Research Paper

Geometric Registration of High Spatial Resolution Images Based on Google Earth Image and Global DEM Data

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ABSTRACT

With the development of remote sensing technology, the application of remote sensing technology is expanding. Before the application of remote sensing images, geometric registration and other preprocessing are often required for tilt correction and projection error correction, which often requires the selection of ground control points. Given the lack of measured ground control points, the correction accuracy will be greatly limited. In this paper, a remote sensing image orthographic correction process based on Google earth and Global DEM is proposed. First, in ENVI5.3, the image to be corrected and the reference image (Google Earth image) were automatically matched with the corresponding ground object points to obtain the coordinate file of the correction control point (.pts), and the coordinates were converted to plane coordinates. Under the ArcGIS10.2 platform, the data of the coordinate table of the correction control points were converted into the ArcGIS point file (SHP). Finally, the point file was spatially superimposed with the elevation data of Global DEM to obtain the elevation value, and then the ground control point file with elevation value was obtained, and then the orthographic correction with control points was carried out. The result showed that compared with the orthophoto correction without control points, the processing process adopted in this paper can improve the accuracy of correction, and the accuracy can meet the requirements of the 1:10000 land survey in the working base map. This research is expected to provide a new method for obtaining high-quality digital orthophoto images needed for land surveys.

1. Introduction

Remote sensing imaging process is affected by many factors, such as distortion of optical system, sensor attitude change, satellite platform movement, curvature of the earth, topography and so on, resulting in geometric distortions such as distortion, extrusion, extension and offset of the remote sensing image relative to the ground (Rocchini, 2004; Jaud et al., 2014). The conventional geometric correction method is difficult to eliminate the impact of the image caused by imaging distortion, with low accuracy. The orthorectification of the image

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combined with the digital elevation model (DEM) can greatly improve the geometric correction accuracy (Toutin et al., 2013; Zhang et al., 2018; Pinto et al., 2019). By selecting a certain number of ground control points on the image and using a Digital Elevation Model (DEM) covering the image range to orthophoto correct, the image can be simultaneously skew corrected and projected difference corrected to resample the image into a polycentric projection plane Orthophoto (Lee et al., 2017; Zhang et al., 2017; Gašparović et al., 2019).

With the development of remote sensing, there are more and more remote sensing data available to people (Boccardo et al., 2004; Zhang et al., 2019). However, these data are often not orthorectified and cannot be directly used for the mapping of land surveys. In the past, due to topographic map data, control point information and professional and technical personnel and other conditions, only the professional mapping agencies can complete the remote sensing image orthorectification. At present, relatively popular remote sensing image processing platform software is integrating more and more data processing capabilities, together with the public releasing of global DEM data (Zhang et al., 2012), the threshold of orthorectification is greatly reduced. Orthorectification can be chosen in many ways. ENVI5.0 and later versions provide the RPC Orthorectification Workflow tool that can perform orthorectification of unrealized ground control points directly without inputting GCPs Orthorectification. However, the calibration accuracy is limited due to the lack of ground control points.

Some scholars have studied the orthographic correction based on different data sources and accuracy tests. Oliveira et al. (2018) proposed a surface-gradient-based method (SGBM) applied to a triangulated irregular network (TIN) for the True Orthophoto Generation. Yousefzadeh et al. (2012) employed affine transformation in different coordinate systems in the orthorectification algorithm to compensate for the systematic DG errors to determine potential mapping errors due to the DG procedure. Reinartz et al. (2011) used the geometric accuracy of TerraSAR-X data to exploit the geometric accuracy of TerraSAR-X data. Geng et al. (2018) presented a novel orthorectification method based on an improved back-projection algorithm based on the geometric constraints of the central perspective plane (CPP). Ye et al. (2017) combined positive and negative transformation of a rational polynomial model with DEM data extraction and designed and implemented an automated orthorectification system. Zhang et al. (2016) designed a method for orthorectification of remote sensing images with Shuttle Radar Topography Mission elevation data by using the method of independent model and DEM regional network adjustment. In the aspect of accuracy evaluation, Yousefzadeh et al. (2012) illustrated the total planimetric RMS errors for each case and provided the maximum elevation ranges over the images. Reinartz et al. (2011) conducted the accuracy evaluation by the standard deviation. Berveglieri et al. (2017) showed the maximum and minimum residuals and root mean square errors (RMSEs) in the accuracy evaluation. Pehani et al. (2016) evaluate the Automatic Three-Step GCP Extraction Algorithm by the average RMSE.

