# *Wide Image Geometric Mosaic and Measure Algorithm of Mobile Mapping System*

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***Abstract*—A wide image mosaic and measure algorithm of mobile mapping system (MMS) has been proposed in this paper. Through constructing the cylinderical panorama projection relationship of triple original digital measurable images (DMIs), the wide image has been mosaiced directly. The corresponding relationship between wide image and object space coordinate has been constructed by utilizing back projection relationship between wide image and original DMIs, and synchro or asynchro stereo DMI pair of the triple original DMIs. Then, the wide image object measure algorithm has been realized. The wide image experiment illustrates that, the method of utilizing cylinderical panorama projection to acquire wide image can be applied in mosaic of sequential wide images in MMS. When original DMI possesses synchro stereo DMI pair, the absolute precision of wide image measure result can be better than 1m and the relative precision of wide image measure result can be better than 0.2m. This accuracy contents with the precision requirement of real vision object measure in city environment.**

***Keywords—Mobile Mapping System (MMS); Digital Measurable Image (DMI); wide image; cylinderical panorama projection; image mosaic; image measure***

## I. INTRODUCTION

Mobile Mapping System（MMS）has already been widely used in aspects of military and civil foundational geographic information collection, rapid mapping and platform service nowadays [1-4]. Sensors like global positioning system (GPS), charge coupled device (CCD), inertial navigation system (INS)/dead Reckoning (DR) are usually equipped on MMS vehicles so that road and either sides' land objects can be rapidly shot as Digital Measurable Image(DMI) in speed of 40-80km/h. The accessory files of these DMIs include position and gesture elements of exterior orientation which are needed in photogrammetry analysis. Each DMI pair is marked with its exact sample time. The stereo DMI pairs can be constructed with support of rigor photogrammetry calibration parameters. Various measure method, seamless data fusion and measure-at-anytime-in-need [5] can be realized.

The LYNX of Optech Company, VMX-250 of RIEGL、IP-S2 of Topcon、MX8 of Trimble, StreetMapper of IGI and Street View vehicle of Google are main MMS products in recent years. In China, the Wuhan University, Leador Company, Capital Normal University, Shandong University of Science and Technology, China Acedemy of Surveying and Mapping, China Acedemy of Sciences in Shenzhen and many research organizations have rolled out their MMS [6].

According to different application aims, sensors of MMS that sample DMIs may either be Ladybug panorama CCDs or be single/double/multi CCD(s) to realize information collection and certain object's measure [7,8]. Considering that exterior orientation elements of these CCDs have been calibrated [9] and are of high imaging resolutions, the captured DMIs can not only be used for user browsing but also be applied for point /line/area measure in DMI.

In this paper, part panorama (or wide image) measure has been researched. Through geometric mosaic processing, measure functions of wide images has been realized. Experiments verified the feasibility and accuracy of the method introduced in this paper. MMS used in this paper was produced by Leador Company in Wuhan, China, as shown in Fig.1. Installing positions of 7 CCDs are shown in Fig.1. Among the 7 CCDs, CCD No.1 and No.2 shoot at the same time as synchro stereo DMI pair, CCD No.3 and No.4 capture simultaneously as synchro stereo DMI pair, CCD No.5 and No.3 have been installed beside CCD No.1 with angles of ±50°. Triple DMIs captured by CCD No.5, No.1 and No.3 synchronously can be mosiaced into a wide image of a viewing angle more than 150°. CCD No.6 and No.7 are used for both sides and rear street view collection. The wide image geometrically mosaiced from triple DMIs shot by CCD No.5, No.1 and No.3 simultaneously has been mainly discussed in this paper, and object measure algorithms have been implemeted in the experiments.

