Imprpovement of Georeferencing accuracy of lower resolution images based on high resolution feature matching technique

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Abstract - A High Resolution Feature Matching (HRFM) technique is presented in this paper to solve the problem of identifying well distributed Ground Control Points (GCP) on lower resolution images. The technique is based on identification of GCPs on a higher resolution image and then transferring the GCP cross-sections to the lower resolution image based on nearest neighbor feature matching. This technique renders the geo-referencing accuracy to sub-pixel level and is found very useful for geo-referencing lower resolution images including microwave images. The geo-reference accuracy based on the HRFM technique is found to be less dependent of the resolution of the target image which suggests a high degree of potential improvement of geo-reference accuracy for low resolution images such as NOAA, MODIS etc.

Keywords - Georeferencing, sub-pixel accuracy, ground control points, high resolution, feature matching

1. Introduction

In general, positional accuracy of an image is in the order of its pixel dimension provided that well distributed GCPs are used for georeferencing the image. Identification of well distributed GCPs is a crucial aspect in georeferencing process (Mather, 1995; Boutoura and Livieratos, 2006; O’Carroll, 2010; Wang et al., 2012; Herrault1 et al., 2013). For low resolution optical images and also for Synthetic Aperture Radar (SAR) images this aspect becomes more crucial (Khlopenkov et al., 2010; Couloigner et al., 2002; Kumar et al., 2006). Researchers found out various ways to deal with this crucial aspect. Rottensteiner et al. (2009) used a generic pushbroom sensor model and strip adjustment approach to arrive at pixel-level accuracy; the method reduces the number of GCPs but still depends on its distribution over specific areas of the images. Khlopenkov et al. (2010) achieved better than 1/3 FOV geolocation accuracy for AVHRR 1-km scenes based on an image matching technique using MODIS images at 250-m resolution as reference; the efficiency of the method depends on density and uniformity of GCP coverage. Couloigner et al. (2002) used an image and topographic data matching technique to automatically identify GCPs in RADARSAT images; the absolute geolocation accuracy from this method is questionable and largely depends on the accuracy of the topographic database. Availability of topographic database in usable form constrains the application of this technique in many cases. Review of other techniques described by Willneff et al. (2011), Errico et al. (2011), Weser et al. (2011), Fraser et al. (2011), Lisaka et al. (1996) and Eugenio et al. (2003) along with those mentioned above suggests that even for achieving pixel level accuracy based on operational techniques, identification of well distributed GCPs is still a basic requirement. To fulfill this requirement, this paper describes a High Resolution Feature Matching (HRFM) technique to measure GCPs with sub-pixel accuracy on lower resolution images.
2. Statement of problem

To achieve sub-pixel positional accuracy, two requirements of GCP identification are to be satisfied: GCP cross-section at sub-pixel level and well distributed GCPs over the image. Both these are long existing operational problems for moderate to low resolution images though there are some methods having operational limitation to address sub-pixel georeferencing accuracy. Kardoulas et al. (1996) gave a comprehensive review on this aspect in his paper. Later Khlopenkov et al. (2010) focused on this issue in details. Figure 1 demonstrates these problems. Figure 1(a) and 1(b) show a comparison of the GCP identification on aerial photo and Landsat TM image respectively. It is seen that GCP cross-sections (green circle) which are sharply visible on aerial photo are not visible on TM image. When this condition prevails over large area of image, it is not possible to identify well distributed GCPs for georeferencing the image even with pixel level accuracy. For comparatively lower resolution images, like MSS, this problem becomes more prominent. The scarcity of GCP for microwave images having resolution lower than 50 m (like RADARSAT ScanSAR narrow/wide) is another dimension of the

**Figure 1** - (a) Identification of GCP locations (green circle) on high resolution image (aerial photo), (b) The GCPs are not visible on LRI (Landsat TM). The GCP locations have geographic features around it that are visible on both the (c) high resolution and the (d) lower resolution images.
problem. Land surface level interaction of microwave energy is very different than that of optical image and it is very difficult to identify GCPs on microwave images due to non-visibility of GCP. Figure 2 shows this problem which compares GCP identification on a RADARSAT standard mode image having 30 m resolution with a Landsat TM image having the same resolution. Corner reflectors or permanent scatterers (natural reflectors such as towers) were used as GCP features (Linlin et al., 2004) for microwave images. However, corner reflector arrangement for GCP identification on microwave image is not practical for many applications (like flood monitoring) and availability of well distributed permanent scatterers is a practical problem.