In this study, the high-resolution worldview-2 image of the sample area of Hangzhou city, Zhejiang province was orthorectified. The reference data sources include Google Earth images and global DEM data. Google Earth is a popular image mapping software. Its spatial resolution has been increasing in recent years. At present, it can achieve a resolution of 0.5m in most urban areas in China, and even in many rural areas, it can also achieve the resolution in meters. In some areas with high spatial resolution, the relative positioning accuracy can reach 1: 2000 mapping specifications (Liu et al., 2015). Elevation data include the Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM) and Shuttle Radar Topography Mission (SRTM). The high-resolution Google Earth satellite imagery can be used in Landuse Map Preparation for urban-related applications (Malarvizhi et al., 2016). By establishing the correspondence between the image to be corrected and the Google Earth image in the corresponding area, the points of the same name are obtained to replace the measured ground control points and in combination with the Global DEM, the orthophoto correction including control point information can be achieved. The results showed that this process can effectively improve the accuracy of the calibration.

2. Study area and data

2.1 Study Area

This study takes the sample area of Hangzhou city, Zhejiang province as an example to verify the effectiveness of the orthorectification process. Zhejiang Province is located in the south of the Yangtze River Delta along the southeast coast of China. Hangzhou is located in the north of China's southeast coast and the north of Zhejiang province (Fig. 1; 29°11′ –30°33′ N and 118°21′ –120°30′ E). It belongs to the subtropical monsoon region. The average temperature is 17.8 ℃, and the annual precipitation is 1454 mm. The terrain of Hangzhou is complex and diverse. The western terrain of Hangzhou is hilly and the eastern terrain is plain. In this study, a 4.5km × 4.0km sample area in the district of Hangzhou was selected for orthorectification.

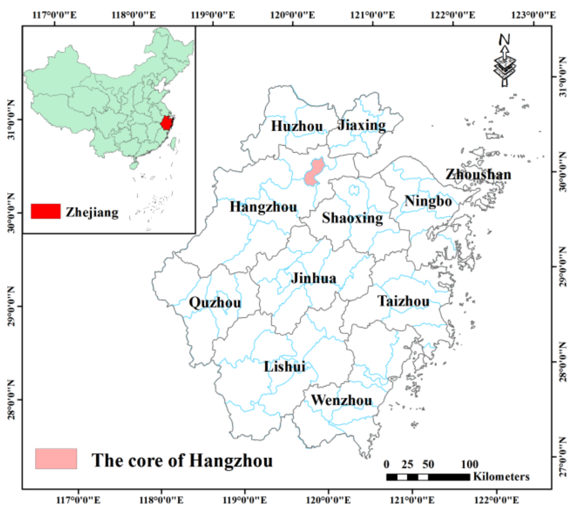


Fig. 1. Study area

2.2 Data Sources

In this study, the image to be corrected is the WorldView-2 imagery, the spatial resolution of the multispectral image is 1.8m including 8 bands, the spatial resolution of the panchromatic image is 0.5m, with imaging times of December 20, 2009. Before orthorectification, the NNDiffuse algorithm was used to fuse the multispectral image with the panchromatic image and resampled to a multispectral image with a spatial resolution of 0.5m.

The reference image of Orthorectification is from Google Earth. Through the third-party software tool, 91 WeiTu (Liu, & Li, 2016), Google Earth images with coordinate information can be downloaded as a reference for orthorectification. We used the World Geodetic System 1984 (WGS-84) ellipsoid to establish reference coordinated data. The central meridian set to the Universal Transverse Mercator and 123 °E, respectively.

SRTM datasets are jointly measured by National Aeronautics and Space Administration (NASA) and National Geospatial-Intelligence Agency (NGA). The total area of access is more than 119 million square kilometers between 60° N to 60° S, covering more than 80% of the Earth's land surface. SRTM data have been validated on the continental scale: absolute and relative vertical accuracy in Eurasia is 6.2m and 8.7m respectively (Rodriguez et al., 2006). The SRTM V3.0 data is an improvement over the original version and comes from seven related data sets, including the Shuttle Radar Topographic Mission-Global 1 arc-second data (SRTMGL1). SRTMGL1 data is the world 1 arc-seconds data, using WGS 84 projection, with the spatial resolution of 30m.

