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The algorithm to generate color point-cloud with the registration between panoramic image and laser point-cloud

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Abstract. Laser point cloud contains only intensity information and it is necessary for visual interpretation to obtain color information from other sensor. Cameras can provide texture, color, and other information of the corresponding object. Points with color information of corresponding pixels in digital images can be used to generate color point-cloud and is conducive to the visualization, classification and modeling of point-cloud. Different types of digital cameras are used in different Mobile Measurement Systems (MMS), the principles and processes for generating color point-cloud in different systems are not the same. The most prominent feature of the panoramic images is the field of 360 degrees view angle in the horizontal direction, to obtain the image information around the camera as much as possible. In this paper, we introduce a method to generate color point-cloud with panoramic image and laser point-cloud, and deduce the equation of the correspondence between points in panoramic images and laser point-clouds. The fusion of panoramic image and laser point-cloud is according to the collinear principle of three points (the center of the omnidirectional multi-camera system, the image point on the sphere, the object point). The experimental results show that the proposed algorithm and formulae in this paper are correct.

1. Introduction

In recent years, the study about the vehicle mobile measurement system, composed by laser scanner, POS and CCD cameras, has made certain achievement. Dense point-clouds without color obtaining by laser scanning system are more precise and direct in measurement, while Images obtaining by digital cameras can provide abundant color and texture. So we could describe the surface features more precisely and intuitively if we combine the point-clouds with the images. Color point-cloud is the intuitive product of the date fusion between the point-clouds and the images. It has a great advantage in visual display, classification and object modeling.

Different types of digital cameras are used in different Mobile Measurement Systems (MMS), the principles and processes for generating color point-cloud in different systems are not the same. The research about the fusion of the laser point-clouds and the digital images can be divided into three categories depending on the types of cameras. The types are plane array camera, linear array camera and panoramic camera. The fusion of the plane array camera and point-cloud is the most studied. For different characteristics of the data, the registration between laser point-clouds data and images of the plane array camera are made based on POS data or the feature matching between the two data sources, which help to generate color point-clouds based on the collinear principle.
Compared with the plane array camera, the linear array camera has wide viewing angle and high acquisition frequency, overcoming the problems that we could not store images promptly and may lose images under certain circumstances, but it’s more difficult in calibration and white balance adjustment. As for panoramic images, the most prominent feature is the field of 360 degrees view angle in the horizontal direction, obtaining image information around the camera as much as possible. Three different image acquisition methods have their advantages and disadvantages and choice should be made base on different needs in different systems. The Lynx Mobile Mapper of Optech from Canada is equipped with up to 2 or 4 plane array CCD cameras. The VMX-250 of RIEGL from Austrian is equipped with 4 or 6 plane array CCD cameras. The IP-S2 system of Topcon Corporation from Japan use Ladybug3 panoramic camera. The linear array CCD camera is also used in some other MMS.

The experimental platform in this article is the vehicle laser scanning and modeling measurement system developed by Capital Normal University. The system mainly consists of laser scanner, panoramic camera, GPS and IMU. The laser scanner is used to obtain the point-cloud data (Figure 2). The digital camera is used to obtain color texture. IMU and GPS provide the attitude and position of the system during the movement. All the equipments are rigidly fixed on the same platform, and is unified by the GPS time. With the experimental field calibration and a series of data fusion process, the laser point-cloud and images can registration accurately. In this article the system equipped Ladybug3 panoramic camera to obtain panoramic images (Figure 3) directly. With the registration between panoramic images and laser point-cloud, we could get the correspondence between the pixels in the image and the points in the point-cloud.

In this paper, on the basis of the registration between panoramic image and point-cloud, we introduce a method to generate color point-cloud from laser point-cloud and panoramic image, using the collinear principle that the center of the omnidirectional multi-camera system, image point on the sphere and object point are in line. The method takes full advantage of the 360 degree panoramic image and laser point-cloud. In the end, the experimental results show that the proposed algorithm and formula in this paper are correct.

Figure 1. Experimental Platform

Figure 2. Laser point-cloud data
2. Methodology

2.1. Coordinate System Definition
Geodetic coordinate system $S(X_0Y_0Z_0)$: Absolute coordinate system, all the data in this system is unified through this coordinate system.

Local three-dimensional Cartesian coordinate system $S_1(X_1Y_1Z_1)$: The system origin is in the center of the current panoramic sphere. We can get the new coordinate system $S_1$ by moving the origin of the system $S$ to the center of the panoramic sphere.

