AUTOMATED GCP DETECTION FOR SAR IMAGERY
I. Road Intersections

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ABSTRACT

Road intersections are very good ground control points in a SAR image because they can be obtained from intersecting road segments even when the intersections themselves are not observed. In a previous study, a Hough Transform-based approach was developed for detecting intersections from a single-look ERS-1 SAR image. A similar Hough Transform-based approach has been applied to detect road intersections in a 6-look ERS-1 SAR image. In the case of multi-look images, however, there are no pure road pixels because roads are thinner than the resolution size and the pixels that include road information are greatly affected by surrounding objects. More spatial information and even approximate road map information are required to improve the capability to detect road intersections. It is found that broad intersections can be automatically determined from a multi-look image and the accuracy of the location of road intersections may be estimated from the heights of sharp peaks in Hough space.

KEY WORDS: Automated GCP selection, SAR image, Automated road intersection detection, Hough Transform

1. INTRODUCTION

Ground control points (GCP) for the geometric correction of Synthetic Aperture Radar (SAR) images are usually selected from point-like features such as road intersections, branch points of rivers, mountain tops, and the points of capes. When compared with other point-like features, a road intersection has better characteristics as a ground control point. Although a road intersection itself may or may not appear in the image, at least some parts of intersecting roads appear near the intersection. Then the location of the intersection can be obtained by extrapolating or interpolating those road segments, assuming they are straight near the intersection. In a previous study[1], we successfully detected road intersections in a suburban area from a single-look ERS-1 SAR image using a Hough Transform based approach. A similar approach was applied to the detection of a road candidate in a tropical forest region from a simulated single-look RADARSAT SAR image[2].

In this study, we have applied a similar approach to a multi-look image. Multi-look images are commonly used in various application fields and therefore there is a greater need for GCP points. Since the resolution of the image is usually coarser than road widths, however, thin road features in multi-look images are easily mixed with surrounding objects and therefore they are more difficult to detect. To overcome the difficulty, we used an approach called the "Information Fusion Approach" [2,3,4] in which we integrated more spatial information extracted from the image than the previous study and also integrated map information.

2. DATA

The image used in this study is an ERS-1 SGF product of Southern Ontario, Canada from data acquired on June 18, 1992. The nominal number of processed looks is 6. The spatial resolution is nominally 30m azimuth by 35m ground range and the pixel spacing is 12.5m by 12.5m. Two small, flat areas near Albuna (700x700) and Tilbury (1000x1000) south of Lake St. Clair and north of Lake Erie were selected for this experiment. Figures 1(a) and 1(b) show the original images of selected areas, both of which are covered with agricultural fields. Figures 2(a) and 2(b) are corresponding approximate road maps created manually from Figures 1(a) and 1(b) using geographical maps. Thick lines indicate two-lane roads with a solid surface and dotted lines indicate two-lane (or more) roads with a loose or stabilized surface. The road network in the Albuna area is simpler than that in the Tilbury area.

The roads roughly parallel to the look direction (horizontal direction, in this case) are observed fairly well, while the roads in the other directions, especially the roads with loose or stabilized surfaces, are sometimes quite difficult to observe. This is due in part to the fact that many fields in the data set look dark.

3. APPROACH

In single-look images, we can observe at least some pure road surfaces as fairly dark objects, although not the darkest objects. In the case of suburban roads[1], we simply extracted dark objects from the image and applied the Hough Transform. In the case of a road in a tropical forest area[2], however, the situation became more difficult. There were many dark area-like features which would be a large source of noise in a Hough space. To operate on such images, a new approach called the "Information Fusion Approach" [2,3,4] that integrates spatial information and semantics along with intensity information was developed.

In this study, the resolution size of the images (approximately 30m) is much larger than the width of 2-lane roads (approximately 10m) as is seen in Figures 1(a) and 1(b). There are no pure road pixels in these images. They are greatly affected by the surrounding objects and are not locally continuous. Generally speaking, the pixels including road information appear dark but not distinctive.. Since there are too many darker or dark areas, lines, and spots, the intensity information loses its significance. An additional problem of detecting roads in this image is the dependence of road observing capability on radar look direction: roads roughly parallel to the look direction (horizontal direction) are easily observed, but roads in the other directions are often difficult to observe. It may be said that globally roads appear as relatively dark straight lines that are not locally continuous. There are, however, many confusing similar straight-line-like features in the image as well. Therefore, it is impossible to detect roads even visually without general knowledge of the area (including map information).