Figure 2 – (a) GCP cross-section which are visible on Landsat TM image of 2010 (30 m resolution) are not visible on RADARSAT standard mode image of 2009 (b) having same resolution.

One of the efficient methods of precision geometric correction of images (particularly AVHRR images) closest to the technique presented in this paper was given by Khlopenkov et al. (2010). This method used a digital image matching procedure through calculation of correlation surface between AVHRR imagery and reference image (MODIS image). GCPs were found from the correlation surface and were used to build polynomial to adjust the image. This method generally produces geometrically well corrected scenes but the efficiency of the method depends on density and uniformity of GCP coverage obtained from the correlation surface and, thus, this method depends solely on the correlation between input and reference image. The other problem with this method is that it is not applicable for microwave images.

Another efficient spectral correlation based procedure has been employed in the AutoSync module of ERDAS Imagine software for automatic measurement of GCP. This procedure generally works well but there are cases where this procedure fails to identify precious GCP. Data quality, time of capture, resolution and spectral range of selected band of input and reference images are the issues in this context (IMAGINE AutoSync User’s Guide, 2009). Thus, even for the efficient methods of georeferencing, identification of well distributed and precious GCP is not ensured.
3. The high resolution feature matching technique

3.1 Description of the technique

A GCP cross-section visible on High Resolution Image (HRI) may not be visible on Lower Resolution Image (LRI), but other bigger features near the GCP may be visible on both the images. Such a case is shown in Figure 1. Figure 1(a) and 1(b) show that GCP cross-sections (green circle) which are sharply visible on aerial photo are not visible on TM image. Figure 1(c) and 1(d) show the visibility of bigger features (road and canal) on both the aerial photo and TM image near the GCP cross-sections. Therefore, digitizing the nearest neighbor features of the GCP along with the GCP cross-section visible on HRI and then matching these digitized features with those on the LRI will help to locate the GCP cross-section on the LRI. This is the basis of the HRFM technique. The HRFM technique needs to apply some specific steps which are given below:

i. Identify GCP cross-section on the HRI (reference image) based on the criteria that the GCP has other geographic features around it (nearest neighbor features) which are also visible on the LRI (input image). The geographic features may be roads, canals, rivers etc.

ii. Digitize the nearest neighbor geographic features along with the GCP cross-section on the HRI and save them. A GCP cross-section and its corresponding nearest neighbor geographic features obtained from HRI are termed as a reference GCP lot. Pick the coordinate values of the GCP cross-sections and preserve them as reference coordinate.

iii. Display the reference GCP lot on the LRI and match the lot (vector layer of the nearest neighbor features) with the geographic features on the LRI through manual shifting. In some cases simple manual shifting may not be satisfactory to match the reference GCP lot and the vector layer may need to be rotated and/or scaled. In order to implement this step, the input image needs to be pre-georeferenced. Therefore, the HRFM technique involves two-stage correction procedures (Schowengerdt, 2006) where the first stage correction (system-corrected products) is done using satellite model based on a priori data and the second stage correction is done using the present technique. Nowadays images are usually supplied with georeference based on satellite model. In case first stage corrected images is not available the input image may be georeferenced based on first order transformation using approximate locations of GCPs obtained from any source.

iv. After matching with the input image, the reference GCP lot becomes the input GCP lot and the reference GCP cross-section becomes the input GCP cross-section. Pick the input coordinate values measuring the input GCP cross-section on the LRI. Figure 3 visually presents the application of the HRFM technique for measuring the GCP on LRI.

v. Georeference the LRI based on the reference and input coordinate values of the GCPs.

