# Research on the adaptive joint spatial synchronization method for lidar and binocular camera

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**Abstract.** Binocular cameras and lidars are widely used in the safety monitoring of the three-span section of transmission lines due to their good complementary characteristics. The existing spatial synchronization methods for binocular cameras and lidars have low accuracy in synchronous measurement due to the calibration process being overly dependent on manual point selection. In this paper, the data of the camera and lidar sensor are aligned spatially, and a joint calibration method is adopted to achieve the spatial synchronization of the lidar and binocular cameras, making the data obtained from the fused measurement after synchronization more accurate. The simulation test results show that compared with using binocular cameras alone or lidars alone for spatial measurement, the fused measurement results using the adaptive joint spatial synchronization method proposed in this paper are more accurate, thereby verifying the effectiveness of this method.

**Keywords:**LiDAR; Binocular camera; Space synchronization.

## 1. Introduction

The characteristics of the "three spans" of transmission lines, usually using lidar, binocular camera, infrared remote sensing and other new technologies, to realize the spatial modeling, information screening and intelligent early warning [1] of external hidden dangers, channel tree barriers and cross-crossing. Binocular camera and lidar are widely used by researchers in the safety monitoring of the three interregional sections of transmission lines because of their good complementary characteristics.

In order to improve the fusion accuracy of multi-sensors in three-region security monitoring, it is necessary [2] to solve the spatial synchronization problem between binocular camera and lidar. This is because the temporal and spatial errors between the camera and the lidar are not constant, and the spatial errors between the camera and the lidar may change with the continuous use of the sensors, thus requiring regular calibrating [3] of the spatial errors between the camera and the lidar.

In view of the difference of data acquisition frequency and spatial position between lidar and binocular camera, in order to improve the fusion effect of sensor target, it is necessary to synchronize the sensor data information in space and improve the robustness of multi-source sensor information perception ability in different environments.Zhang Mingming et al. made a comprehensive analysis and comparison of the spatial synchronization of different sensors, used the advanced global nearest neighbor matching algorithm to process the signal, and used the weighted fusion method to integrate the matching target, to overcome the limitations of a single sensor, thus significantly improving the accuracy of spatial synchronization[4]. Felix et al proposed optimized spatial synchronization for fusion camera and radar detection, assessing the synchronization accuracy of the [5] by combining tracking in the image frame with the Kalman filter in the road frame. Although the above method can achieve the spatial synchronization calibration of camera and lidar, the calibration results are too dependent on the accuracy of manual point selection [6]. In practice, it is difficult to accurately annotate the corresponding feature information due to the density of the point cloud, so the spatial synchronization results are unsatisfactory [7]. Considering that the calibration process may require constant and regular repetition, it is necessary to seek calibration tools that reduce repetition and are universality.

Therefore, this paper focuses on multi-sensor fusion in three-span safety monitoring, which mainly solves the problem of spatial synchronization between binocular camera and lidar. Aiming at the existing spatial synchronization method of binocular camera and laser radar, the accuracy of synchronous measurement is not high because the calibration process is too dependent on manual point selection. An adaptive spatial synchronization method for binocular camera and laser radar is realized. The data of camera and laser radar sensor are aligned in space. The joint calibration method is used to realize the spatial synchronization of laser radar and binocular camera, which makes the data obtained by fusion measurement more accurate after synchronization.The flow chart of joint calibration is shown in Figure 1.

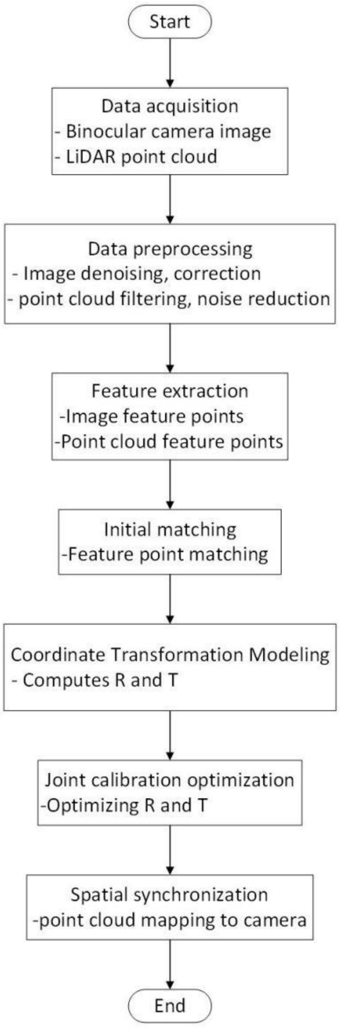

Fig. 1. Joint calibration flow chart

## 2. Coordinate transformation modeling of spatial synchronization

The premise of spatial synchronization between lidar and binocular camera sensor is to carry out coordinate transformation between them. Based on the time synchronization of lidar and binocular camera sensor data, it is necessary to jointly calibrate lidar and binocular camera to achieve spatial synchronization of multi-source sensors. It is a basic work to calibrate the internal and external parameters of binocular camera before joint calibration. Therefore, it is necessary to realize the transformation and unification between the laser radar coordinate system, the image coordinate system, the binocular camera coordinate system and the world coordinate system.The principle of coordinate transformation is shown in Figure 2.