In order to handle these difficulties, the "Information Fusion Approach" was used, integrating much spatial information and semantics as well as traditional pixel-by-pixel or window-by-window intensity information. Figure 3 illustrates the schematic diagram of the hierarchical "Information Fusion Approach." Observed data are processed by a traditional pixel-by-pixel image processing method first. This is followed by gradual integration of the spatial information of image cues (single continuous pixel groups), of groups of image cues, and then integration of semantics to reach the final objective of terrain understanding, in this case the detection of road intersections.

4. PROCEDURE

The steps in the procedure used in this study are described as follows:

Step 1: Speckle reduction
Although the nominal number of processed looks of the images is 6, there is still too much noise for further image analysis. Since the road widths are thinner than the resolution size, the road information should be preserved as much as possible, while random speckle noise is reduced. For that purpose, speckle reduction was performed by the SFP (Small Feature Preserving) filter developed by the authors[6].

Step 2: Extraction of dark image cues systematically at various threshold levels
The pixels that include roads appear as dark objects. However, the level of darkness varies depending on a number of conditions as seen in Figures 1(a) and 1(b). They are widely distributed in a histogram. Instead of using fuzzified darkness as we used in a previous study[1], we extracted dark image cues at various threshold levels. Here "image cues" means "single continuous image objects"[5]. Six threshold levels are tentatively determined at equally spaced intensity levels in the darker side of the main lobe of the histogram. At each threshold level, dark image cues are extracted.

Step 3: Evaluation and accumulation of line likeness and boundary likeness

The line-likeness of each pixel belonging to image cues at different threshold levels was evaluated and accumulated, because many pixels containing the road information are likely to form line-like objects. They appear in many other threshold levels, if they are distinctive. The accumulated line-likenesses for two test areas are shown in Figures 4(a) and 4(b). As is easily seen from these Figures, it is very difficult to detect all roads only from the accumulated line-likeness. Roads roughly parallel to the look direction can be detected from these images, but roads in the other directions, especially those in Figure 4(b), are very difficult to detect. Since some of the field boundaries could be interpreted as road segments, the boundary-likeness of each pixel is also evaluated and accumulated. The accumulated boundary likeness of two areas are shown in Figures 5(a) snd 5(b).

Step 4: Combination of line-likeness and boundary-likeness
Since the accumulated line-likeness is not sufficient to detect all roads, it was expected that some combination of line-likeness and boundary-likeness may help to detect road candidates more accurately. Actually, integration of boundary-likeness results in detecting excess road candidates. We tried the mixing ratio of 1:1, 2:1, and 3:1 for line-likeness and boundary-likeness. However, it is found that if road map information is integrated in the next step, the actual mixing ratio does not much matter. Therefore, a mixing ratio of 2:1 was used in this experiment.

Step 5: Integration of approximate road map information.
It is found that the combination of line-likeness and boundary-likeness results in detecting too many road candidates while the single use of line-likeness results in detecting too few road candidates. To get an appropriate number of road candidates, the input data to the Hough Transform is refined by integrating the dilated image (dilation 4 times with a 5x5 circular window) of the map shown in Figures 2(a) and 2(b). Figure 6 shows the input image of the Albuna area as an example input image to the Hough Transform.

Step 6: Hough Transform
The Hough Transform was carried out with a precision of 1 pixel in radius and 1/4 degree in angle for the Albuna area and 1/5 degree in angle for the Tilbury area in angle. The Hough Transformed image of the Albuna area is shown in Figure 7 as an example. The horizontal axis represents angle and the vertical axis represents radius. Very bright crosspoint-like areas correspond to the roads in the normal coordinates. Ideally those peaks should be very bright, symmetrical, and sharp, but many sources of noise make them very irregular, asymmetrical, and diffused.

Step 7: Noise reduction in Hough space
An averaging operation with a 3x3 window was applied to the Hough Transformed images to suppress random noise associated with the input to the Hough Transform.

Step 8: Extraction of sharp and high peak areas from Hough space
An erosion operation with a 3x3 window was applied to the averaged image. The difference image created by subtracting the eroded image from the averaged image shows only the sharp peaks in Hough space and eliminates broad peaks caused by noise from various sources. The difference image is then thresholded to preserve only high peaks and eliminate random noise. The bright areas in Figure 8 are shown for the Albuna area.

Step 9: Search for local maximum
To find the most plausible peak location corresponding to a road from each peak area such as shown in Figure 8, a morphological operation was used to find a local maximum value within a certain neighbourhood (a 13x13 circular window).

Step 10: Inverse Hough Transform
The inverse Hough Transform was applied to the local maxima obtained in the previous step to get road candidate lines in normal space. The peak heights in Hough space, which correspond to the number of pixels belonging to the line, are assigned to these lines as the brightness of lines. (When a peak in Hough

space is higher, the line appears brighter.) Therefore, it may be said that the brightness of the line reflects the plausibility of the existence of the line.

