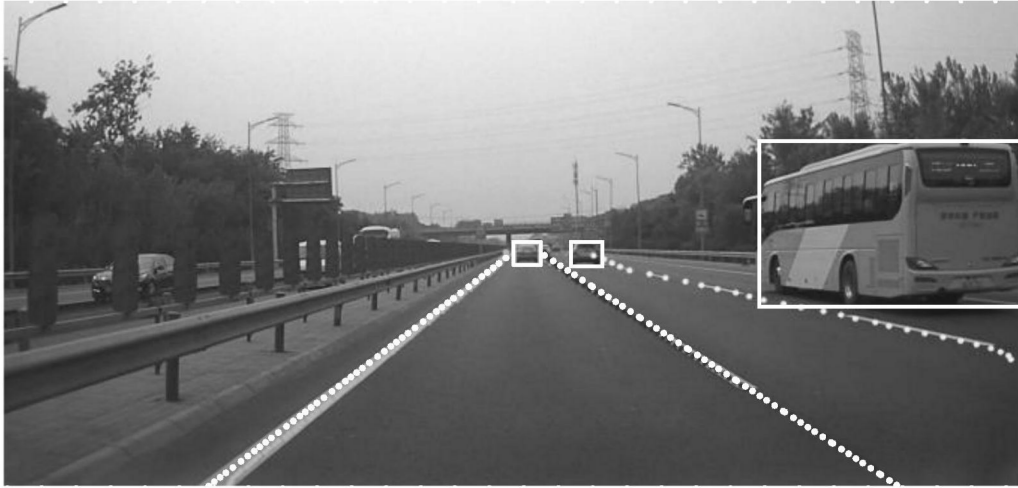


FIG. 2



FIG. 3

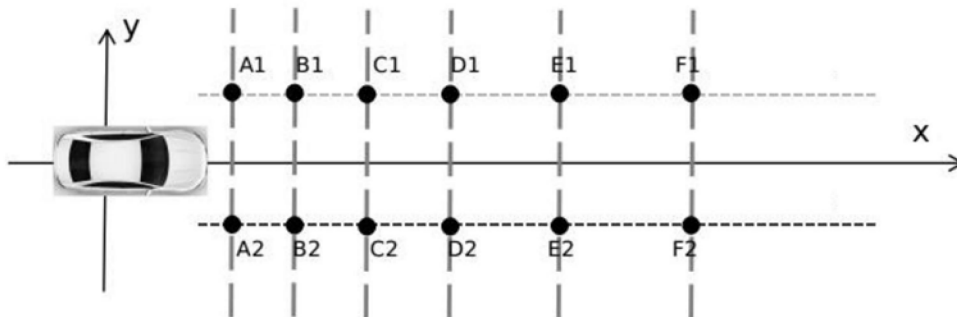


FIG. 4

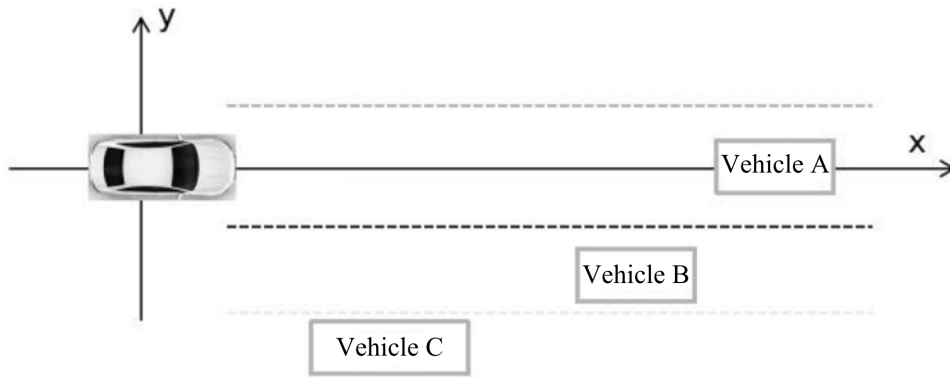


FIG. 5



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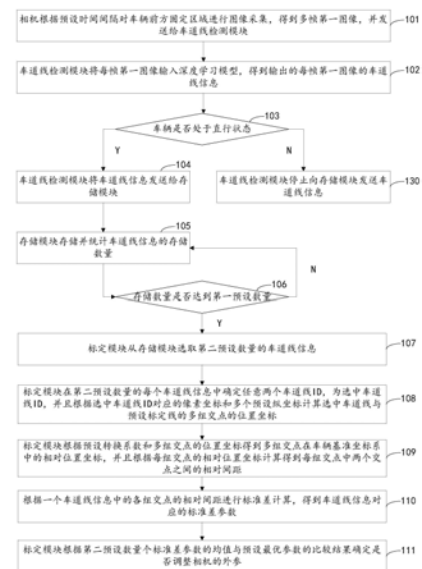
权利要求书2页 说明书6页 附图3页

