# Research on Ranging Range Based on Binocular Stereo Vision Plane-Space Algorithm

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**Abstract.** In the Internet of Vehicles, the binocular stereo vision ranging method has the advantages of high efficiency, simple system structure and low cost, and its ranging function is an indispensable part of the intelligent network vehicle terminal, but how to use it to determine the ranging range is rarely studied. To solve the problem that the binocular stereo vision plane-space algorithm cannot evaluate the distance range on the limited surface, this paper proposes a surface constraint-range sweep algorithm, which is applied to evaluate the distance range between pedestrians and vehicles in Internet of Vehicles environment. First, according to the image sensor information of the ranging model, the model parameters of the plane-space algorithm are calculated. Next, whether the projection of the target point is on the image sensor is calculated according to the principle of geometric optical imaging. For the point projected on the image sensor, the error margin of the algorithm point can be set according to the working environment. If the error margin is met, the measurement point is considered to be within the limited surface value range. Finally, according to the actual object, the point cloud of the target surface is obtained by using the geometric optics theory, and the range of the plane-space algorithm on the limited surface is calculated, so as to construct the ranging evaluation model of the plane-space algorithm. The experimental results show that the efficiency of the algorithm can reach 99. 8% by adjusting the parameters of the surface constraint-range sweep algorithm. The surface constraint-range sweep algorithm can more accurately evaluate the range of the plane-space algorithm on the limited surface.

**Keywords:** Internet of Vehicles · Plane-space algorithm · Surface constraint-range sweep algorithm · Target surface point cloud

## 1 Introduction

Based on the Intranet, Internet, and Mobile Internet of the vehicle, the Internet of Vehicles wirelessly connects the vehicle centric system in accordance with the agreed communication protocol and data exchange standard [1], and the vehicle terminal interconnection is one of the main ways to realize the function of the Internet of Vehicles. Traditional intelligent network connected vehicle terminals include T-Box, Tracker, OBD, ETC OBU,


Q. Liang et al. (Eds.): CSPS 2022, LNEE 873, pp. 51–58, 2023.
https://doi.org/10.1007/978-981-99-1260-5_7

etc. The tracker can realize positioning management and obtain real-time vehicle location information. Binocular stereo vision is the process of obtaining depth information from a pair of left and right camera images [2]. It does not require the priori conditions of the target object, and the distance measurement can be completed through the parallax of the left and right image sensors, which is widely used in vehicle positioning.

As an important branch of computer vision, binocular stereo vision is mainly based on the parallax principle, which uses two image acquisition devices located in different positions to obtain two images of the measured object, and then calculates the three-dimensional information of the object by calculating the coordinate difference of a point in the reference image and the corresponding point in the target image. There are many examples for the realization of binocular stereo vision ranging and positioning functions [3–8], but there is little research on using it to determine the ranging range. In the 1980s, Marr [9] proposed a visual computing theory and applied it to binocular matching. By calculating the disparity of two plane images, a stereo image with depth can be further generated, thus laying the theoretical foundation for the development of binocular stereo vision. Reference [10] focuses on the image matching method based on Canny edge detection and Harris corner detection, and calculates the distance according to the principle of parallax. Its experiments show that binocular stereo vision ranging is related to the focal length and resolution of the camera, and the ranging error can be maintained at about 6%. Reference [3] proposes an algorithm that combines MATLAB calibration and OpenCV matching to achieve binocular stereo vision ranging. Simulation experiments show that when the ranging range is less than 2 m, the measurement error of the algorithm does not exceed 5%, and the measurement accuracy is affected by the texture of the measured object. The description of the ranging range of the algorithm is not exhaustive. In [11], Ye Qingzhou et al. proposed a flame localization and ranging algorithm based on binocular stereo vision. The accuracy of the algorithm's flame location is higher than 95% within the measurement range of 0.5 m to 5 m, and the ranging error is less than 5%. The experiment mainly measures the distance of target objects within a fixed range, and does not explain how to evaluate the range of the algorithm. Zhang Jiaxu [12] et al. proposed a target distance measurement algorithm based on deep learning and binocular stereo vision, which realized obstacle target recognition and localization. Through the ranging experiment at a fixed distance, the error analysis between the measured value and the actual value is used to evaluate the accuracy of the algorithm, and when the distance is 4.5 m, the algorithm has the highest accuracy, and the corresponding error is 0.9%. Reference [13] mainly studies the distance measurement of vehicles, and proposes an automatic driving distance measurement system based on image processing. The system selects camera bases with different heights to perform ranging experiments at a fixed distance. When the selected base is 0.6 m, the error is the smallest. Reference [14] proposes a distance estimation system based on pedestrian detection results to obtain the distance between pedestrians and cameras. The experiment uses NVIDIA's graphics processor to accelerate pedestrian detection and distance estimation. When the ranging range is less than 5 m, the relative error of the ranging system is less than 8%. Reference [15], Zhang Enshuo proposed a new binocular stereo vision ranging algorithm, which uses the plane coordinates measured by the image sensor to calculate the three-dimensional coordinates of the target point, and reflects the space information of the target object by selecting the appropriate target boundary points. Experimental data show that the error rate of the algorithm is less than 2% within 1 m.