Advanced Spaceborne Theemal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM) data was developed by the Ministry of Economy, Trade and Industry in Japan (METI), and NASA. ASTER GDEM version 2 adopted an advanced algorithm to improve the version 1, improving the spatial resolution and elevation accuracy of data. METI of Japan and NASA of the United States verified the data accuracy of V2 version GDEM. The results showed that the version 2 corrected the errors in the version 1. ASTER GDEM data uses WGS 84 projection, with a spatial resolution of 30m.

3. Research methods

3.1 Research Ideas

The digital orthophoto map (DOM) not only has the geometrical precision of the map but also has the color and texture information of the image. It is an important data source of GIS and an important work map of the land survey. Obtaining a digital orthophoto map requires the aid of the ground control points and the DEM data within the original image. Generally speaking, the ground control points need to be obtained using up-to-data topographic maps or field measurements, resulting in higher costs and more difficult access. The Google Earth image has the advantages of high resolution, timely update, and its relative positioning accuracy can meet the requirements of 1: 2000 mapping specification (Liu et al., 2015). This study intends to verify the feasibility of replacing the actual ground control point in making a land survey work map. The idea is as follows:

1. By establishing the corresponding relationship between the image to be corrected and the Google Earth image in the corresponding area, the point of the same name is automatically acquired to obtain the point of the same name file, which records the projection plane rectangular coordinates of the image to be corrected and the pixel coordinates of the reference image.

2. According to the header file record information of the image, the pixel coordinates of the reference image is converted into the projection plane Cartesian coordinates, and the same name point file is converted to ArcGIS point file.

3. By overlay analysis, the ArcGIS point file with the same name and global DEM data that is latest released are superimposed to obtain the ground control point file containing the elevation information, which can achieve the orthorectification with control point information, and then evaluate its precision.

4. The mosaic images are masked by the range of the study area to obtain a DOM of the complete study area and then evaluate its precision.

5. According to the second national land survey technical regulations, judge whether the above-mentioned precision of orthorectification image can meet the accuracy requirements in a specific scale.

See Fig. 2 for details of the process.

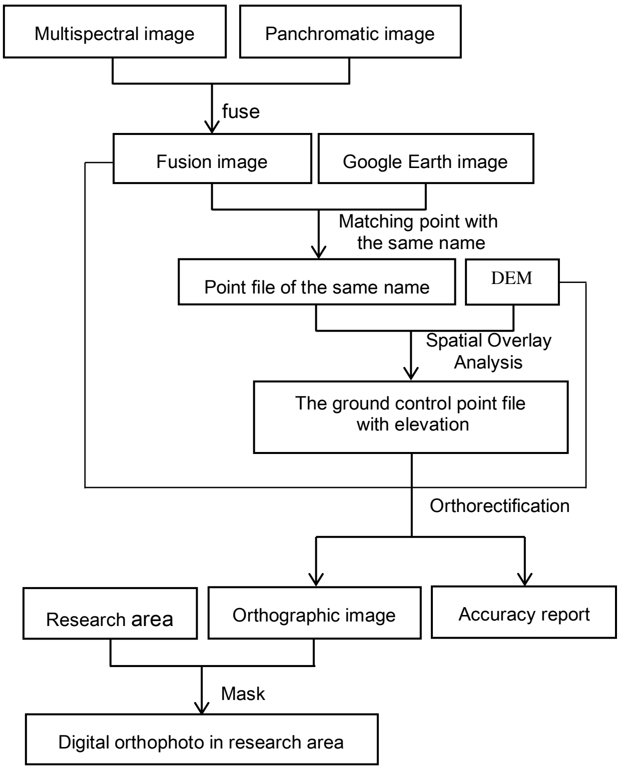


Fig. 2. Experimental process flow chart.

3.2 Research Ideas

1.1.1 Attribute data acquisition based on spatial location.

In order to obtain the elevation of the topographic object points of the same name, we adopt the method of acquiring attribute data based on spatial location (Zhang et al., 2011). The principle is as follows: for the topographic object points file of the same name obtained by matching the same name points, find the elevation point closest to it, and assign the elevation point value to the plane control point to obtain the control point file containing elevation information. These control points are formally the same as the measured ground control point and meet the ENVI 5.3 orthorectification module requirements for the input control point format. In the meantime, in order to check whether the elevation obtained is correct, the distance between the elevation point and the control point needs to be recorded as an attribute. If the distance is less than the threshold, the property is correctly obtained; otherwise, find the reason.