(54) 发明名称

一种相机外参动态标定方法

(57) 摘要

本发明涉及一种相机外参动态标定方法,包括:相机根据预设时间间隔进行图像采集,得到多帧第一图像;车道线检测模块将每帧第一图像输入深度学习模型,得到车道线信息;当车辆处于直行状态时,将车道线信息发送给存储模块;当车道线信息的数量达到第一预设数量时,标定模块选取第二预设数量的车道线信息;确定选中车道线ID,并计算选中车道线与预设标定线的多组交点的位置坐标;根据预设转换系数和位置坐标得到相对位置坐标,并且计算每组交点中两个交点之间的相对间距;根据各组交点的相对间距得到标准差参数;根据第二预设数量个标准差参数的均值与预设最优参数的比较结果确定是否调整相机的外参。



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1. 一种相机外参动态标定方法,其特征在于,所述动态标定方法包括:

相机根据预设时间间隔对车辆前方固定区域进行图像采集,得到多帧第一图像,并发送给车道线检测模块;每帧所述第一图像具有图像ID;

所述车道线检测模块将每帧所述第一图像输入深度学习模型,得到输出的每帧所述第一图像的车道线信息;所述车道线信息包括图像ID、每条车道线的车道线ID、所述车道线ID对应的像素坐标;

确定所述车辆是否处于直行状态;

当所述车辆处于直行状态时,所述车道线检测模块将所述车道线信息发送给存储模块;当所述存储模块内车道线信息的数量达到第一预设数量时,所述标定模块从所述存储模块选取第二预设数量的所述车道线信息;所述第二预设数量小于所述第一预设数量;

所述标定模块在第二预设数量的每个车道线信息中确定任意两个车道线ID,为选中车道线ID,并且根据所述选中车道线ID对应的像素坐标和多个预设纵坐标计算选中车道线与预设标定线的多组交点的位置坐标;所述每组交点包括一个预设纵坐标与所述选中车道线ID对应的两个车道线的两个交点;

所述标定模块根据预设转换系数和所述多组交点的位置坐标得到所述多组交点在车辆基准坐标系中的相对位置坐标,并且根据每组交点的相对位置坐标计算得到每组交点中两个交点之间的相对间距;根据一个车道线信息中的各组交点的相对间距进行标准差计算,得到所述车道线信息对应的标准差参数;所述标准差参数具有对应的图像ID;

所述标定模块根据所述第二预设数量个所述标准差参数的均值与预设最优参数的比较结果确定是否调整所述相机的外参;

其中,当所述标准差参数的均值不等于预设最优参数时,所述标定模块根据梯度下降法或者网格搜索法调整所述外参,得到调整后的外参;

所述标定模块根据预设相机内参和所述调整后的外参进行乘法计算,并且将所述计算结果赋值给所述预设转换系数,并再次执行所述相机外参动态标定方法。

2. 根据权利要求1所述的相机外参动态标定方法,其特征在于,所述标定模块根据所述第二预设数量个所述标准差参数的均值与预设最优参数的比较结果确定是否调整所述相机的外参之后,所述方法还包括:

当所述标准差参数的均值等于预设数值时,所述标定模块确定所述预设转换系数不变。

3. 根据权利要求2所述的相机外参动态标定方法,其特征在于,在所述相机根据预设时间间隔对车辆前方固定区域进行图像采集,得到多帧第一图像之后,所述动态标定方法还包括:

所述相机将所述多帧第一图像发送给目标检测模块;

所述目标检测模块根据机器视觉技术或者人工神经网络技术对所述第一图像进行识别处理,得到目标信息,并发送给标定模块;所述目标信息包括目标ID和所述目标ID对应的像素坐标。

4. 根据权利要求3所述的相机外参动态标定方法,其特征在于,所述动态标定方法还包括:

所述标定模块根据所述转换系数和所述目标的像素坐标得到所述目标的相对位置坐

标。

5. 根据权利要求1所述的相机外参动态标定方法,其特征在于,所述确定所述车辆是否处于直行状态具体包括:

所述车道线检测模块从所述车辆的控制器获取车速和方向盘转角,并且根据所述车速和方向盘转角判断所述车辆是否处于直行状态。

6. 根据权利要求5所述的相机外参动态标定方法,其特征在于,当所述车速小于预设车速和/或所述方向盘转角大于等于预设转角时,所述车道线检测模块判断所述车辆不处于直行状态,停止向所述存储模块发送所述车道线信息;

当所述车速大于等于预设车速并且所述方向盘转角小于预设转角时,所述车道线检测模块判断所述车辆处于直行状态。

7. 根据权利要求1所述的相机外参动态标定方法,其特征在于,在所述车道线检测模块将所述车道线信息发送给存储模块之后,所述动态标定方法还包括:

所述存储模块存储并统计所述车道线信息的存储数量,判断所述存储数量是否达到第一预设数量。

一种相机外参动态标定方法

技术领域

[0001] 本发明涉及自动驾驶技术领域,尤其涉及一种相机外参动态标定方法。

背景技术

[0002] 近年来,自动驾驶车辆在智能交通出行、物流配送、清洁作业等多场景中广泛应用。相机作为自动驾驶车的主要传感器,常用于检测车辆行驶过程中障碍物位置,而检测的障碍物位置的准确度,与相机外参直接相关。

[0003] 目前的相机外参标定主要分为两类。

[0004] 第一类是依赖于特定的标定板或者标定物体的。因此需要人工进行标定场景的布置,且标定出来的外参为一组固定的参数。当车辆出现颠簸的情况时,这组固定的外参标定参数不再适用。

[0005] 第二类是利用消失点或者平行的车道线的外参标定。这类标定虽然对于标定场景的要求相对较低,但是,单次标定所获得的一组外参参数同样为固定值,不适用车辆颠簸时目标位置的感知。

[0006] 由此可知,现有的自动驾驶车辆的相机的外参,都是在车辆处于平缓的道路情况时的标定数据。一旦车辆行驶过程中,出现颠簸或者上下坡时,基于该固定外参所获得的车辆基准坐标系下的目标位置精度会降低,相应的自动驾驶车辆的安全系数也降低。

发明内容

[0007] 本发明的目的是针对现有技术的缺陷,提供一种相机外参动态标定方法,可以在车辆离线状态下实现初始的外参标定,还可以在车辆行驶过程中实时进行动态相机外参标定。尤其是在车辆颠簸或者上下坡道的情况下,能够自动地矫正相机的外参标定参数,提高视觉检测目标的位置精度,进而提高车辆行驶的安全系数。

[0008] 为实现上述目的,本发明提供了一种相机外参动态标定方法,所述动态标定方法包括:

[0009] 相机根据预设时间间隔对车辆前方固定区域进行图像采集,得到多帧第一图像,并发送给车道线检测模块;每帧所述第一图像具有图像ID;

[0010] 所述车道线检测模块将每帧所述第一图像输入深度学习模型,得到输出的每帧所述第一图像的车道线信息;所述车道线信息包括图像ID、每条车道线的车道线ID、所述车道线ID对应的像素坐标;

[0011] 确定所述车辆是否处于直行状态;

[0012] 当所述车辆处于直行状态时,所述车道线检测模块将所述车道线信息发送给存储模块;当所述存储模块内车道线信息的数量达到第一预设数量时,所述标定模块从所述存储模块选取第二预设数量的所述车道线信息;所述第二预设数量小于所述第一预设数量;

[0013] 所述标定模块在第二预设数量的每个车道线信息中确定任意两个车道线ID,为选中车道线ID,并且根据所述选中车道线ID对应的像素坐标和多个预设纵坐标计算选中车道

线与预设标定线的多组交点的位置坐标；所述每组交点包括一个预设纵坐标与所述选中车道线ID对应的两个车道线的两个交点；

[0014] 所述标定模块根据预设转换系数和所述多组交点的位置坐标得到所述多组交点在车辆基准坐标系中的相对位置坐标，并且根据每组交点的相对位置坐标计算得到每组交点中两个交点之间的相对间距；根据一个车道线信息中的各组交点的相对间距进行标准差计算，得到所述车道线信息对应的标准差参数；所述标准差参数具有对应的图像ID；

