

# VALIDATION ON INTERNET SATELLITE IMAGE MOSAICS AND E-MAPS

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## ABSTRACT:

As everyone can browse high-resolution satellite image and e-map products on the Internet freely, such as the Google™ Maps (image mosaics and e-maps) since 2005, some significant mapping defects, such as misalignment of image tiles and imperfect registration of images and e-maps, have been identified. This paper is aimed at study of geometric characteristics of the web image mosaics that have to be validated and evaluated in order that the possibilities and limitations of using these free image products can be appreciated. A statistical approach is adopted to derive critical parameters, such as the maximal value, mean and RMSE, from sampled features for describing geometric deviations of the features across adjacent image tiles. An error model is also proposed to quantify the resultant effect from error propagation in the procedures of geometric validation. The test data were sampled from relatively flat areas in the context of urban environments as well as in rural areas with significant terrestrial undulation in Taiwan. Mismatched road features and other ground features in image mosaics accessed on the Internet were selected and measured. The experimental results show that the averaged deviations of features at different locations within the image mosaics varies from 14.5m to 20.4m, and the maximal error ranges from 27.2m to 60.3m. The RMSE of misaligned features of the image mosaics differs from 4.7m to 14.0m. It is estimated that the geometric quality of the free image mosaics on the Internet is comparable with that of maps at 1:25000 scales.

## 1. INTRODUCTION

In nowadays, everyone can browse high-resolution satellite image and e-map products freely, such as the image mosaics and e-maps provided by Google™ Maps, (Google, 2008), opening a new era of spatial informatics. Although these image mosaics are historical ones and there is no guarantee for geometric qualities, they do successfully attract the general public and are frequently employed in various fields by different professions, such as the media for locating news events, tourism industry for promoting hot spots of travelling, real estate agents for highlighting residential locations and its environs, town-planning agencies for proposing urban renewal projects, schools for improving geographical education and individuals for satisfying curiosity and exploration. For photogrammetrists, cartographers, Geographical Information System (GIS) and remote sensing professionals, these free image mosaic products may also be useful in index-map preparation and in primitive interpretation for specific tasks, such as interpreting ground features in Light Detection and Ranging (LIDAR) data as well as in Synthetic Aperture Radar (SAR) intensity images. The production of image mosaic of high accuracy and of good precision is in routine practice by many privately owned mapping industries and national agencies in many countries. Also, the related knowledge and algorithms are well established and basic requirements, such as correct Digital Elevation Models (DEMs) and ground control points (GCPs) are well known in photogrammetric and remote sensing community (Wolf and Dewitt, 2000; Mikhail *et. al.*, 2001). Unfortunately, some significant mapping defects, such as imperfectly aligned ground features, can be identified easily in these free image products on the Internet. As the vendors provide these image mosaics for personal uses, free of charge, these products, however, cannot be exempted from serious

geometric validation and quality evaluation. Also, it is expected that there will have many more civil applications and commercial implementation of e-maps and image mosaics based on these products on the Internet to be developed, which are also the main purpose of the vendor for providing free satellite image mosaics and e-maps to the general public. Therefore, the quality and quantity of these mapping defects deserve much more concerns for the benefits of vendees and the general public. On the other hand, these products have to be validated and evaluated in order that the possibilities and limitations of using these free image mosaics can be appreciated and exploited.