3.2 Basis of improvement achieved using the HRFM technique
Accuracy of georeferencing depends both on the quality of GCP and mathematical transformation used (Herrault et al., 2013). Error due to mathematical transformation was described and treated by many authors (Thapa, 1992; Klang, 1996; Bitelli, 2009; Katiyar, 2011, Herrault et al., 2013). It was suggested to keep this error, in terms of root mean square (Mather, 1995; Imam, 2011), less than the dimension of a pixel (Thakur, 2008). However, the overall accuracy of georeferencing can only be assessed based on the Root Mean Square Error (RMSE) of transformation if the quality of GCP is higher. The quality of a GCP depends on its measurement (marking) accuracy on both the input and reference images. GCP measurement accuracy is naturally higher on HRI than that on LRI. The HRFM technique uses this fact to improve the GCP measurement accuracy on a LRI. The HRFM technique improves the georeferencing accuracy of a LRI by transferring the point measurement accuracy of a HRI to it. Figures 4 and 5 illustrate this aspect. This figure considers a case where a road cross-section is a GCP. The width of the roads are such that they are visible on a HRI as shown in figure 4(a) but are not visible on the input image (figure 4(b)) because of its lower resolution. For reference image the error component is only the point measurement error ($E_h$) of the HRI (figure 5(a)). After application of the HRFM technique the point measurement error on the input image depends on the point measurement error ($E_h$) transferred from HRI to the LRI and the nearest neighbor feature matching error ($E_m$) as shown in figure 5(b). The sign of the $E_m$ depends on its direction relative to the direction of $E_h$. Considering the same direction for both the $E_h$ and $E_m$, the total point measurement error at a direction (x or y) on a LRI applying the HRFM technique is, thus,
\[ E_{\text{FM}} = E_h + E_m \]  \hspace{1cm} (1)

If perfect matching of the nearest neighbor feature is achieved, the GCP will be transferred on the LRI with the same point measurement error of the HRI.

Improvement (Imp) of point measurement accuracy using the HRFM technique can be expressed as,

\[ \text{Imp} = E_{ld} - E_{\text{FM}} \]
\[ = E_{ld} - (E_h + E_m) \]  \hspace{1cm} (2)

where \( E_{ld} \) is the point measurement error on the LRI in case the GCP is measured directly on the LRI (conventional technique). Equation 2 provides the basis for improvement of the georeferencing accuracy based on the HRFM technique. In general \( E_{ld} > E_h \), therefore, if \( E_m \) is kept negligible there will be a positive improvement in georeferencing accuracy.

If the correct pixel containing the GCP is identified and digitized as seen in red color in figure 4, the point measurement error remains within pixel dimension of the image on which the GCP is measured and it may be as much as the pixel dimension. Thus, in terms of the highest error, equation 2 can be written as

\[ \text{Imp} = PD_l - (PD_h + E_m) \]  \hspace{1cm} (3)

where \( PD_l \) is the pixel dimension of the LRI account for the highest point measurement error on the LRI in case of direct GCP measurement (\( E_{ld} \) tends towards \( PD_l \)) and \( PD_h \) is the same as of \( PD_l \) for the HRI (\( E_h \) tends towards \( PD_h \)).

**Figure 4 -** Error components involved with the HRFM technique. (a) High resolution reference image. (b) Lower resolution input image. Point 1 is the actual GCP (road cross-section), point 2 is the measured GCP on the HRI, point 3 is the position of the measured GCP on the LRI after nearest neighbor feature matching, \( E_h \) is the point measurement error on HRI, \( E_m \) is the nearest neighbor feature matching error due to which point 2 is shifted to point 3, \( E_{\text{FM}} \) is the total absolute point measurement error on the LRI. For simplicity of presentation errors in a direction are shown.
4. Results

4.1 Validity of the HRFM Technique

The objective of the validation experiment is to see the performance of the HRFM technique with respect to the conventional technique. The relation between these two techniques is given below.

The total absolute accuracy of georeferencing of a LRI at a direction (x or y) using the HRFM technique can be given by,

\[ E_{ITFM} = E_{FM} + E_{TFM} \] (4)

where \( E_{TFM} \) is the transformation error at a direction (x or y). In case of direct measurement of GCP, total absolute accuracy of georeferencing is given by,

\[ E_{ITD} = E_{id} + E_{td} \] (5)

where \( E_{td} \) is the transformation error at a direction (x or y) for direct measurement. If the same method of transformation and threshold value (RMSE) of transformation error are used for both the techniques, transformation errors for both the referenced images may be considered similar (i.e. \( E_{TFM} = E_{td} \)). We obtain,

\[ E_{ITD} - E_{ITFM} = E_{id} - E_{FM} \] (6)

Comparing equations 2 and 6 it is seen that equation 2 also apply for improvement of georeferencing accuracy in absolute term under the assumptions made for derivation of the equations. Based on equation 2, validity of the HRFM technique was assessed using two sets of data. Description of the datasets and procedures for validation were given in the following paragraphs.