[0015] 所述标定模块根据所述第二预设数量个所述标准差参数的均值与预设最优参数的比较结果确定是否调整所述相机的外参；

[0016] 其中，当所述标准差参数的均值不等于预设最优参数时，所述标定模块根据梯度下降法或者网格搜索法调整所述外参，得到调整后的外参；

[0017] 所述标定模块根据预设相机内参和所述调整后的外参进行乘法计算，并且将所述计算结果赋值给所述预设转换系数，并再次执行所述相机外参动态标定方法。

[0018] 优选的，所述标定模块根据所述第二预设数量个所述标准差参数的均值与预设最优参数的比较结果确定是否调整所述相机的外参之后，所述方法还包括：

[0019] 当所述标准差参数的均值等于预设数值时，所述标定模块确定所述预设转换系数不变。

[0020] 进一步优选的，在所述相机根据预设时间间隔对车辆前方固定区域进行图像采集，得到多帧第一图像之后，所述动态标定方法还包括：

[0021] 所述相机将所述多帧第一图像发送给目标检测模块；

[0022] 所述目标检测模块根据机器视觉技术或者人工神经网络技术对所述第一图像进行识别处理，得到目标信息，并发送给标定模块；所述目标信息包括目标ID和所述目标ID对应的像素坐标。

[0023] 进一步优选的，所述动态标定方法还包括：

[0024] 所述标定模块根据所述转换系数和所述目标的像素坐标得到所述目标的相对位置坐标。

[0025] 优选的，所述确定所述车辆是否处于直行状态具体包括：

[0026] 所述车道线检测模块从所述车辆的控制器获取车速和方向盘转角，并且根据所述车速和方向盘转角判断所述车辆是否处于直行状态。

[0027] 进一步优选的，当所述车速小于预设车速和/或所述方向盘转角大于等于预设转角时，所述车道线检测模块判断所述车辆不处于直行状态，停止向所述存储模块发送所述车道线信息；

[0028] 当所述车速大于等于预设车速并且所述方向盘转角小于预设转角时，所述车道线检测模块判断所述车辆处于直行状态。

[0029] 优选的，在所述车道线检测模块将所述车道线信息发送给存储模块之后，所述动态标定方法还包括：

[0030] 所述存储模块存储并统计所述车道线信息的存储数量，判断所述存储数量是否达到第一预设数量。

[0031] 本发明提供的相机外参动态标定方法，可以在车辆离线状态下实现初始的外参标定，还可以在车辆行驶过程中实时进行动态相机外参标定。尤其是在车辆颠簸或者上下坡

道的情况下,能够自动地矫正相机的外参标定参数,提高视觉检测目标的位置精度,进而提高车辆行驶的安全系数。

附图说明

[0032] 图1为本发明实施例提供的相机外参动态标定方法的流程图;

[0033] 图2为本发明实施例提供的图像坐标系下车道线的示意图;

[0034] 图3为本发明实施例提供的图像坐标系下标定线的示意图;

[0035] 图4为本发明实施例提供的车辆基准坐标系下标定线的示意图;

[0036] 图5为本发明实施例提供的车辆基准坐标系下目标的示意图。

具体实施方式

[0037] 下面通过附图和实施例,对本发明的技术方案做进一步的详细描述。

[0038] 本发明提供的相机外参动态标定方法,可以在车辆离线状态下实现初始的外参标定,还可以在车辆行驶过程中实时进行动态相机外参标定。尤其是在车辆颠簸或者上下坡道的情况下,能够自动地矫正相机的外参标定参数,提高视觉检测目标的位置精度,进而提高车辆行驶的安全系数。

[0039] 为便于理解本发明的技术方案,首先对以下涉及到的像素坐标系、车辆基准坐标系和相机外参进行说明。

[0040] 像素坐标系是一个二维的坐标系,以像素为单位,图像的左上方的第一个像素点为原点,水平向右方向为u轴,竖直向下方向为v轴。

[0041] 在本发明实施例中,所建立的车辆基准坐标系是以车辆后轴得到中心点在地面的投影为原点,垂直地面向上为z轴,沿车辆正前方为x轴,垂直x轴指向车辆左侧为y轴。

[0042] 相机外参包括旋转矩阵和平移矩阵,旋转矩阵包括x、y、z轴的3个旋转参数,平移矩阵包括x、y、z轴的3个平移参数。在本发明实施例中动态标定的相机外参就是指上述的3个旋转参数和3个平移参数。

[0043] 旋转矩阵描述了车辆基准坐标系的坐标轴相对于相机坐标轴的方向,平移矩阵描述了在相机坐标系下空间原点的位置。旋转矩阵和平移矩阵共同描述了如何把点从车辆基准坐标系转换到相机坐标系。