Panoramic ball three-dimensional Cartesian coordinate system $S_2(X_5Y_5Z_5)$: The system origin is also in the center of the current panoramic sphere. Y-axis points to the Dealer direction, X-axis points to the right side of the vehicle body, the Z-axis vertically upward.

Panoramic ball Polar coordinate system $P(B, L, R)$: The polar coordinate system with the origin in the center of the panoramic sphere.

Panoramic image plane coordinate system ($o - xy$): The Cartesian coordinate system with the origin in the principal point of a panoramic image.

2.2. Color Point-Cloud Algorithm
The coordinate of each point in the point-cloud data is absolute coordinate, indicating the actual position of the object point. According to the collinear principle, the object point, center of photography and image point are collinear. So we can calculate the pixels’ coordinates based on the
three-dimensional coordinates of the corresponding object points, and then assign the object points with the RGB value of the pixels.

- **Step1.** Coordinates transform form \( S(X_t Y_t Z_t) \) to \( S_1(X_1 Y_1 Z_1) \), as Formula 1;

\[
\begin{bmatrix}
X_1 \\
Y_1 \\
Z_1
\end{bmatrix} = \begin{bmatrix}
X_t \\
Y_t \\
Z_t
\end{bmatrix} - \begin{bmatrix}
dX \\
dY \\
dZ
\end{bmatrix} 
\]

(1)

Where, \((dX, dY, dZ)\) is the geodetic coordinate of the center of the current panoramic sphere.

- **Step2.** Coordinates transform form \( S_1(X_1 Y_1 Z_1) \) to \( S_2(X_2 Y_2 Z_2) \), as Formula 2;

\[
\begin{bmatrix}
X_2 \\
Y_2 \\
Z_2
\end{bmatrix} = \begin{bmatrix}
a1 & a2 & a3 \\
b1 & b2 & b3 \\
c1 & c2 & c3
\end{bmatrix} \cdot \begin{bmatrix}
X_1 \\
Y_1 \\
Z_1
\end{bmatrix} 
\]

(2)

Where, \((a1, a2, a3, b1, b2, b3, c1, c2, c3)\) are the parameters of the rotation matrix, determined by the three attitude angles of the panoramic sphere: \(\phi\) (Roll angle), \(\omega\) (Pitch angle), \(\kappa\) (Heading angle), as Formula 3.

\[
\begin{bmatrix}
a1 & a2 & a3 \\
b1 & b2 & b3 \\
c1 & c2 & c3
\end{bmatrix} = \begin{bmatrix}
\cos \phi & 0 & -\sin \phi \\
0 & 1 & 0 \\
\sin \phi & 0 & \cos \phi
\end{bmatrix} \cdot \begin{bmatrix}
1 & 0 & 0 \\
0 & \cos \omega & -\sin \omega \\
0 & \sin \omega & \cos \omega
\end{bmatrix} \cdot \begin{bmatrix}
\cos \kappa & -\sin \kappa & 0 \\
\sin \kappa & \cos \kappa & 0 \\
0 & 0 & 1
\end{bmatrix} 
\]

(3)

- **Step3.** Calculate the polar coordinates \(P(B, L, R)\) of the image point in the panoramic sphere by the coordinates \((X_2 Y_2 Z_2)\) of the corresponding point in \(S_2\).where, the meaning of \(B\) and \(L\) is shown in Figure 1. \(R\) means the radius of the panoramic sphere;

\[
B = \begin{cases} 
\frac{\pi}{2} - \tan^{-1} \left( \frac{Y_2}{X_2} \right), & \text{when } X_2 > 0 \\
\left( \frac{\pi}{2} + \tan^{-1} \left( \frac{Y_2}{X_2} \right) \right), & \text{when } X_2 < 0 
\end{cases}
\]

(4)

\[
L = \tan^{-1} \left( \frac{Z_2}{\sqrt{X_2^2 + Y_2^2}} \right) 
\]

(5)

- **Step4.** Calculate the image plane coordinates \((x, y)\) of the corresponding image point by the polar coordinates \((B, L)\);

- **Step5.** Calculate the pixel’s coordinates \((m, n)\) by the image plane coordinates \((x, y)\) of the corresponding image point. The step 4 and 5 can be expressed as Formula 6 and 7;

\[
m = \frac{\text{Width}}{2} + \frac{B}{2\pi} \cdot \text{Width} 
\]

(6)

\[
n = \frac{\text{Height}}{2} - \frac{L}{\pi} \cdot \text{Height} 
\]

(7)

Where, Width means the width of the panoramic image, Height means the height of the panoramic image.