1.1.2 Precision evaluation model

To evaluate the accuracy of orthorectification, the errors at the X-axis (east direction) and the Y-axis (north direction) of the verification point on the corrected image and the points of the same name on the reference image is counted, including the original point error of each point, as well as the maximum error and the root mean square error, and then statisticing the corresponding plane error parameters. The geographic coordinate difference of the verification point in the orthophoto images and reference images (the original level error) is expressed as:

$$D_i = \sqrt{D_{X_i}^2 + D_{X_i}^2} = \sqrt{(X_i - X_{Bi})^2 + (Y_i - Y_{Bi})^2} \quad [1]$$

Where *i* denotes the ground verification point number for accuracy evaluation. D_{X_i} denotes the difference of the ith verification point on the *X*-axis in the corrected image and the reference image and D_{Y_i} denotes the difference of the ith verification point on the Y-axis in the corrected image and the reference image. X_i and Y_i respectively represent the *X* coordinate and *Y* coordinate of the ith verification point on the corrected image. X_{B_i} and Y_{B_i} are the *X* coordinate and *Y* coordinate of the ith verification point on the reference image, respectively.

We can get the root mean square error in X-direction, *Y*-direction, and in-plane as well.

$$RMSE_x = \sqrt{\frac{\sum_{i=1}^{n}(X_i - X_{Bi})^2}{n}} \quad [2]$$

$$RMSE_y = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - Y_{Bi})^2}{n}}$$

[3]

$$RMSE_R = \sqrt{RMSE_x^2 + RMSE_y^2} \quad [4]$$

Where $RMSE_x$ and $RMSE_y$ indicate the root mean square error of the *X*-axis and *Y*-axis directions respectively and $RMSE_R$ indicates the horizontal root mean square error. The error reflects the overall deviation of the orthophoto relative to the reference image, which can evaluate the overall accuracy of the orthorectified image.

4. Results and analysis

4.1 Orthorectification

1.1.3 Getting the points of the same name

Automatically obtain points of the same name with Image Registration Workflow in ENVI5.3, and filter the points of the same name, delete the points with larger errors, and remove the points that fall on the high-rise buildings to obtain the same name points file (.PTS) including the coordinates information of the points. It contains the projected coordinates of the image to be corrected and the pixel coordinates of the reference image. In the process of filtering the same name point, it is necessary to make the spots distribute the whole image evenly, and add points of the same name appropriately in the sparse area to increase its distribution density.

1.1.4 The conversion of Pixel coordinates and projection plane rectangular coordinate

In the process of acquiring the points of the same name, the reference image has only pixel coordinates, and the projection plane rectangular coordinates of the reference image need to be calculated according to the information recorded in the image header file.

$$\begin{cases} X_{Bi} = (U_{Bi} - 1) \times dx + X_{B0} \\ Y_{Bi} = Y_{B0} - (V_{Bi} - 1) \times dy \end{cases} \quad [4]$$

Where i denotes the point number of the same name, X_{B_i} and Y_{B_i} denote the plane rectangular coordinates of the point i of the same name on the reference image, U_{B_i} and V_{B_i} denote the pixel coordinates of the point *i* of the same name on the reference image, *dx* and *dy* denote the physical size of the pixel in the X and Y directions. We use Google Earth image with 0.5m resolution as the reference image, *dx* and *dy* are both 0.5m. X_{B0} is left-most the plane rectangular coordinates of the reference image (Extent Left) and Y_{B0} is the top plane rectangular coordinates of the reference image (Extent Top). These values all can be obtained from the reference image header file.

1.1.5 Getting the control point file containing elevation information

The points obtained in the above steps do not have elevation information, which can not be used as an Orthorectification control point file. Under the ArcGIS10.2 platform, *X_Bi* and *Y_Bi* on reference images calculated in the step. 2 are used as the X Field and the Y Field respectively, then the point file of the same name obtained in the previous step is imported by the Add XY Data tool and saved as a point file of ArcGIS (.SHP). Use the Zonal Statistics as Table tool in the Spatial Analyst Tools toolbar to get elevation information of the points of the same name. Before transiting to ENVI5.3 for orthorectification, it is also necessary to convert the plane rectangular coordinates of the control points into latitude and longitude coordinates. The plane rectangular coordinates can be switched to Latitude and longitude coordinates by Projection and Transformations toolset under the ArcGIS 10.2 platform, and then calculate latitude and longitude coordinates through the Calculate Geometry tool.

Next, it is time for making the control point file. The control point file contains coordinate parameter information, real latitude and longitude coordinates and elevation values of the control points, and pixel coordinates of the control point corresponding to the image to be corrected. It likes the same name point file and the suffix of the control point file is also ".PTS".