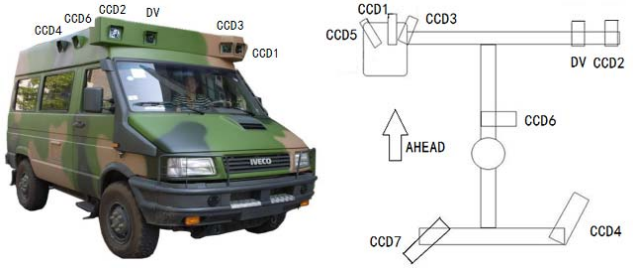


Fig. 1. Ways to Install 7 CCDs in MMS

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Researchers have discussed on models like Ladybug panorama, sphere, fisheye, cubes, cylinderical panorama projection and different measure algorithms in mass [10-12]. On the MMS platform used in this paper, the triple DMIs can be mosaiced through partly panoramic cylinders projection. After the cylinderical projection, the geometric relationship can be constructed between wide image coordinate and object space coordinate, so that image mosaic can be well realized just by geometric deformation projection. Object space coordinates in originate DMI captured by CCD No.1 can be obtained by utilizing the synchro stereo relationship between CCD No.1 and No.3. Similarly, Object space coordinates in originate DMI captured by CCD No.1 can be obtained by utilizing the synchro stereo relationship between CCD No.2 and No.4. However, object space coordinates in originate DMI captured by CCD No.5 can be obtained by using the asynchro stereo relationship of CCD No.5. Then object measure can be achieved through geometric tranform from 3 DMIs to wide image.

## II. WIDE IMAGE OBTAINING AND GEOMETRIC MOSAIC

### A. Features of Panorama Projection

The wide image referred in this paper is part panorama image obtained by cylinderical panorama projection principle. Common panorama projection principles include spherical projection, cubes projection and cylinderical projection. The spherical projection is suitable for observing in 3 degrees of freedom, but it refers to nonlinear deformation in X and Y directions and the data structure for storing the full view image is relatively complexer. The cubes panorama image is easy for computer accessing and control, but it should be constructed by images after 90° plane projection, or else the image would deform seriously. Cylinderical projection transforming relationship is relatively simpler and with smaller deformation, and it possesses the feature of no deformation in vertical direction. Therefore, cylinderical panorama is proper for realizing horizontal 360° observing and is convenient for computer storage [13]. In this paper, the geometric relationship has been constructed by part cylinderical panorama projection in MMS experiment platform of Fig.1.

### B. Projection and Geometric Mosaic of Cylinderical Wide Image

According to the calibration parameters of all CCD cameras beforehand, the focal length of CCD No.1 is 1276.56 of physical unit. The physical unit should be conversed into pixel unit in convenient for image projection caculation. As shown in Fig.2, if the width and height of the original DMI is $W$ and $H$ (pixel), the half horizontal viewing angle of the camera is $\theta$, the focal length of the camera is $f$。Then the horizontal viewing angle $2\theta$ will decide the approximate viewing angle of the wide image which is mosaiced from original triple DMIs. Fig.3 presents the cylinderical front projection relationship and

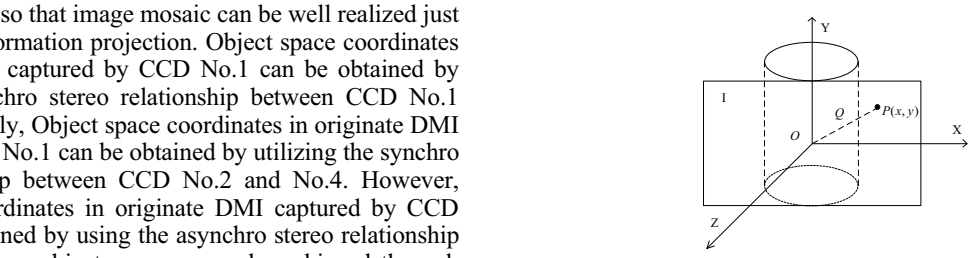


Fig. 2. Relationship between Camera's Pixel Focal Length and Width of Wide Image




Fig. 3. Cylinderical Front Projection

the ±50° installing included angles are known, hence the wide image viewing angle is 150° approximately, and the $f$ can be estimated in unit of pixel as

$$2\theta = 150°/3,\ f = W/(2\tan\theta). \tag{1}$$

Then a point $p(x,y,z)$ in original DMI will be $p(x-W/2, y-H/2, -f)$ when it is in camera coordinate system $p(x_c, y_c, z_c)$. If point $Q$ is the corresponding point of point $p$ after cylinderical projection. As shown in Fig.3, the middle point of the cylinder is the base point of the camera coordinate system, the focal length $f$ is the cylinder radius. When extending the cylinder surface into a flat plane, the relationship between $Q(x', y')$ and $p(x,y)$ can be derived as

$$\begin{cases} x' = f\arctan(-(x-W/2)/f) + f\arctan(W/2f) \\ y' = f(y-H/2)/\sqrt{(x-W/2)^2+f^2} + H/2 \end{cases} \tag{2}$$