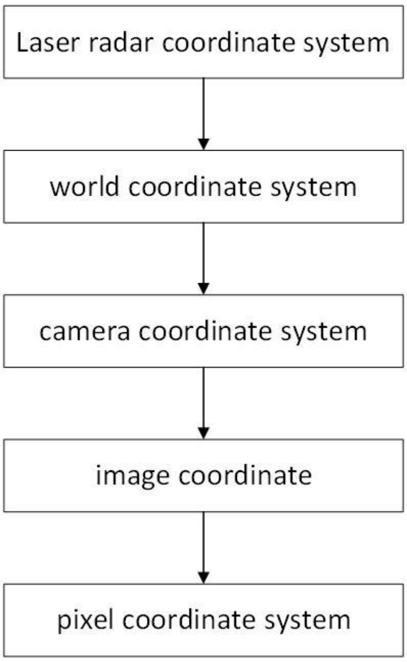

Fig. 2. Principle of coordinate transformation

By obtaining the 3D coordinates and 2D image coordinates of many marker points, the internal and external parameter matrices of the binocular camera are obtained by the optimization method. Here, the planar target joint calibration method is used to realize the spatial synchronization of lidar and binocular camera. The three-dimensional point cloud coordinates are mapped to two-dimensional coordinates by reflection projection, and the spatial matching of point cloud data and image information is realized, that is, the joint calibration of external parameters of binocular camera and lidar is carried out. For the laser radar coordinate system, the laser emission module of the laser radar is generally used as the origin, and the Y axis is along the direction of the data transmission cable, the Z axis is upward, and the X axis is to the right.For the lidar coordinate system, the laser emission module of lidar is generally the origin, the direction along the data transmission cable is the Y axis, the upward axis is the Z axis, and the X axis is the right.

For the binocular camera coordinate system, take the camera focus as the origin, forward B axis, down Y axis, and right X axis. In its imaging coordinate system, the two-dimensional image plane to which the points in the three-dimensional space are mapped through the pinhole imaging model is called the image imaging coordinate system. The origin of the imaging coordinate system is set as the intersection of the imaging plane and the optical axis of the camera, and the x and y axes are parallel to the x and y axes of the camera coordinate system. The image acquired by the camera is stored in the form of pixels in the computer, and the actual camera coordinates are the coordinates under the image element coordinate system. Therefore, the interconversion between the binocular camera coordinate system and the image element coordinate system should be carried out. In order to better describe the transformation between the camera-pixel coordinate system, the image coordinate system is regarded as the intermediate coordinate system to realize the transformation.

Suppose that the coordinates of a point in the radar coordinate system are (X1, Y1, Z1), and the camera coordinates are (X, Y, Z). The radar and the camera are placed on the same platform, and the radar coordinates are changed to the binocular camera coordinates to realize the unification of the two spatial coordinate systems. The specific change methods are shown as follows:

$$[X,Y,Z,1]^T = \begin{bmatrix} R & T \\ 0 & 1 \end{bmatrix} [X1,Y1,Z1,1] \tag{1}$$

Where R, T is the rotation and translation transfer matrix of the radar coordinate system to the binocular camera coordinate system.

At the same time, according to the point cloud position coordinates to determine the calibration plate plane, first of all to extract the point cloud coordinates of the calibration plate plane. As a data structure, KD-tree is used to represent a set of k-dimensional spatial points, and the KD-tree method is used to select the point cloud around the specified point.

## 3. Adaptively adaptive joint spatial synchronization method

By integrating the spatial synchronization of the measurement data of the lidar sensor and the binocular camera, the coordinate conversion model of spatial synchronization is constructed here, and the internal and external parameter matrix of the binocular camera is obtained. The joint calibration method is further adopted to realize the spatial synchronization of lidar and binocular machine. By reflecting the projection, the three-dimensional point cloud coordinates are mapped to the two-dimensional coordinates one by one, so as to achieve spatial matching.

Specifically, the rotation matrix and the translation matrix are used to realize the conversion between the coordinate system. If the unit normal vector of the binocular camera coordinate system and the lidar coordinate system under the position and attitude of a certain object are R and G respectively, then the coordinate conversion equation can be expressed as:

$$[X_c, Y_c, Z_c]^T = R[X_L, Y_L, Z_L]^T + G \tag{2}$$

Where, G is the spatial coordinate translation matrix. R is the rotation matrix of the spatial coordinates.

t represent the coordinates of objects under binocular camera and lidar coordinates, respectively. The normal vector P in the lidar coordinate system converted to the binocular camera coordinate system is expressed as:

$$\beta = RP \tag{3}$$

At this time, the rotation matrix has the following property characteristics:

$$R^T \bullet R = I, \det R = 1 \tag{4}$$

According to the above formula for constructing the objective function about R, the singular value analysis method is used to obtain the rotation matrix. At the same time, the spatial synchronization calibration plane is determined according to the point cloud position coordinates. First, the point cloud coordinates are extracted, and the point cloud data is pre-processed. Set the fitted plane equation expression to ax + by + cz + s=0.