The algorithms or systems proposed in different ranging studies mainly carry out ranging experiments at a fixed distance, and the determination of ranging range is not explained in some studies. Based on the plane space algorithm proposed by Zhang Enshuo, this paper studies the ranging range of the plane-space algorithm on a limited surface according to geometric optics theory, and proposes a surface constraint-range sweep algorithm, which effectively solves the problem of obtaining the distance range of vehicles or pedestrians in the environment of Internet of vehicles.

## 2 Plane-Space Algorithm

Firstly, the plane-space algorithm proposed by Zhang Enshuo is introduced. According to literature [15], the plane - space algorithm model is shown in Fig. 1:

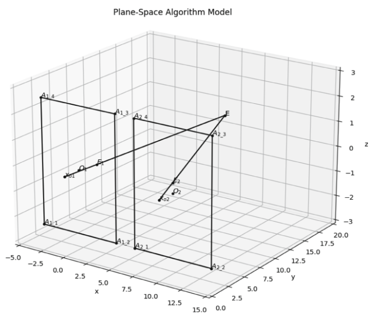


**Fig.1.** Mathematical model of plane-space algorithm

The rectangle $A_{1\_1}A_{1\_2}A_{1\_3}A_{1\_4}$ and $A_{2\_1}A_{2\_2}A_{2\_3}A_{2\_4}$ are the positions and sizes of the left and right image sensors of the binocular ranging system. The midpoint of $A_{1\_1}A_{1\_4}$ is on the origin of the standard coordinate system, its normal vector is parallel to the y axis of the standard coordinate system, and the x and y axes of image sensors $A_{1\_1}A_{1\_2}A_{1\_3}A_{1\_4}$ and $A_{2\_1}A_{2\_2}A_{2\_3}A_{2\_4}$ are parallel to the x and z axes of the standard coordinate system respectively. The point $E$ is the measured target, and points $E_1$ and $E_2$ are the projections of point $E$ on image sensors $A_{1\_1}A_{1\_2}A_{1\_3}A_{1\_4}$ and $A_{2\_1}A_{2\_2}A_{2\_3}A_{2\_4}$. $x_{o1}$ and $x_{o2}$ are the rear focus corresponding to image sensors $A_{1\_1}A_{1\_2}A_{1\_3}A_{1\_4}$ and $A_{2\_1}A_{2\_2}A_{2\_3}A_{2\_4}$, and $x_{o1}$ and $x_{o2}$ are on the x-axis. $O_1$ and $O_2$ are the projection coordinates of the optical axis corresponding to image sensors $A_{1\_1}A_{1\_2}A_{1\_3}A_{1\_4}$ and $A_{2\_1}A_{2\_2}A_{2\_3}A_{2\_4}$ respectively. The distance between the left and right image sensors and $x_{o1}, x_{o2}$ is $y_1$. Let $E_1(x_1, y_1, z_1)$, $E_2(x_2, y_1, z_2)$, $x_{o1}(x_{o1}, 0, 0)$ and $x_{o2}(x_{o2}, 0, 0)$ be known. If the target is calculated according to points $E_1(x_1, y_1, z_1)$

and $E_2(x_2, y_1, z_2)$, the coordinates of the target point are $E(x, y, z)$:

$$\begin{cases} x = \frac{x_1 x_{o2} - x_2 x_{o1}}{(x_{o2} - x_{o1}) + (x_1 - x_2)} \\ y = \frac{(x_{o2} - x_{o1}) y_1}{(x_{o2} - x_{o1}) + (x_1 - x_2)} \\ z = \frac{(x_{o2} - x_{o1}) z_2}{(x_{o2} - x_{o1}) + (x_1 - x_2)} \end{cases} \tag{2.1}$$