Fig.4 shows the triple DMIs synchronically captured by CCD No.5, No.1, and No.3 in some typical position. Appearently, the three DMIs have different brightness for the sunlight difference. After cylinderical projection, the width and height of the original DMIs have changed, the image width after cylinderical projection is $W = 2f\theta$. Through analysing the $y'$ in (2), we can see that $y'$ is the image height after projection. When $x = 0$ or $x = W$, $y'$ has the minimum value, while when $x = W/2$, $y'$ has the maximum value. It means that image width after projection has diminished, and the image height has changed from the minimum to maximum and to minimum again. Fig.5 shows the cylinderical projection transformation result of the three original DMIs in Fig.4. In addition, as the three CCD camera was installed in fixed positions, after the three original DMIs projected to the same cylinder surface, automatic mosaic can be achieved by setting offset values. Fig.6 shows the wide image after just setting proper offset values and cutting the four borders of the mosaic result. As shown in Fig.6, the mosaic result is ideal on



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Fig. 4. Three Original DMIs

Fig. 5. Cylinderical Projection of Fig.4

Fig. 6. Mosaic Result

conditions of ignoring the sunlight difference and color uniforming problem of the seam. In this experiment, all sequential DMIs captured by CCD No.5, No.1, and No.3 have been mosaiced using the same parameters, the mosaic results is in a consistently ideal level.

### C. Back Projection of Wide Image

The above section illustrates the geometric projection from three original DMIs to wide image. It is the forward process when obtaining a wide image by projection and mosaic. As the pixels in original DMIs are closely linked with elements of exterior and inner orientation in MMS platform, and original DMIs are more convenient for coordinate transform and calculation, it is often neccessary to derive back from a point coordinates in wide image to the corresponding coordinate in original DMI. The back projection relationship of the wide image is the inverse function of (2) [14]. So a point $Q(x', y')$ in wide image has a relationship with the corresponding point $p(x, y)$ in original DMI as (3).

$$\begin{cases} x = f \cdot g((x' - f \arctan(W / 2f)) / f) + f \arctan(W / 2f) \\ y = (y' - H / 2)\sqrt{(x - W / 2)^2 + f^2} / f + H / 2 \end{cases} \quad (3)$$

## III. Measure Algorithm of Wide Image

Point or lines in objects in the wide image can be measured given the corresponding relationships (2) and (3) between wide image coordinate and original DMI coordinate. In the experiment, through using the synchro stereo relationship both between CCD 1and3 and between CCD 2and4, and utilizing the asynchro stereo relationship of CCD 5, can the object space coordinate in original DMIs captured by CCD 5,1,3 be obtained. Then taking advantage of the geometric transform relationship from 3 DMIs to wide image, can the object measure in wide image be realized. The point measure algorithm is an object measure algorithm in the wide image. The point neasure algorithm is the way to obtain the point in object space coordinate which is cooresponding to and transformed from the point in wide image. Point measure algorithm is similar to and simpler than line measure algorithm, so only the line measure algorithm will be introdued in Fig.7.

The line measure algorithm aims to measure any single or continuous line segment(s) in wide image, so that the physical actual length of the line segment(s) of certain accuracy range can be obtained. The concrete algorithm flow is as shown in Fig.7.