1.1.6 Orthorectification based on the control points

ENVI5.3 provides the Orthorectification Workflow. During the process of orthorectification, importing the resulting ground control point file (.PTS) and selecting 3 × RMSE [X or Y] in Statistics tab, and in the GCPs tab, laying down the error of the points calculated by the tool more than three times, correcting the spatial geometric distortion of the image, finally the multi-center projective plane orthographic image is produced.

4.2 Orthorectification Accuracy Comparison

To compare the results of accuracy evaluation, we also need to use the RPC Orthorectification Workflow tool to calibrate the two-scene images without control points under the ENVI5.3 platform. In this study, we evaluated the relative position accuracy of orthorectified images, and for comparison, we need to perform single-point correction on the orthographic images without control points, that is, the translations in X and Y directions. The translation amount is determined by the average value of the difference at X coordinate and Y coordinate of the same name points.

In the same way of acquiring verification points automatically, the verification point that is uniformly distributed over the entire image is obtained by the Image Registration Workflow tool under the environment of ENVI5.3, and the geometry accuracy of orthorectified image with presence or absence of control points is evaluated by the frequency distribution of the root mean square error and the error of the position-point.

1.1.7 The maximum error and the root mean square error analysis

Table 1 shows the maximum error and root mean square error of checkpoints in X-direction, Y-direction, and the plane of different DEM data sources under the presence or absence of control points condition. It can be seen that for any DEM data, orthorectification with control points is significantly better than orthorectification without control points.

For the image Orthorectified based on ASTER GDEM, the root mean square error in the X direction was increased from 3.96m to 3.09m, and the accuracy is improved by 21.97%. Besides, the root mean square error in the Y direction was increased from 2.71m to 2.16m, and the accuracy is improved by 20.30%. For the image Orthorectified based on SRTMGL1, the root mean square error in the X direction was increased from 4.01m to 3.09m, and the accuracy is improved by 22.94%. The root mean square error in the Y direction was increased from 2.71m to 2.20m, and the accuracy is improved by 18.82%.

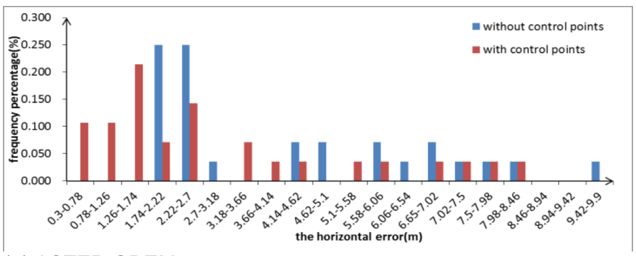
For the image orthorectified based on ASTER GDEM, the maximum error of the orthographic level was increased from 9.81m to 8.14m using control points. The root mean square error is increased from 4.80m to 3.77m, and the overall accuracy is improved by 21.46%. For images orthorectified based on SRTMGL1, use control points to increase the maximum error of the ortho level from 9.79m to 8.02m. The root mean square error increased from 4.840m to 3.80m, and the overall accuracy improved by 21.49%. It can be seen that acquiring control points through Google Earth images and using a high spatial resolution image based on the control point method for orthorectification can effectively improve the accuracy of orthorectification. Besides, there is no significant difference in the accuracy test of orthographic correction for different DEM data.

Table 1. the analysis of the result in different DEM data (unit: m)

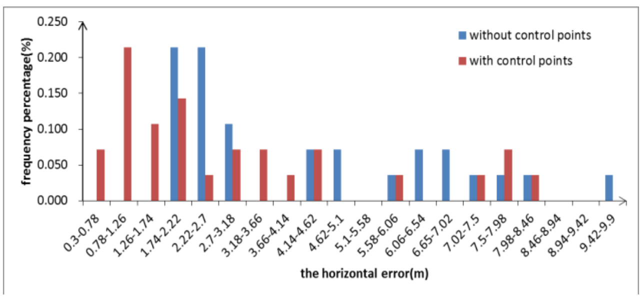
DEM data	Orthorectification with control points					
	X		Y		plane	
	Max.	RMSE	Max.	RMSE	Max.	RMSE
ASTER GDEM	6.79	3.09	4.73	2.16	8.14	3.77
SRTMGL1	6.69	3.09	4.46	2.20	8.02	3.80
DEM data	Orthorectification without control points					
	X		Y		plane	
	Max.	RMSE	Max.	RMSE	Max.	RMSE
ASTER GDEM	6.80	3.96	7.07	2.71	9.81	4.80
SRTMGL1	6.82	4.01	7.03	2.71	9.79	4.84