[0044] 图1为本发明实施例提供的相机外参动态标定方法的流程图,以下结合图1对本发明技术方案进行详述。

[0045] 步骤101,相机根据预设时间间隔对车辆前方固定区域进行图像采集,得到多帧第一图像,并发送给车道线检测模块;

[0046] 具体的,相机设置在车辆前端的中间位置,保证相机的镜头朝向车辆的正前方,也就是车辆坐标系下的y轴上,通过刻度尺和车辆的车型可以得知相机在车辆基准坐标系的相对于原点的平移。相机根据预设时间间隔对车辆前方固定区域进行图像采集,每个时间点采集的第一图像视为一帧第一图像。每帧第一图像具有图像ID。

[0047] 步骤102,车道线检测模块将每帧第一图像输入深度学习模型,得到输出的每帧第一图像的车道线信息;

[0048] 具体的,每帧第一图像输入训练后的深度学习模型,深度学习模型对每帧第一图

像进行识别以及语义分割,得到车道线信息。车道线信息包括图像ID、每条车道线的车道线ID、车道线ID对应的像素坐标。也就是说,一个车道线信息对应一帧第一图像,每个车道线信息中包含多个车道线。

[0049] 图2为本发明实施例提供的图像坐标系下车道线的示意图,每条车道线如图所示,为离散点组成。

[0050] 步骤103,确定车辆是否处于直行状态;

[0051] 具体的,车道线检测模块从车辆的控制器获取车速和方向盘转角,并且根据车速和方向盘转角判断车辆是否处于直行状态。

[0052] 当车速小于预设车速和/或方向盘转角大于等于预设转角时,车道线检测模块判断车辆不处于直行状态,执行步骤130;当车速大于等于预设车速并且方向盘转角小于预设转角时,车道线检测模块判断车辆处于直行状态,执行步骤104。

[0053] 步骤130,车道线检测模块停止向存储模块发送车道线信息;

[0054] 具体的,在车辆不处于直行状态时,不对相机外参进行动态标定。

[0055] 步骤104,车道线检测模块将车道线信息发送给存储模块;

[0056] 具体的,在车辆处于直行状态时,基于车道线检测模块检测得到的车道线信息进行相机外参的动态标定。

[0057] 步骤105,存储模块存储并统计车道线信息的存储数量;

[0058] 具体的,存储模块是一个固定大小的缓存空间。当超出缓存空间时,存储模块删除最早存储的固定数量的车道线信息,以释放缓存空间。

[0059] 步骤106,判断存储数量是否达到第一预设数量。

[0060] 当存储模块内车道线信息的数量达到第一预设数量时,执行步骤107。当存储模块内车道线信息的数量未达到第一预设数量时,再次执行步骤105。

[0061] 步骤107,标定模块从存储模块选取第二预设数量的车道线信息;

[0062] 具体的,标定模块随机选取第二预设数量的车道线信息,用以减少某一异常帧的车道线信息对相机外参的影响。其中,第二预设数量小于第一预设数量。

[0063] 步骤108,标定模块在第二预设数量的每个车道线信息中确定任意两个车道线ID,为选中车道线ID,并且根据选中车道线ID对应的像素坐标和多个预设纵坐标计算选中车道线与预设标定线的多组交点的位置坐标;

[0064] 具体的,相邻的每两个预设纵坐标的差为固定值。这个固定值是可以根据需求改变的。每个车道线信息中包含多个车道线ID,标定模块选取每个车道线信息中的任意两个车道线ID为选中车道线ID,并且根据多个预设纵坐标确定两个选中车道线上对应的一组交点。每组交点包括一个预设纵坐标与选中车道线ID对应的两个车道线的两个交点。

[0065] 图3为本发明实施例提供的图像坐标系下标定线的示意图,图4为本发明实施例提供的车辆基准坐标系下标定线的示意图。图3中两个选中车道线与多个纵坐标有多组交点,转换到车辆坐标系下,多组交点如图4所示,分别是 A_1A_2 、 B_1B_2 、 C_1C_2 、 D_1D_2 、 E_1E_2 、 F_1F_2 。

[0066] 步骤109,标定模块根据预设转换系数和多组交点的位置坐标得到多组交点在车辆基准坐标系中的相对位置坐标,并且根据每组交点的相对位置坐标计算得到每组交点中两个交点之间的相对间距;