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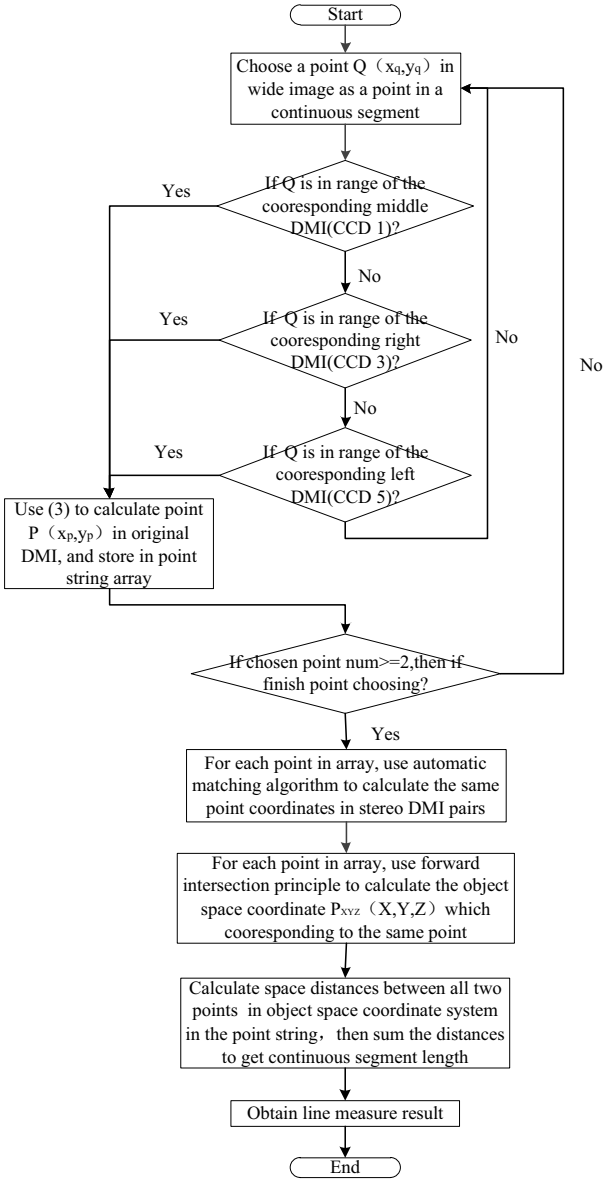


Fig. 7. Line Measure Algorithm FLow

## IV. Measure Experiment

### A. Point Measure Experiment

To verify the feasibility and precision of the point measure algorithm in wide image, in this paper 60 marked points have been chosen in intervels of about 10m on a section of quiet road. Points have been marked on sides of the road or on road surface. All points' geodetic coordinates (precision in cm level) have been collected by high precision measuring GNSS (Global Navigation Satellite System) receiver for comparision with point measure results as actual values. MMS experiment platform has been used for collecting sequential DMIs in experiment section of the street. Matlab® has been applied for calculating the transformation process from geometric mosaic and wide image coordinate to object space coordinate. 60 measure results have been calculated in 20 wide images on the left, middle and right sides. Calculation results of the RMS ( $\sqrt{\Delta X^2+\Delta Y^2+\Delta H^2}$ ) between measure results and actual coordinate values are as follows in Table 1.

TABLE I. Experiment Result of Point Measure

| Sequential Wide Image No. | Point Measure RMS（m） | | |
|---|---|---|---|
| | *Left Side* | *Middle* | *Right Side* |
| 1 | 1.2668 | 0.6846 | 0.8224 |
| 2 | 1.0987 | 0.5872 | 0.7726 |
| 3 | 1.1153 | 0.5385 | 0.9430 |
| 4 | 1.0016 | 0.6165 | 0.8140 |
| 5 | 1.2090 | 0.6984 | 0.7252 |
| 6 | 1.4785 | 0.7304 | 0.8804 |
| 7 | 1.4141 | 0.5356 | 0.8512 |
| 8 | 1.2034 | 0.6985 | 0.9627 |
| 9 | 1.1293 | 0.5830 | 0.8504 |
| 10 | 1.3437 | 0.7859 | 0.9763 |
| 11 | 1.4432 | 0.7513 | 0.8964 |
| 12 | 1.0221 | 0.6171 | 0.9383 |
| 13 | 1.3709 | 0.6268 | 0.8255 |
| 14 | 1.1895 | 0.6114 | 0.7401 |
| 15 | 1.4264 | 0.7204 | 0.8161 |
| 16 | 1.2879 | 0.7486 | 0.6047 |
| 17 | 1.4020 | 0.6803 | 0.8307 |
| 18 | 1.3151 | 0.5171 | 0.7338 |
| 19 | 1.0193 | 0.7107 | 0.8832 |
| 20 | 1.1657 | 0.6795 | 0.8244 |

In Table 1, the absolute precision of point measure in wide image is better than 1.5m. The point measure precision of left side with only asynchro stereo DMIs is better than 1.5m, while the point measure precisions of middle and right sides with synchro stereo DMIs are better than 0.8m and 1.0m.

### B. Line Measure Experiment

Similarly, to verify the feasibility and precision of the line measure algorithm in wide image, in this paper 60 marked points also have been chosen in intervels on a section of quiet road. Points have been marked on sides of the road or on road surface. Actual values of all line lengths (precision in mm level) have been collected by soft ruler for comparision with line measure results. MMS experiment platform has been used for collecting sequential DMIs in experiment section of the street. Matlab® has been applied for calculating the line measure process in wide image. 60 line measure results have been calculated in 10 wide images on the left, middle and right sides. Calculation results of the RMS ($\sqrt{\Delta L^2}$) between line measure results and actual line length values are as follows in Table 2.