- **Step6.** Assign the object points with the RGB value of the pixels, as Formula 8;

\[
RGB(X_s, Y_s, Z_s) = RGB(m, n, N) 
\]

(8)

Where, \(RGB(X_s, Y_s, Z_s)\) means the RGB values of the point \((X_s, Y_s, Z_s)\), \(N\) means the serial number of the images, \(RGB(m, n, N)\) means the RGB values of the pixel \((m, n)\).

### 2.3. Generation of Color Point-Cloud

The experimental data of this paper consists of three parts, including point-cloud data, panoramic images and image-related information file. The relevant information of the image includes the file path, position, posture, and GPS time of each image in the photographic moment. Point-cloud data in this system is obtained by continuous laser scanning. The data format is as follows:\(x, y, z\) represent
the three-dimensional coordinates, \( t \) represents GPS cycle per second. Panoramic images are collected every 5 meters. The format of the image is BMP or JPEG. The first step to generate color point-cloud is to read these data.

In this experiment, the distance between the scan lines of point-cloud data is about 0.2 meters (speed of about 40 km/h), while the distance between two adjacent panoramic images is 5 meters. Some objects in the panoramic image are blocked by the others, and the visibility of objects is different in several adjacent panoramic images. For the above reasons, the second step to generate color point-cloud is choosing the right panoramic image for each point. In this paper, the follow strategies are proposed to solve the problems. First, select the nearest panoramic image for each point based on GPS time or geometric distance. Second, analyse the visibility of the point-cloud in panoramic image, and select the adjacent panoramic images to color the points if the objects are blocked in the current image. But in further applications, specific programs still need to be adjusted according to the characteristics and needs of the actual data.

The third step is to calculate the pixel coordinates of the image point corresponds to object point, and the RGB value of the pixel is assigned to the object point. The same operation is performed for all of the object points until the color point-cloud is generated.

3. Result and analysis
In this experiment, the effect of the color point-cloud is mainly affected by the following factors: the precision of the point cloud, resolution and geometric distortion degree of the images, accuracy of the registration between point-cloud and images. Laser scanner used in this experiment is the domestic laser RANGLE-II, and the relative measurement accuracy of the point-cloud data is better than 1cm. Ladybug 3, resolution of which is \( 2048 \times 1024 \), is the panoramic camera used in the experiment, whose error in 10 m distance is 1 cm, and in 50 m is 5 cm. When the object is far from the Center of Photography, a pixel may correspond to many neighbouring points, so the higher the resolution of the panorama image is, the richer the color of point-cloud and the higher the accuracy will be, proving Ground Calibration method can be used to calculate the registration parameters of point-cloud and image.

![Figure 5. Origin Point-Cloud](image1)
![Figure 6. Panoramic Image](image2)

The experiment data used in this paper is collected in a viaduct section of Guangzhou by the vehicle laser scanning and modeling measurement system developed by Capital Normal University. Laser point-cloud data shown in Figure 5, and panoramic image shown in Figure 6. Through the algorithm presented in this paper, the color point-cloud shown in Figure 7 is automatically generated. Comparing the color point-cloud with the original image, it can be found that the color can be completely coinciding, showing that the formula is correct.
Further analysis of the color point-cloud data shows that, the effect of the color for the point-cloud unobstructed is very good. For example, trees, houses and street lamp along the way, etc. (As shown in Figure 8). Even when the objects 150 meters away from the Center of Photography, the result is still good. However, for the objects blocked and on top of the high buildings, there is a problem of color disorder. Through analysis, the reasons are as follows. Firstly, the car is located in the viaduct, and the sight of panoramic camera is partly blocked by the roadside fence so that the camera can’t obtain the images in the lower place. In the further work, the optimization in the occlusion handling strategy and acquisition route will be done. Secondly, there’re some problems in the panoramic camera equipped in this system. The main factor is the lack of resolution of the camera. The default resolution of Ladybug 3 is 2048 × 1024. The distortion of the camera also affects the result. In the future, we will develop a high resolution omnidirectional multi-camera system composed with several SLR cameras to replace the existing panoramic camera (Ladybug 3), which will have a major part in the improvement of the effect of the experiment.
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Reference