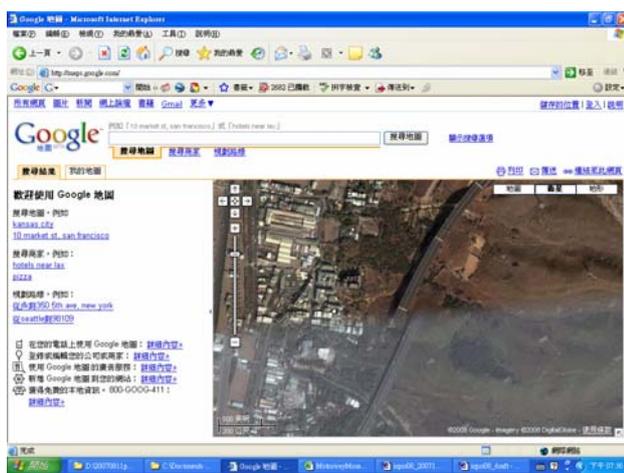
This paper is aimed at the study of geometric characteristics of the above-mentioned free image mosaics on the Internet. In term of image mosaics, the geometric quality of the image products can be validated based on using field surveying method, such as Global Positioning System (GPS), by evaluating the mapping accuracy, or employing consistency check on the quantities of mismatched features by estimating the mapping precision. The practices of evaluating the accuracy of image mosaics and e-maps covering a wide area are relatively expensive and time-consuming, and the outcomes have to be related to the local datum and the corresponding coordinate transformation procedures, which is not quite feasible for the general public. In addition, the image mosaics may be updated frequently and the effort of field surveying can result as useless. On the contrary, the practices of estimating the precision of image mosaics are relatively fast, simple and feasible for any individual. In general, perfectly rectified and registered image mosaics have to show a seamless image comprised by numerous image tiles without gaps and mismatched features in between image tiles. This paper is focused on the study of relative misalignment of image tiles in

satellite image mosaics, regarding to ground features, such as roads, with no consideration on the issue of absolute accuracy. The method proposed in this paper cost almost nothing and can be carried out in relatively short time. An error model is also developed to give quantitative evaluation on the procedures of the proposed method. In section 2, the method for evaluating the precision of image mosaics are proposed together with the error model. Test data and experimental results are covered in section 3 with statistical analysis. Discussion and future work are presented in section 4. Conclusions are given as in section 5.

## 2. THEORY AND ERROR MODELS

### 2.1 Geometric Validation on Image Mosaics

Ground features in image mosaics, such as roads, crossing the edge of image tiles, should be kept intact, and the same feature shown in both image tiles have to be matched together seamless, except high-rise buildings and structures. Tilt and relief displacement has to be eliminated or compensated as well. If GCPs and DEMs of good quality are available, orthogonal rectification should be employed to remove tilt and relief displacement as exhibited in images. Although basic principles of rectification for producing image mosaics are quite well known and procedures for doing this are well established (Wolf & Dewitt, 2000; Mikhail *et al.*, 2001), they are not always appropriately done in the freely provided high-resolution satellite image mosaics on the Internet. The mapping defects can be identified by any layman as demonstrated in Figure 1, showing the image mosaic with mismatched features of the Formosa Freeway (Superhighway or Motorway No.3) approximately at the 184<sup>th</sup> km near Long-Jing Interchange in western Taiwan (Google, 2008). An enlarged image of the same section of the freeway is as shown in Figure 2 (Google, 2008). A graphical scale is shown in the image mosaics, which is subject to change according to different image scales. The most concerned here is to quantitatively evaluate these mapping defects using an appropriate approach that any individual can easily evaluate these mapping defects in their areas of interest.



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Figure 1. A typical web-page of of image mosaics provided by Google-Maps, accessed at URL:<http://maps.google.com> on the Internet (Google, 2008). Location: the Formosa Freeway (or Motorway No.3) at the 184<sup>th</sup> km near Long-Jing Interchange in western Taiwan



Figure 2. An enlarged sample (sub-scene) of free image mosaics as shown in Figure 1 (Google, 2008). A graphical scale is shown in the bottom-left corner of the image mosaics.

In photogrammetric point of view, the image mosaics on the Internet can be treated as semi-controlled mosaics that demonstrate satellite image tiles without or with incomplete orthographic rectification. Image tiles were stitched together with certain degree of error regarding to alignment of specific ground features. Since a nominal scale ( $scale_{nominal}$ ) is shown in the image mosaics on the Internet (Google, 2008), estimation for the magnitude of misalignment of ground features can be done easily and straightforward. Assuming that the nominal scale as shown in the image mosaics is correct, a simple formula is proposed to calculate the nominal deviation of mismatched features of an image mosaic as followed.

$$D_i = p_i \cdot (scale_{nominal}) = \frac{p_i S}{s};$$

$$D_T = \sqrt{\frac{1}{n} \sum_{i=1}^n D_i^2} = \frac{S}{s} \sqrt{\frac{1}{n} \sum_{i=1}^n p_i^2} \quad (1)$$