High resolution input and reference images having similar pixel dimension: Since both the input and reference images were of similar resolution, point measurement errors on them were considered similar, i.e. \( E_h = E_{id} \). From equation 2 we obtained,

\[ \text{Imp} = -E_m \] (7)

Based on equation 7, negative improvement (higher georeferencing error with respect to the conventional method) was expected for this dataset extent of which will depend on the nearest neighbor feature matching error, \( E_m \). Experiment with this dataset should validate the fact that if the
resolution of reference image is equal to or lower than that of input image, the HRFM technique is not applicable. In this experiment, high resolution images were used to reduce the mismatching error to negligible level so that georeferencing accuracy using the HRFM technique came close to that using the direct measurement method.

Aerial photos captured on 1999 at a scale of 1: 25000 and scanned at 1200 Dot Per Inch (DPI) to render 0.5 m pixels were used as high resolution reference image. The aerial photographs were orthorectified using ERDAS Imagine software. The Digital Elevation Model (DEM) used for orthorectification was generated during the orthorectification process. The GCPs used for orthorectification were collected using DGPS. Quick Bird image having 0.6 m resolution captured on 2010 was used as input data. The input image was not underwent orthorectification processes using the HRFM technique. So, flat areas were selected as test areas (three) to avoid the error in georeferencing due to topographic variation. The input image was georeferenced using both the conventional and the HRFM techniques. Figure 6 shows the application of the HRFM technique. Check points were used to quantify the positional error of the georeferenced images (Cuartero et al., 2010). Second order polynomial transformation and nearest neighbor resampling technique were used for georeferencing the images. The transformation error for this dataset was 0.34 m RMS.

Lower resolution input and higher resolution reference images: For this dataset equation 2 is applicable directly for assessing the validity of the HRFM technique in absolute term under conditions applied for the above mentioned dataset (please refer to the assumption of equation 6). As described earlier (please refer to equation 2), positive improvement of georeferencing accuracy was expected for this dataset. The reference image was the same aerial photos (0.5 m resolution) used earlier. The input was RapidEye image having 5 m resolution acquired on 2011. The same test areas and the similar procedures mentioned above were used for this dataset. The transformation error for this dataset was 1.51 m RMS.

Figure 6 – Example of application of the HRFM technique for identifying GCPs on Quick Bird image (left) using aerial photos (right) as reference image.
Table 1 presents the positional errors of the georeferenced Quick Bird and RapidEye images. It is seen that conventional technique achieved near pixel level accuracy for both the Quick Bird and RapidEye images. As expected, the HRFM technique achieved a bit less for Quick Bird image and higher for RapidEye image comparing to the conventional technique. Deterioration (deviation in table 1) of georeference accuracy using the HRFM technique for Quick Bird image was due to the nearest neighbor feature matching error (equation 7). The improvement of georeference accuracy for the RapidEye image was owing to lower point measurement error on the RapidEye image achieved using the HRFM technique; this lower point measurement error compensated well for the nearest neighbor feature matching error (equation 3). The quantitative values of georeferencing error indicate that the HRFM technique can be applied to georeference lower resolution images with sub-pixel accuracy if the nearest neighbor feature matching error is lower.

### 4.2 Application for moderate resolution images

The HRFM technique was applied on Landsat TM and MSS images of frames 137/43 and 138/44 and two RADARSAT ScanSAR WideA (SCWA) images covering approximately whole Bangladesh. The aerial photos mentioned above were used as high resolution reference image for georeferencing the Landsat and RADARSAT images. Figure 7 shows the application of the HRFM technique for RADARSAT image. Second order polynomial transformation and nearest neighbor resampling technique were used for georeferencing the images. To verify the positional accuracy of the georeferenced images, the method devised by Cuartero et al. (2010) was used. The positions of center lines of roads and small-width rivers digitized from the aerial photos were used as independent check lines and were compared with the same digitized from the georeferenced Landsat TM and RADARSAT images. Table 2 presents the positional accuracy of the Landsat TM, MSS and RADARSAT images. Shifts of 10.3 m CE90, 18.2 m CE90 and 27.7 m CE90 were seen for Landsat TM, MSS and RADARSAT images respectively. Neglecting the digitization error, these values can be

![](image)
considered as the positional accuracy of the georeferenced images.