## 3 Surface Constraints - Range Sweep Algorithm

In actual working environment, it is usually necessary to have a detailed knowledge of the target, such as the outline of a pedestrian, the shape of a vehicle, and so on. Therefore, the performance of the algorithm can be estimated from one or more sets of normative values for that type of contour or shape. The surface constraint-value range scanning algorithm is a method related to the plane-space algorithm for calculating the value range on limited surface. Therefore, the surface constraint-range sweep algorithm is derived using the relevant parameters of the plane-space algorithm and the principle of optical imaging. The parameters related to the model in the plane-space algorithm are $x_{o1}, x_{o2}$, $y_1$, where $x_{o1}, x_{o2}$ determines the distance of the left and right sensors, and $y_1$ determines the focal length of the left and right image sensors. Let the length and width of the left and right image sensors are $w$ and $h$, the distance between the two sensors is $d$, and the focal length is $f$, then

$$\begin{cases} x_{o1} = \frac{w}{2} \\ x_{o2} = \frac{3}{2}w + d \\ y_1 = f \end{cases} \tag{3.1}$$

The input parameters of the model are $x_1, x_2, z_2$. If the target point can be detected at this time, it must meet the requirements of the existence of the projection of these three points on the corresponding sensor, that is

$$\begin{cases} x_1 \in (0, w) \\ x_2 \in (w + d, 2w + d) \\ z_2 \in (-\frac{1}{2}h, \frac{1}{2}h) \end{cases} \tag{3.2}$$

Bring the model input parameters $x_1, x_2, z_2$ into formula (2.1), let the coordinates of the target point be $E_{text}(x_{text}, y_{text}, z_{text})$, the standard coordinates of the target point are $E_{std}(x_{std}, y_{std}, z_{std})$, and set the error sequence $(error_x, error_y, error_z)$ according to the actual situation. If met

$$\begin{cases} |x_{text} - x_{std}| \le error_x \\ |y_{text} - y_{std}| \le error_y \\ |z_{text} - z_{std}| \le error_z \end{cases} \tag{3.3}$$

If any point on the target point cloud $E_{std}(x_{std}, y_{std}, z_{std})$ corresponds to $E_{text}(x_{text}, y_{text}, z_{text})$) and $x_1$, $x_2$, $z_2$ meet both formula (3.2) and formula (3.3), the point is considered to be within the algorithm value range. Let the number of valid points of the estimated model be $Cnt_e$, and the total number of points is $Cnt_s$, then the effective rate is

$$r = \frac{Cnt_e}{Cnt_s} \tag{3.4}$$

# 4 Experimental Analysis

## 4.1 Experimental Principle and Steps

According to the principle of geometrical optics, after calculating the projection of all points on the surface with known average shape on the image sensor, the corresponding algorithm value is calculated according to the projection value. If the difference between the algorithm value and the standard value is within the set range, the point is considered to be within the algorithm value domain. The experimental steps are as follows:

1. Obtain the point cloud of the measured target surface according to the actual situation;
2. For any point, calculate the projection of the point on the image sensor;
3. Calculate the algorithm value of the target point according to the projection coordinates obtained in step 2;
4. Compare the algorithm value with the real value of the target point. If the difference between the coordinates of the algorithm value and the real value is less than the error redundancy, and the target point is projected within the imaging range of the image sensor, that is, if formula (3.2) and (3.3) are satisfied at the same time, the point is considered to be within the algorithm value range;
5. Draw the simulation results by marking the marked target point cloud as blue, the points in the value range as red, the points that do not conform to the algorithm value as black, and the invisible points as green. Then calculate the efficiency of the algorithm for the target according to formula (3.4).

## 4.2 Experimental Data and Analysis

$w$, $h$, $d$, $f$, $p$ and $disVec$ are respectively the width and height of image sensors, distance between the left and right image sensors, focal length, pixel size and target displacement of image sensors. The unit of width and height of the image sensor is pixel, the unit of distance between left and right image sensors is millimeter, the unit of focal length is millimeter, the unit of pixel size is micrometer, and the unit of target displacement is meter. This project mainly conducts simulation experiments on the outline of people and the shape of vehicles.

### 4.2.1 Human Silhouette Simulation

The standard posture of a person is taken as an example for simulation, in which the width of the image sensor is 1920$p$, the height of the image sensor is 1080$p$, the resolution of the input image at this time is 1920 × 1080, the distance between the left and right image sensors is 500 mm, the focal length of the image sensors is 5 mm, the pixel size is 6 μm, the error margin sequence $\left(error_x, error_y, error_z\right)$ is uniformly set as $1e^{-5}$, and the target displacement is [−120.5 m, 105 m, 0]. The simulation results are shown in Fig. 2, and the effective rate is $r = 89.83\%$.