TABLE II. Experiment Result of Line Measure

| Sequential Wide Image No. | Line Measure RMS（m） | | |
|---|---|---|---|
| | *Left Side* | *Middle* | *Right Side* |
| 1 | 0.4141 | 0.0865 | 0.1591 |
| 2 | 0.4451 | 0.0701 | 0.1378 |
| 3 | 0.4287 | 0.0921 | 0.1910 |
| 4 | 0.2135 | 0.0523 | 0.1925 |
| 5 | 0.4612 | 0.0502 | 0.1799 |
| 6 | 0.4413 | 0.0436 | 0.1305 |
| 7 | 0.2143 | 0.0913 | 0.1821 |



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| | | | |
|---|---|---|---|
| 8 | 0.3790 | 0.0716 | 0.1289 |
| 9 | 0.3330 | 0.0609 | 0.1712 |
| 10 | 0.4973 | 0.0688 | 0.1813 |
| 11 | 0.3250 | 0.0856 | 0.1115 |
| 12 | 0.3866 | 0.0842 | 0.1167 |
| 13 | 0.2104 | 0.0678 | 0.1839 |
| 14 | 0.2830 | 0.0541 | 0.1263 |
| 15 | 0.3533 | 0.0732 | 0.1544 |
| 16 | 0.3842 | 0.0833 | 0.1125 |
| 17 | 0.4236 | 0.0765 | 0.1631 |
| 18 | 0.3088 | 0.0612 | 0.1423 |
| 19 | 0.4313 | 0.0723 | 0.1531 |
| 20 | 0.4786 | 0.0891 | 0.1399 |

In Table 2, the relative precision of line measure in wide image is better than 0.5m. The line measure precision of left side with only asynchro stereo DMIs is better than 0.5m, while the line measure precisions of middle and right sides with synchro stereo DMIs are better than 0.1m and 0.2m.

### C. Experiment Result Analysis

As shown in Table 1 and Table 2, objects in the middle DMIs with synchro stereo DMIs have the average minimum error. Objects in right side DMIs with synchro stereo DMIs have average relative bigger error than objects in middle for the influence of shoot angle. Objects in left side DMIs calculated with only asynchro stereo DMIs have often been influenced by base line error which lies in MMS GPS positioning error. Objects in left side DMIs have the average maximum error and cannot satisfy the relative precision requirement of line measure. It is considered that the measure precision is generally used for describing the close-range objects less than 40m in DMIs of MMS [15]. Therefore, the original DMIs should possess synchro stereo DMIs so that could the object measure precision in wide image keep in a consistently better level. Except for the measure errors in synchro stereo DMIs, the new-brought-in error sources and error properties have been analysed in Table 3. In addition, in the experiment process, back projection and the same points chosen artificially have brought in errors fairly the same.

TABLE III. ERROR ANALYSIS OF WIDE IMAGE MEASURE

| No. | Error Sources | Error Properties |
|---|---|---|
| 1 | Obtain image point coordinates in original DMI through back projection | Pixel points choosing and geometric deformation in back projection bring in errors. |
| 2 | Calculate object space coordinates by the same points in asynchro stereo DMI pairs | GPS positioning error has influenced baseline precision. The position precision of DGPS in MMS is in dm level. |

## V. CONCLUSIONS

This paper has researched on the object measure method in wide image which was mosaiced from DMIs collected by MMS platform. The geometric relationship between original DMI and wide image, projection algorithm and geometric mosaic method have been studied. The corresponding relationships of pixel points in projection and back projection between original DMI and wide image have been introduced. The point and line object measure algorithms have been designed and performed in wide images. Experiment results illustrate that the method of obtaining wide image through cylinderical panorama projection and geometric mosaic can be applied in sequential DMIs of MMS platform. On condition that synchro stereo DMIs possess orginal DMIs, the relative precision of wide image measure is better than 0.2m. This accuracy contents with the requirement for real vision object measure in city environment. A CCD camera is suggested to be added in MMS platform to construct synchro stereo relationship with CCD No.5 in order to keep consistent accuracy when measuring object in a whole wide image.

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