From tables 1 and 2 it is seen that the HRFM technique achieved sub-pixel georeferencing accuracy for all the images (RapidEye, Landsat TM and MSS and RADARSAT SCWA) whose resolution are lower than that of the reference image.

5. Discussion
The mathematical equations presented in this study describe the georeferencing error in one dimension and are only to support the theory behind the HRFM technique. The different error components presented are independent and so combine in an RMS way (not presented for simplicity). Quantitative value of point measurement errors ($E_{ld}$, $E_h$) and nearest neighbor feature matching error ($E_{m}$) included in equation 2 depend highly on operator’s skill and uncertainties associated with these errors are difficult to quantify. However, an attempt was made to quantify the uncertainty associated with the improvement achieved using the HRFM technique. Equation 2 gives the actual improvement achieved and equation 3 gives the highest improvement that could be achieved if the pixel containing the GCP cross-section is identified and digitized. In general, the pixel containing the GCP cross-section is
identified with high degree of certainty and, thus, equation 3 is valid and calculable if \( E_m \) is considered negligible. As an example if RapidEye image (5 m) is used as reference image for georeferencing Landsat TM image (30 m) and a perfect matching of the nearest neighbor features is achieved (\( E_m \) equals zero), the highest improvement in georeferencing accuracy may be as much as 25 m leaving 5 m error margin. Usually the improvement will be lower leaving higher error margin since \( E_m \) is greater than zero and \( E_{ld} \) is less than \( PD_L \) for the condition on which Equation 3 is derived.

An important term of equation 3 is the matching error of the nearest neighbor features (\( E_m \)). This error plays the most critical role for the HRFM technique. High value of \( E_m \) may override the credibility of the present technique. A number of nearest neighbor features matching exercise was carried out using different resolution datasets and it was found that operator’s experience is imperative for keeping the value of \( E_m \) at lower level. It was also seen that the value of \( E_m \) increased with the increase of pixel dimension.

In respect of point measurement error, improvement of georeferencing accuracy depends on the resolution of both the LRI and HRI (equation 3). Table 1 and 2 give an idea of georeferencing error of images having variable pixel size (5 m, 30 m, 80 m and 100 m), based on high resolution reference image (aerial photos) of 0.5 m resolution. In order to examine the dependency of georeferencing error on resolution of input images, their ratio (indicating georeferencing error normalized with respect to resolution) was plotted against the resolution. The overall picture from this plot (Figure 8) is that georeferencing accuracy achieved using the HRFM technique depends on the resolution of image and this dependency is comparatively less for lower resolution images.

![Graph](image)

**Figure 8** – Dependency of georeferencing error on the resolution of image.

### 6. Conclusion

The HRFM technique solves the problem of identification of well distributed GCP on lower resolution images as well as it improves the georeference accuracy of lower resolution images to sub-pixel level. This technique is very useful for georeferencing microwave images where identification of GCP is very difficult. Application of the technique is more time consuming than the conventional approach as it involves additional work for generation of nearest neighbor feature layer from high resolution images and then matching it with the features of the lower resolution images. Because of this time requirement, the HRFM technique can be used for measuring GCPs on the part of the image where GCP identification is difficult; for remaining part of the image conventional technique can be used. This approach can also be undertaken while using the AutoSync module of ERDAS Imagine software. As mentioned earlier, AutoSync module is very efficient for automatic measurement of GCP but its efficiency depends on some characteristics of input data. The HRFM technique can be used as a supplement where the AutoSync module fails to measure good GCPs.
Based on the technical aspects, the method given by Khlopenkov et al. (2010) can be considered as the closest one to the HRFM technique. Both the technique use high resolution feature matching for obtaining sub-pixel georeference accuracy. Khlopenkov’s method depends solely on the correlation between input and reference image and its efficiency depends on the spectral characteristics of the input and reference images. This method is tested only for AHHRR images using MODIS images as reference. The HRFM technique works on vector based nearest neighbor feature matching and is free from spectral characteristics of the input and reference images. It can be applied using any pair of input and reference images. However, the reference image should have higher resolution than the input image. The other advantage of HRFM technique is that it performs very well for microwave images. Khlopenkov’s method is not applicable for microwave images.

The georeference accuracy based on the HRFM technique was found less dependent on the resolution of the target image having much lower resolution. This suggests a high degree of potential improvement of georeference accuracy for low resolution images such as NOAA, MODIS etc.

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Reference