[0067] 具体的,在图像坐标系下,两个选中车道线是不平行的,要确定两个选中车道线是

否平行,需要将上一步骤中得到的多组交点转换到车辆基准坐标系下,从而根据车辆基准坐标系下的相对位置坐标计算每组交点中两个交点的相对间距。

[0068] 车辆基准坐标系转换到像素坐标系的公式如下:

$$[0069] \quad z_c \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = K [R \quad T] \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix} \quad (\text{式 } 1)$$

[0070] 转换系数 $q=Z_c/(K[R \ T])$ (式2)

[0071] 其中, Z_c 为比例系数、 K 为相机的内参矩阵、 R 为旋转矩阵、 T 为平移矩阵。

[0072] 步骤110,根据一个车道线信息中的各组交点的相对间距进行标准差计算,得到车道线信息对应的标准差参数;

[0073] 具体的,通过一个车道线信息中的各组交点的相对间距进行标准差计算,用以判断该车道线信息中两个选中车道线是否平行。标准差参数具有对应的图像ID。

[0074] 标准差参数的计算公式如下:

$$[0075] \quad \bar{D} = [D(A_1, A_2) + D(B_1, B_2) + D(C_1, C_2) + D(D_1, D_2) + D(E_1, E_2) + D(F_1, F_2)] / 6 \quad (\text{式 } 3)$$

$$[0076] \quad \text{COST} = \sqrt{\{ [D(A_1, A_2) - \bar{D}]^2 + [D(B_1, B_2) - \bar{D}]^2 + [D(C_1, C_2) - \bar{D}]^2 + [D(D_1, D_2) - \bar{D}]^2 + [D(E_1, E_2) - \bar{D}]^2 + [D(F_1, F_2) - \bar{D}]^2 \} / 6} \quad (\text{式 } 4)$$

[0077] 其中, $D(A_1, A_2)$ 、 $D(B_1, B_2)$ 、 $D(C_1, C_2)$ 、 $D(D_1, D_2)$ 、 $D(E_1, E_2)$ 、 $D(F_1, F_2)$ 分别为各组交点的相对间距, \bar{D} 为6个相对间距的平均值,COST为6个相对间距的标准差。

[0078] 步骤111,标定模块根据第二预设数量个标准差参数的均值与预设最优参数的比较结果确定是否调整相机的外参;

[0079] 具体的,一个车道线信息中的每组交点的相对间距都相同的时候,判定两个选中车道线相互平行,此时标准差参数为0。也就是说,只要标准差参数不为0,就表示两个选中车道线不平行。

[0080] 标定模块对第二数量个标准差参数进行平均值计算,并且将计算得到的结果与最优参数进行比较,根据比较结果确定是否需要调整相机外参。最优参数可以是0也可以是一个区间。

[0081] 当标准差参数的均值不等于预设最优参数时,标定模块根据梯度下降法或者网格搜索法调整外参,得到调整后的外参。标定模块根据预设相机内参和调整后的外参进行乘法计算,并且将计算结果赋值给预设转换系数,并再次执行相机外参动态标定方法。

[0082] 其中,梯度下降法是沿着标准差参数梯度向下的方向求解最小值,梯度下降的步长以及最大迭代次数可以根据需求设置,最终通过梯度向下法的循环迭代获取不同方向的最小值。每个方向的最小值对应相机外参的其中一个参数,从而得到调整后的相机外参。

[0083] 网格搜索法是按照预设的外参变量步长和调整的上下阈值,对所有的外参参数的组合的情况进行相应的COST的计算,然后选出一组计算结果最优的组合的相机外参作为调整后的外参。

[0084] 当标准差参数的均值等于预设数值时,表明此时的相机外参是符合车辆当前行驶状态的,标定模块确定预设转换系数不变。

[0085] 确定转换系数后,可以将图像坐标系下的目标的像素坐标转换为车辆基准坐标系下的目标的相对位置坐标,从而可以得到目标相对于车辆的位置,实现更精准实现车辆避障或者路线规划。

[0086] 具体为相机将多帧第一图像发送给目标检测模块。目标检测模块根据机器视觉技术或者人工神经网络技术对第一图像进行识别处理,得到目标信息,并发送给标定模块。其中,目标信息包括目标ID和目标ID对应的像素坐标。标定模块根据转换系数和目标的像素坐标得到目标的相对位置坐标。