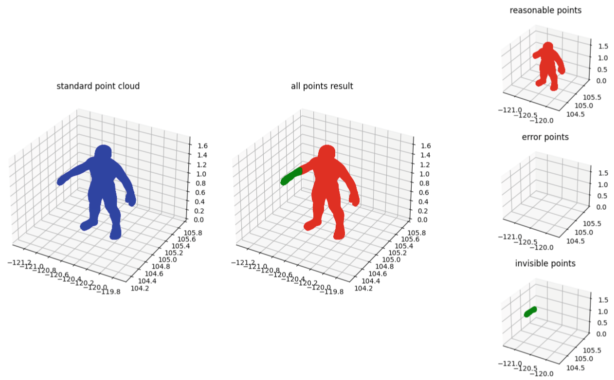


**Fig.2.** Range evaluation image of human standard contour

By adjusting the simulation parameters, the target displacement is adjusted to [−120.7 m, 105.5 m, 0], the simulation result is shown in Fig. 3, and the effective rate is $r = 98.97\%$.

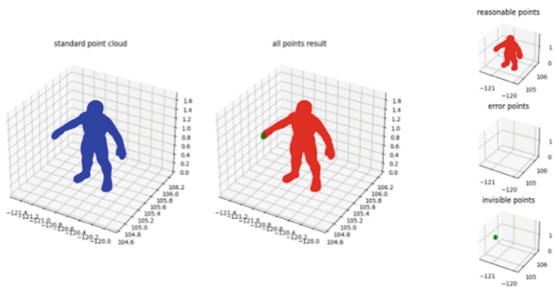


**Fig.3.** Value range evaluation image of standard posture after adjusting parameters

### 4.2.2 Vehicle Shape Simulation

Taking the shape of the vehicle as an example for simulation, in which the width of the image sensor is 1920*p*, the height of the image sensor be 1080*p*, the resolution of the input image is 1920 × 1080, the distance between the left and right image sensors is 500 mm, the focal length of the image sensors is 5mm, the pixel size is 6μm, the error margin sequence $\left(error_x, error_y, error_z\right)$ is uniformly set as $1e^{-5}$, and the target displacement is [−117.7 m, 107.4 m, 0]. The simulation results are shown in Fig. 4, and the effective rate is $r = 99.80\%$.

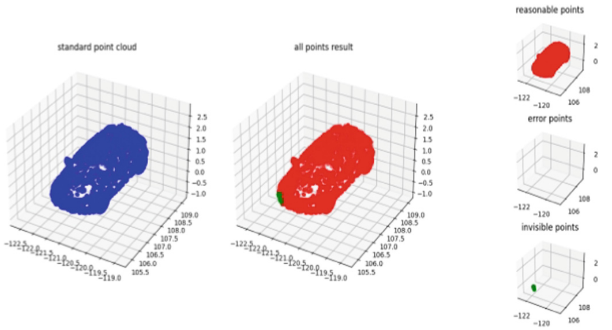


**Fig.4.** Value range evaluation image of vehicle shape

## 5 Conclusion

In the context of the Internet of Vehicles, this paper studies how to evaluate the plane-space algorithm to determine the ranging range on a limited surface, and proposes a surface constraint-range sweep algorithm. The experimental results show that the ranging range of the surface constraint-range sweep algorithm can be adjusted by changing the target displacement and other parameters, and in the simulation of the vehicle shape, the efficiency can reach 99.8% when the target displacement is $[-117.7m, 107.4m, 0]$. When similar model parameters are brought into the plane-space algorithm, the results of the above simulations do not appear. Therefore, the surface constraint-range sweep algorithm performs well in evaluating the distance range of the target object, and effectively obtains the distance range of the target object in the environment of the network of vehicle. However, due to the complexity of the model data, the algorithm has certain requirements for the computing power of the device, and the real-time performance is not good enough. This problem can be solved by adding the number of cores of the device processor or optimizing the calculation amount of the algorithm.

**Acknowledgment.** Shubin Wang (wangshubin@imu.edu.cn) is the correspondent author and this work was supported by the National Natural Science Foundation of China (61761034), the Natural Science Foundation of Inner Mongolia (2020MS06022).

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