Where a, b, c, and s are the unknown fitting parameters. Choosing four calibration space coordinates of the point cloud can calculate the position parameters of the plane equation, and then other point cloud space coordinates can be replaced into the equation to calculate the distance between the point cloud and the plane to obtain:

$$D = \frac{| ax + by + cz + s |}{\sqrt{a^2 + b^2 + c^2}} \tag{5}$$

By setting the number of iterations, comparing the number of effective points in the results before and after the iteration until they no longer increase, the plane with the most effective points is the fitting plane of spatial synchronous calibration.

## 4. Simulation validation

For camera and lidar spatial synchronization algorithms, the datasets to visually describe and analyze the effectiveness of the adaptive joint spatial synchronization method.

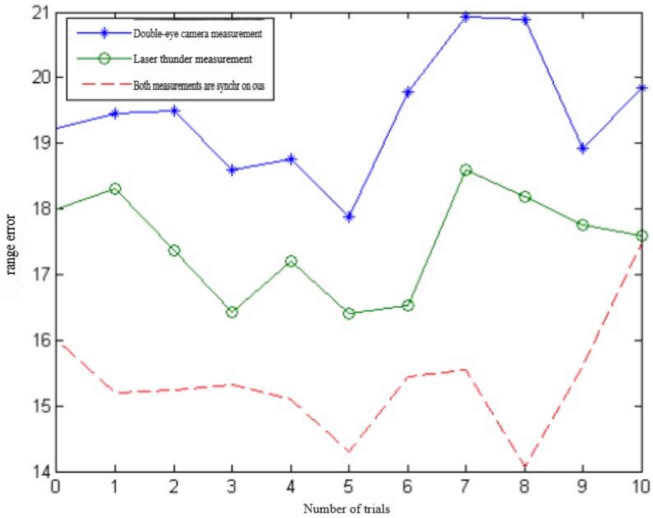

Fig. 3. Comparison chart of test times of measurement method.

From the simulation test results, it is evident that aligning the data from the binocular camera and the LiDAR sensor in space significantly improves the accuracy of spatial measurements. During the spatial synchronization process between the camera and LiDAR, the simulation demonstrated minimal scene errors, validating the effectiveness of the proposed adaptive joint spatial synchronization method. The results highlight the limitations of using either the binocular camera or LiDAR alone and underscore the advantages of the joint calibration approach.

(1)Limitations of Using Only the Binocular Camera

When relying solely on the binocular camera for spatial measurement, the accuracy is heavily dependent on visual feature matching. However, this approach is susceptible to environmental factors such as lighting conditions and texture variations. In the simulation tests, the binocular camera exhibited significant measurement errors, particularly in low-texture or poorly lit environments. For instance, in complex scenarios such as the three-span section of transmission lines, the measurement error was notably higher, making it insufficient for high-precision monitoring requirements.

(2)Limitations of Using Only the LiDAR

While LiDAR provides high accuracy in distance measurement, its performance is constrained by the sparsity of point cloud data and the reflective properties of target surfaces. In the simulation, LiDAR's measurement error increased when applied to complex structures such as cross-span sections of transmission lines. The sparse point cloud data often failed to capture fine details, particularly at edges and intricate parts of the target.

(3)Advantages of the Joint Calibration Method

The proposed adaptive joint spatial synchronization method leverages the complementary strengths of the binocular camera and LiDAR. By fusing high-resolution image data from the binocular camera with precise distance measurements from LiDAR, the method achieves superior accuracy and robustness. The simulation results demonstrate the following key advantages:

① Reduced Error:The fused measurement error was significantly lower compared to using the binocular camera or LiDAR alone, demonstrating a clear improvement in measurement precision.

② Enhanced Robustness:The fusion method maintained stable performance under challenging conditions, such as varying lighting and partial occlusions, demonstrating strong adaptability to complex environments.

③ Improved Scene Adaptability: The joint calibration method proved effective in diverse scenarios, including the three-span section and cross-span areas of transmission lines, consistently delivering high measurement accuracy.

## 5. Conclusion

The characteristics of the ' three-span ' key section of the transmission line are usually based on new technical means such as laser radar, binocular camera, infrared remote sensing and other multi-sensors. In order to improve the accuracy of multi-sensor fusion in three-span section safety monitoring, it is necessary to solve the problem of spatial synchronization between binocular camera and lidar. This paper focuses on multi-sensor fusion in three-cross-section safety monitoring, mainly solving the problem of spatial synchronization between binocular camera and lidar. Aiming at the existing spatial synchronization method of binocular camera and laser radar, the accuracy of synchronous measurement is not high because the calibration process is too dependent on manual point selection. The data of camera and laser radar sensor are aligned in space. The joint calibration method is used to realize the spatial synchronization of laser radar and binocular camera, which makes the data obtained by fusion measurement more accurate after synchronization. The simulation test results also verify the effectiveness of the proposed method.Future research directions include further optimizing the joint calibration algorithm, reducing the calculation time, and expanding to other application scenarios.

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