Step 11: Extraction of lines near the approximate road area
As the road candidate lines in the Albuna areas are either parallel or perpendicular to other candidates, there are not too many false intersections expected. On the other hand, in the Tilbury image there are too many false intersections in the output of the previous step because of the diversity of directions of the roads. In order to avoid the excessive number of false intersections, the previous results are multiplied by the dilated approximate road maps. Figure 9 and Figure 10 show the road candidates superimposed on the dilated approximate road maps. It should be noted that true roads do not necessarily reside in the centre of the dilated road areas.

Step 12: Extraction of road intersections
Although road intersections can be calculated from the result of step 11, we extracted them graphically using IICS (Integrated Image Computing System)[7] based on whether or not the spatial pattern code of each pixel matches the cross intersections and T intersections.

5. RESULTS and DISCUSSION

Figure 9 shows the road candidates for the Albuna area and Figure 10 for the Tilbury area overlaid with dilated approximate road maps, which appear as dark strips in Figure 10. The brightness of the lines reflects the plausibility of the existence of roads. Comparing with Figure 1(a) and Figure 1(b), it is found that these results are fairly consistent with visual observation.

In Figure 9, roughly horizontal lines are generally brighter. Comparing with Figure 2a, it is found that the lines corresponding to the roads with hard surfaces appear as bright single lines. Roads with loose surfaces in the same direction are slightly darker. On the other hand, the roads perpendicular to them appear darker, although they have a hard surface.

There are several cases of multiple lines for a single road candidate. One of the reasons is that these roads are not very well observed in the original image as shown in Figure 1(a). The other cause is probably the peak search method in Hough space. In this study, we tentatively used a method based on mathematical morphology. Although the Hough Transformed image was averaged and noise reduced before searching for the peaks, there may still be some noise and the method may pick accidental peaks. It may be better to consider peak shapes theoretically by assuming some statistical distribution of the pixels belonging to a peak, such as a Gaussian distribution.

The result for the Tilbury area is more complex. The road directions in the image are roughly classified into 4 groups: nearly horizontal, nearly vertical, and in the two diagonal directions. Most of the roads are short so that they are likely to be buried in noise in the Hough Transform. Furthermore, the roads with loose surfaces in diagonal directions are hardly observed at all. If the original image is divided into several subimages and a similar peak enhancement method to that used in the previous study[1] is applied, the result may be improved for short roads. However for the vague roads, there is not much to be done. Even if they can be extracted, the location accuracy cannot be very high.

6. CONCLUSIONS

Road intersections for use as ground control points can be determined from multi-look SAR images automatically using a Hough Transform-based method. There are, however, no pure road pixels in multi-look images and the backscattering intensities of the pixels containing road information are not very distinct. Therefore, the integration of spatial information and non-image information such as map information is also required to detect roads. The following considerations are necessary to select the intersections for ground control points. First of all, the road intersections for ground control points should be determined from the road segments clearly observed in the image. Secondly, the image size should be small enough to preserve the accuracy of the location of the intersections. Thirdly, a better peak search method in Hough space will make it possible to extract weaker roads. Lastly, assigning the peak height in Hough space to the attribute of extracted roads can be used to indicate how well the road can be determined.

7. ACKNOWLEDGMENTS

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8. REFERENCES

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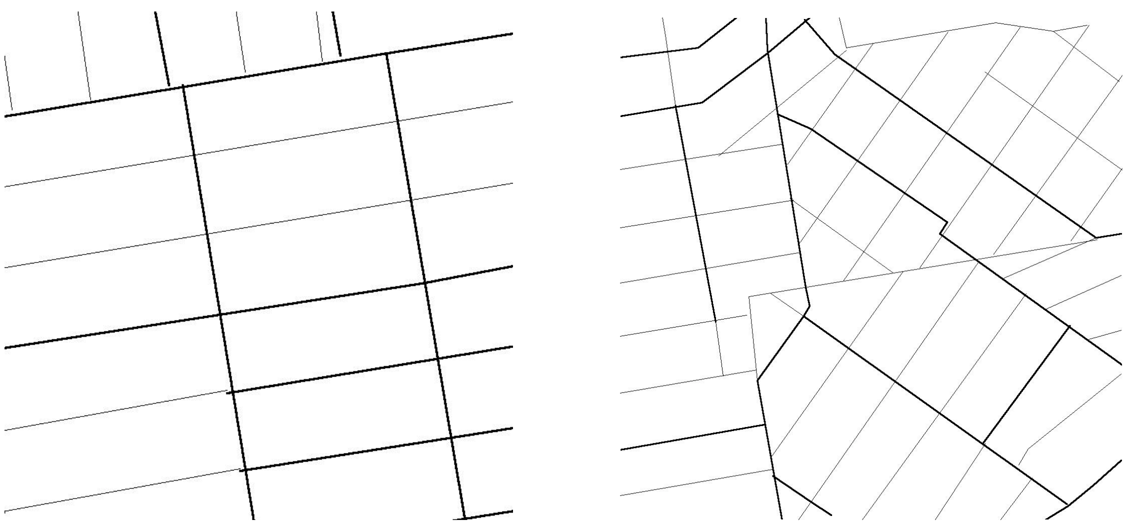
(a) Area near Albuna. (b) Area near Tilbury.