1.1.8 The distribution analysis of point error

Figure 3 (a) shows the frequency distribution of point error with and without control point orthogonalization based on ASTER GDEM. Figure 3 (b) shows the frequency distribution of point error with and without control point orthogonalization based on SRTMGL1. The abscissa in the figure is the horizontal error, starting from 0.3, the spacing is 0.48m, and the ordinate is the frequency percentage. It can be seen that the orthorectification method with ground control points reduces the overall error level effectively and the error distribution is more concentrated. It can be seen that the frequency of point error is mainly distributed in 1.74 to 2.7 in the image Orthorectified without control points and in 0.3 to 2.7 in image Orthorectified with control point based on ASTER GDEM. The frequency of point error is mainly distributed in 1.74 to 3.18 in the image Orthorectified without control points and in 0.3 to 2.22 in image Orthorectified with control point based on SRTMGL1. The orthorectification method with ground control points reduces the overall error level effectively and the error distribution is more concentrated.



(a) ASTER GDEM



(b) SRTMGL1

Fig. 3. Error distribution of verification points for different DEM data

Figure 4 shows the comparison of the effect of different orthorectification methods. They are all local enlarged drawings. Figure 4 (a) is the Google Earth image, (b) and (c) are the image Orthorectified without control points and the image Orthorectified with control point based on ASTER GDEM, and (d) and (e) are the image Orthorectified without control points and the image Orthorectified with control point based on SRTMGL1, respectively. By comparing Figure 4 (b) and (c), and Figure 4 (d) and (e), it can be seen that the corrected images with control points or without control points have obvious point deviation. By using Google Earth images as reference images, it can improve orthophoto correction effects effectively.

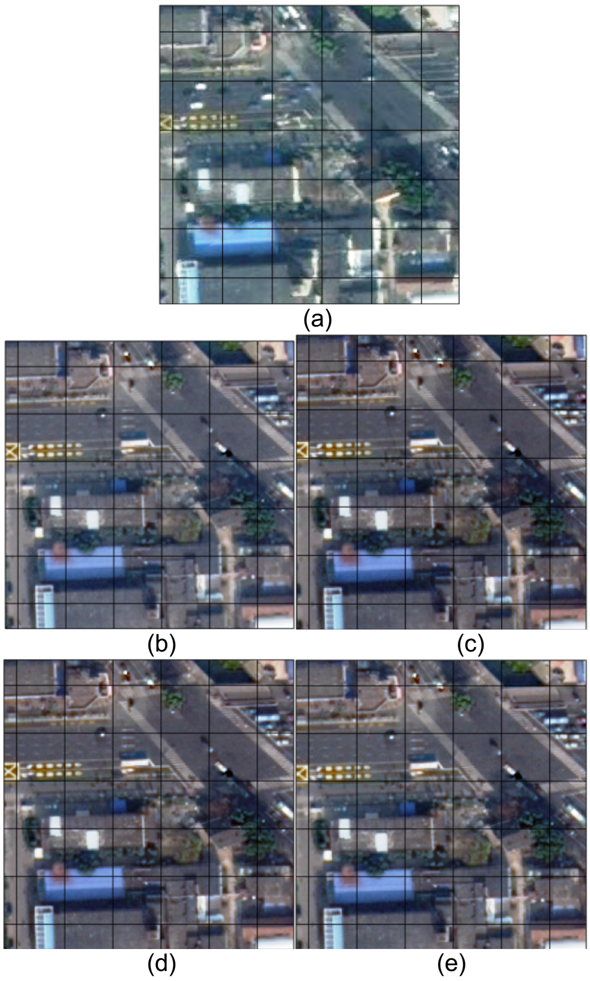


Fig. 4. the effect comparison between different orthophoto correction methods
Note: The spacing of the warp and weft networks is 20m

5. Conclusion

Traditional orthorectification requires the help of the ground-based control points and topographic maps, which causes a high cost. This study uses Google Earth images and global DEM data that is publicly available to build an orthorectification process based on the ENVI5.3 platform. The experiment is carried out by taking the sample area of Hangzhou city, Zhejiang province as an example. The experimental results show that the orthorectification of high spatial resolution remote sensing images based on Google Earth and Global DEM proposed in this study is feasible and the precision can meet the requirement of 1: 10000 land survey for work base map.

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