[0087] 图5为本发明实施例提供的车辆基准坐标系下目标的示意图,目标的相对位置坐标就是在车辆基准坐标系下目标相对于车辆的坐标。其中,目标可以理解为当前在路面行驶的其他车辆、行人或者其他影响车辆行驶的障碍物。

[0088] 本发明提供的相机外参动态标定方法,可以在车辆离线状态下实现初始的外参标定,还可以在车辆行驶过程中实时进行动态相机外参标定。尤其是在车辆颠簸或者上下坡道的情况下,能够自动地矫正相机的外参标定参数,提高视觉检测目标的位置精度,进而提高车辆行驶的安全系数。

[0089] 专业人员应该还可以进一步意识到,结合本文中所公开的实施例描述的各示例的单元及方法步骤,能够以电子硬件、计算机软件或者二者的结合来实现,为了清楚地说明硬件和软件的可互换性,在上述说明中已经按照功能一般性地描述了各示例的组成及步骤。这些功能究竟以硬件还是软件方式来执行,取决于技术方案的特定应用和设计约束条件。专业技术人员可以对每个特定的应用来使用不同方法来实现所描述的功能,但是这种实现不应认为超出本发明的范围。

[0090] 结合本文中所公开的实施例描述的方法或方法的步骤可以用硬件、处理器执行的软件模块,或者二者的结合来实施。软件模块可以置于随机存储器(RAM)、内存、只读存储器(ROM)、电可编程ROM、电可擦除可编程ROM、寄存器、硬盘、可移动磁盘、CD-ROM、或技术领域内所公知的任意其它形式的存储介质中。

[0091] 以上所述的具体实施方式,对本发明的目的、技术方案和有益效果进行了进一步详细说明,所应理解的是,以上所述仅为本发明的具体实施方式而已,并不用于限定本发明的保护范围,凡在本发明的精神和原则之内,所做的任何修改、等同替换、改进等,均应包含在本发明的保护范围之内。