- where  $D_i$  = deviation in ground distance of the  $i^{th}$  measured feature
- $p_i$  = deviation in pixels of the  $i^{th}$  measured feature
- $D_T$  = estimated deviation in ground distance of all measured features
- $n$  = total number of measured features
- $S$  = designated ground distance equivalent to one unit at the nominal scale
- $s$  = number of pixels equivalent to one unit at the nominal scale

The nominal scale ( $scale_{nominal}$ ) shown in the image mosaics is a graphical scale that can be measured directly on computer screen in pixels. The deviation of an image mosaic is measured with respect to the shortest ground distance between homologous points of specific object or features shown in both image tiles of an image mosaic, provided that the shape of the object or a feature measured is acute and well defined. In case of a linear feature without any corner point measurable, the shortest distance between the homologous linear features in both image tiles of the image mosaic can be measured alternatively. Since  $S$  is a designated ground distance

equivalent to one unit as shown at the nominal scale, thus it is a constant and measurement can be done easily.

### 2.2 An Error Model for Geometric Validation

In equation (1), errors may occur in the measuring procedures. In terms of measuring deviations in an image mosaic with respect to a feature, error propagation resulted from different parameters in equation (1) is as followed.

$$\sigma_i = \sqrt{\sigma_{p_i}^2 \left(\frac{S}{s}\right)^2 + \sigma_s^2 \left(\frac{p_i S}{s^2}\right)^2} = \left(\frac{S}{s}\right) \sqrt{\sigma_{p_i}^2 s^2 + \sigma_s^2 p_i^2} \quad (2)$$

where  $\sigma_i$  = propagated error in estimating the deviation of the  $i^{\text{th}}$  feature in pixels  
 $\sigma_{p_i}$  = estimated measuring error of the deviation of the  $i^{\text{th}}$  feature in pixels  
 $\sigma_s$  = estimated measuring error regarding to the graphical scale

In case that an incorrect scale is shown in the image mosaics with an error factor of  $k$  (a multiplier), the formula and the error model as mentioned above can be revised as in equation (3) and (4), respectively.

$$D_i = \frac{p_i S k}{s}; \quad D_T = \frac{S k}{s} \sqrt{\frac{1}{n} \sum_{i=1}^n p_i^2} \quad (3)$$

$$\sigma_i = \left(\frac{S k}{s}\right) \sqrt{\sigma_{p_i}^2 s^2 + \sigma_s^2 p_i^2} \quad (4)$$

For example, the deviation of a mismatched feature identified in an image mosaic at a nominal scale of 50 m / 92 pixels, with an error factor 1.0 (free of error) was measured as 111 pixels, equation (3) gives the deviation in ground distance as 60.3m. Assuming that the measuring errors on computer screen is estimated as 2 pixels for the measured feature and for the graphical scale shown on the Internet, respectively, the error model gives a magnitude of error propagation as 1.7 m according to equation (4) and the parameters defined above. Although the radiometric quality of images at different location can vary significantly and lead to various measuring errors, it can be seen that the error propagation of the measurement done by a human operator can have a significant effect only at a smaller mapping scale.

### 3. EXPERIMENTAL RESULTS AND DISCUSSION

Evaluation of mismatched features can be carried out by measuring the shortest distance between the homologous points near the boundary of overlapped image tiles within an image mosaic. Since the image mosaics as observed on the Internet do not show enough overlapped areas, it has been difficult to identify homologous points. In case that homologous points cannot be identified and road features have to be considered, the shortest distance, alternatively, can be measured along the normal direction of the homologous linear feature, which represents the lateral deviation only, instead of the overall error. There are two cases of experiments for geometric validations on image mosaics to be considered. The first case considers the

“global” geometric consistency of extended linear features at a wide scope up to hundreds of kilometres, covering many image mosaics, such as a motorway. On the other hand, the second case considers the geometric consistency of features related to a specific image tile and the neighbouring image tiles within an image mosaic in the context of local geometry.

#### 3.1 Case I: Features Crossing Many Image Tiles

The test image mosaics for validating geometric misalignment of ground features covering adjacent image tiles were selected on the Internet (Google, 2008) along the routes of Dr. Sun Yat-Sen Freeway (Motorway No.1) and the Formosa Freeway (Motorway No.3, an example is shown as in Figure 1 and 2) in Taiwan. There are 12 sections (features) of image mosaics extracted and measured for the Dr. Sun Yat-Sen Freeway and 16 sections for the Formosa Freeway. Statistics of the measured deviations of the identified features are shown as in Table 1 and 2 for the Motorway No.1 and No.3, respectively. Figure 3 and 4 gives histograms of distribution of the measured deviations of identified features for the Motorway No.1 and No.3, respectively..

Motorway No.1	
Total Number of Features	12
<b>Mean</b>	<b>14.5 m</b>
RMSE	10.3 m
Maximal	33.7 m
Minimal	1.1 m

Table 1. The statistics of deviations of the features measured in high-resolution satellite image mosaics on the Internet for the Motorway No.1 in Taiwan.

Motorway No.3	
Total Number of Features	15
<b>Mean</b>	<b>15.3 m</b>
RMSE	14.0 m
Maximal	60.3 m
Minimal	1.1 m

Table 2. The statistics of deviations of the features measured in high-resolution satellite image mosaics on the Internet for the Motorway No.3 in Taiwan.

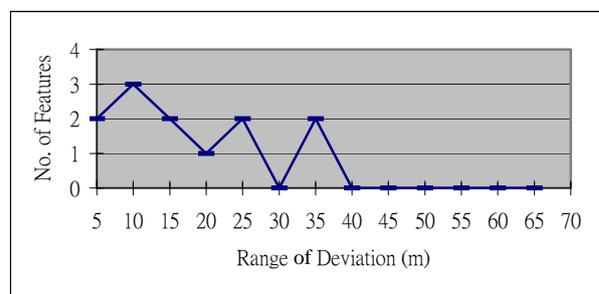


Figure 4. The histogram of deviations of the features measured in high-resolution satellite image mosaics on the Internet for the Motorway No.1 in Taiwan.

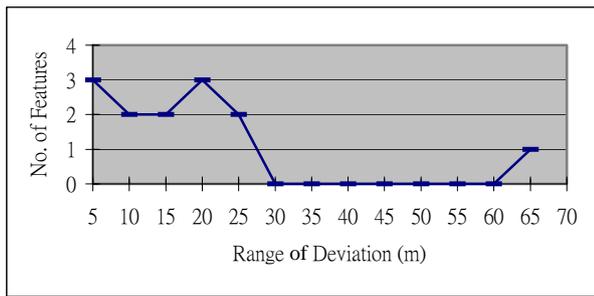


Figure 5. The histogram of deviations of the features measured in image mosaics for the Motorway No.3 in Taiwan.

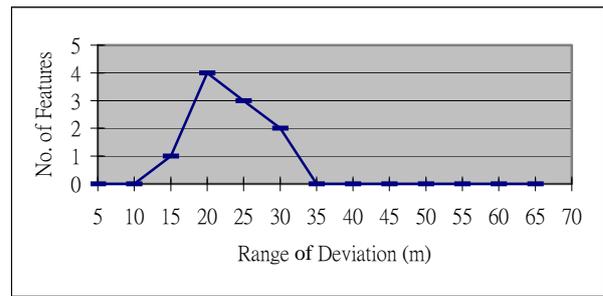


Figure 7. The histogram of deviations of the features measured in image mosaics on the Internet centred at Kaohsiung City.

### 3.2 Case II: Features Surrounding Specific Image Tiles

The test image tiles of Case II for measuring mismatched features covering adjacent image tiles were selected and extracted on the Internet (Google, 2008) centred at Taipei and Kaohsiung City, respectively. Statistics of the measured deviations of identified features are shown as in Table 3 and 4 for Taipei and Kaohsiung test site, respectively. Figure 6 and 7 give histograms of distribution of the measured deviations for Taipei and Kaohsiung test site, respectively.