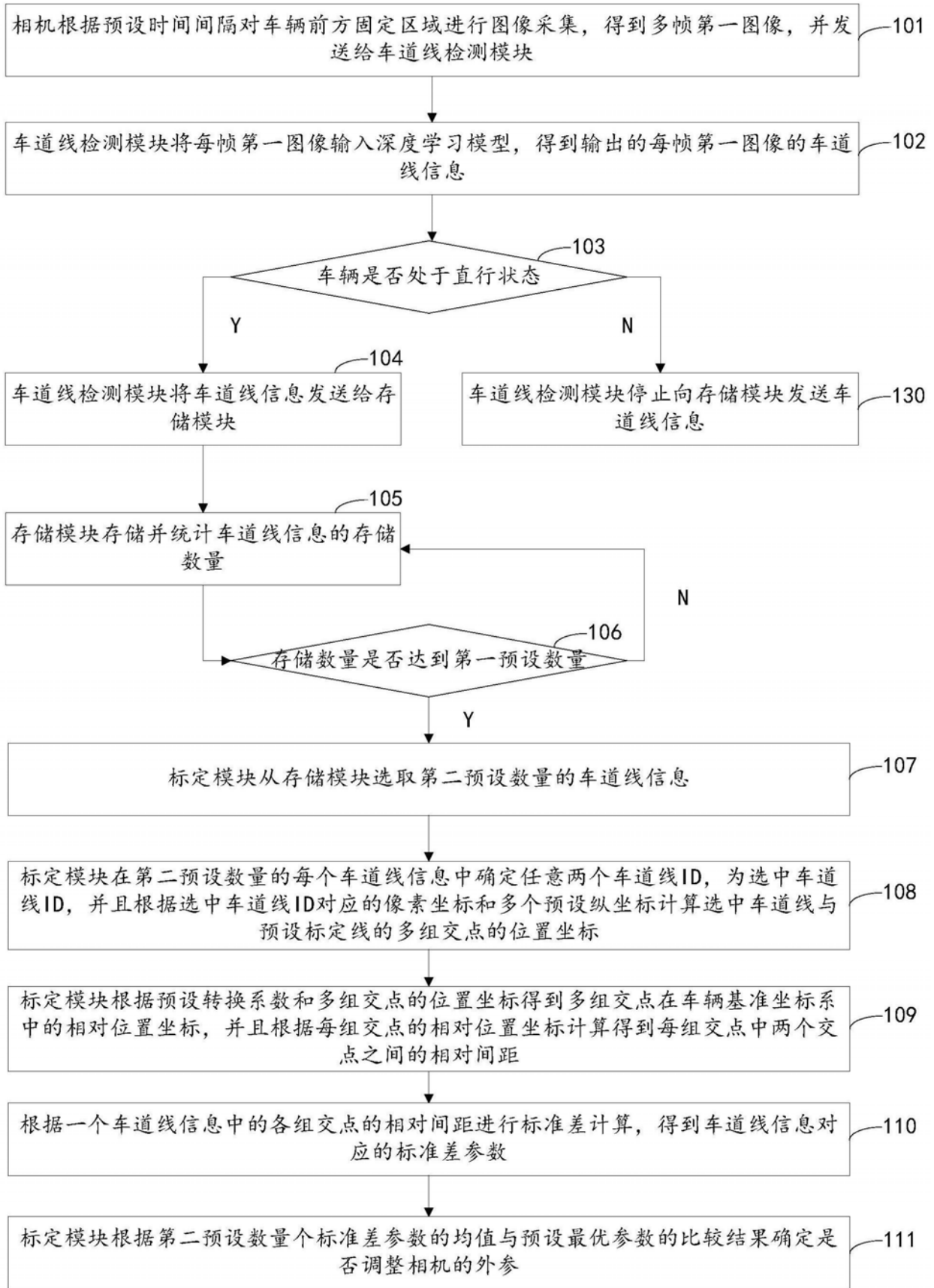


图1

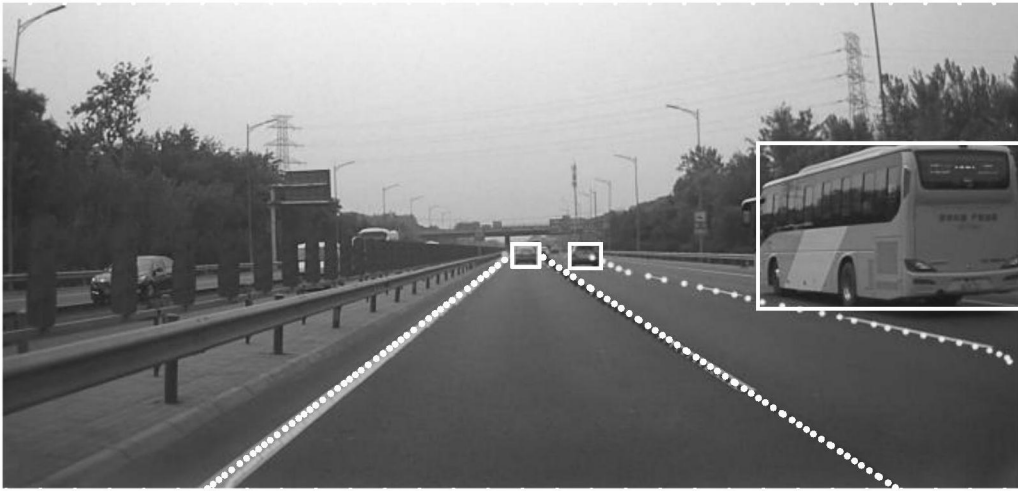


图2



图3

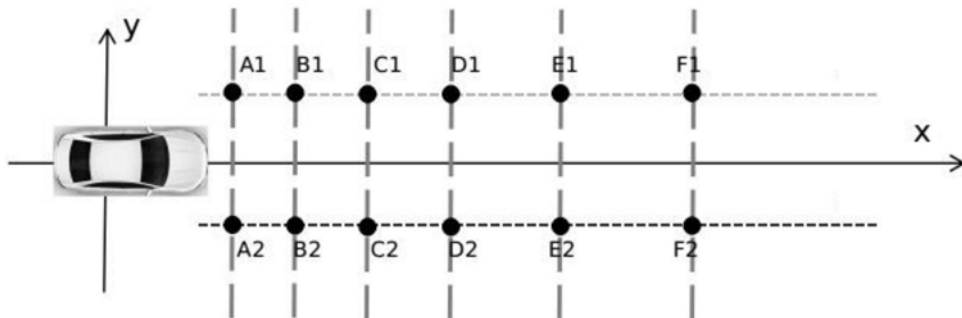


图4



图5



October 11, 2025

Certification

Welocalize Translations

TRANSLATOR'S DECLARATION:

I, Li Xiao Yuan, a translator fluent in the English and Chinese languages, on behalf of Welocalize, do solemnly and sincerely declare that the following is, to the best of my knowledge and belief, a true and correct translation of the documents listed below in a form that reflects the intention and meaning of the original text.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

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