Location (City)	Taipei
Total Number of Features	7
<b>Mean</b>	<b>16.2 m</b>
RMSE	11.0 m
Maximal	33.1 m
Minimal	4.9 m

Table 3. The statistics of deviations of the measured features centred at Taipei City.

Location (City)	Kaohsiung
Total Number of Features	11
<b>Mean</b>	<b>20.4 m</b>
RMSE	4.7 m
Maximal	27.2 m
Minimal	14.7 m

Table 2. The statistics of deviations of the measured features centred at Kaohsiung City.

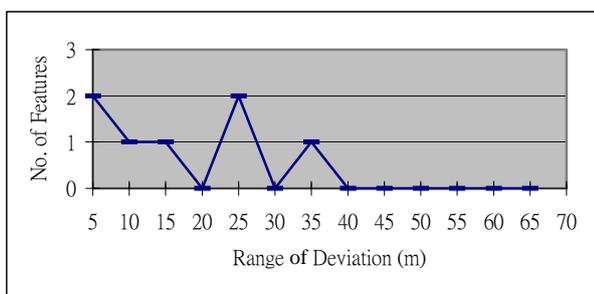


Figure 6. The histogram of deviations of the features measured in image mosaics on the Internet centred at Taipei City.

### 4. DISCUSSION AND FUTURE WORK

The methods and requirements for producing image mosaics of reasonable quality are well known in photogrammetry and remote sensing community (Wolf and Dewitt, 2000; Mikhail *et al.*, 2001). Unfortunately, orthogonal rectification for satellite images cannot always be done easily due to insufficient knowledge of local datum, incorrect DEMs and inaccurate GCPs. This is also the case in image mosaic production at a global scale. Extended linear features, such as motorways, can stretch more than hundreds of kilometres. Presumably, e-map producers tend to stitch image tiles according to road features, therefore, a quantitative evaluation on misalignment of road features give a basic way to validate the mapping quality of image mosaics. However, measuring road features may take risks of underestimating the deviations of image mosaics on the Internet since road features do not necessarily provide well-defined and acute points to be measured. On the other hand, image mosaic producers may stitch image tiles together reasonably along road features, but ignore other ground features accordingly. Other kinds of ground features, such as boundary of rice field or embankment, have to be considered in some cases where road features are not well defined regarding to error evaluation.

In general, the experimental results show that the RMSE of misalignment of features at different locations of the image mosaics observed on the Internet varies from 4.7m to 14.0m, and the maximal error ranges from 27.2m to 60.3m. It is also quite interesting to compare the averaged shifts of features between both cases that give mean deviations from 14.5m to 20.4m. In terms of high-resolution satellite imagery of multi-spectral bands (for instance, 2.4m/pixel for QuickBird satellite data), the magnitudes of averaged deviations in the image mosaics as shown above are approximately equivalent to 6~9 pixels. It is estimated that the geometric quality of the image mosaics on the Internet is comparable with that of map at 1:25000 scales. The results suggest that image mosaics and e-maps on the Internet could be useful in versatile applications of mapping and interpretation at medium scales. An example of potential applications is suggested to be in interpreting Synthetic Aperture Radar (SAR) intensity images. SAR intensity data are known to be difficult in interpretation and relative study progress slowly (Chen and Dowman, 2001; CSA, 2008; ESA, 2008; JAXA 2008; DLR, 2008). Optical images, particularly high-resolution satellite data, are potentially useful in understanding SAR intensity data. Integrating information available from high-resolution satellite optical and SAR data could be able to provide further valuable information in the future and related work is in progress.

## 5. CONCLUSIONS

In terms of visual interpretation, imperfect registration of image mosaics on the Internet may mislead the general public to interpret spatial information conveyed by web image mosaics and e-maps. In order to validate the geometric precision of the image mosaics, a quantitative evaluation model is proposed in the paper. Mapping scale is one of the factors affecting visual perception of image mosaics that have to be considered in the error model. Some significant cases of mapping defects found on the Internet were discussed and evaluated qualitatively and quantitatively. It is suggested that measuring road features might take risks of underestimating the deviation of image mosaics. Although the historic image mosaics accessible on the Internet do not fulfil the need of real-time mapping, it is still useful for the general public and professionals to make full use of these free image mosaics in various fields.

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