Figure 1. Original images of selected areas.



(a) Area near Albuna. (b)Area near Tilbury.

Figure 2. The existing road maps of the corresponding areas in Figure 1.

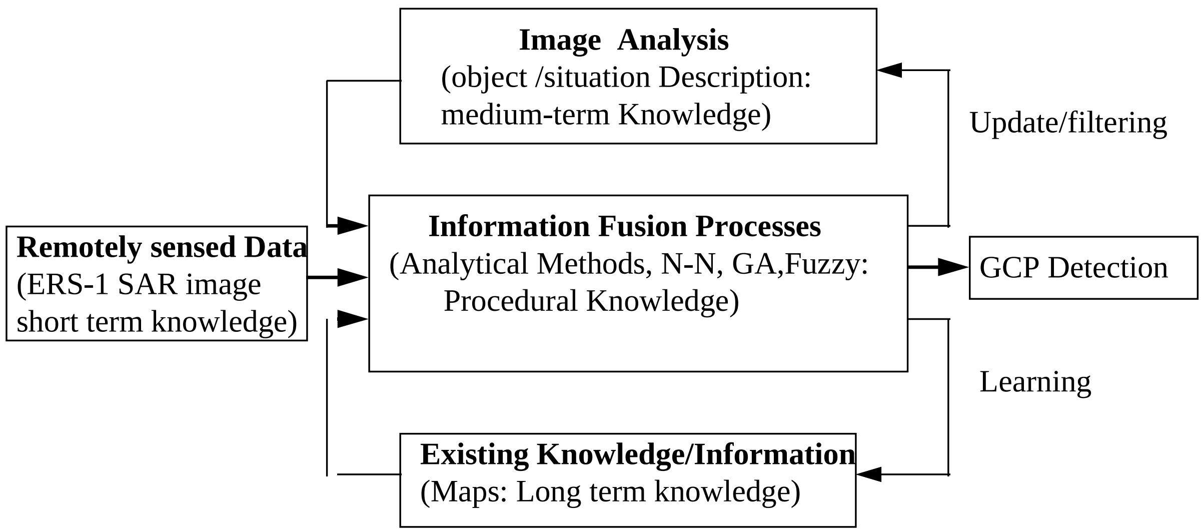
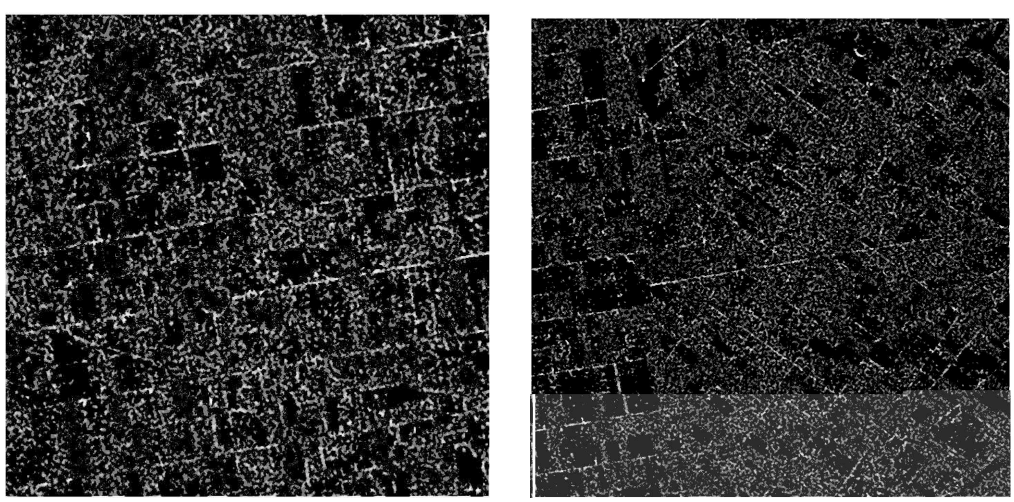
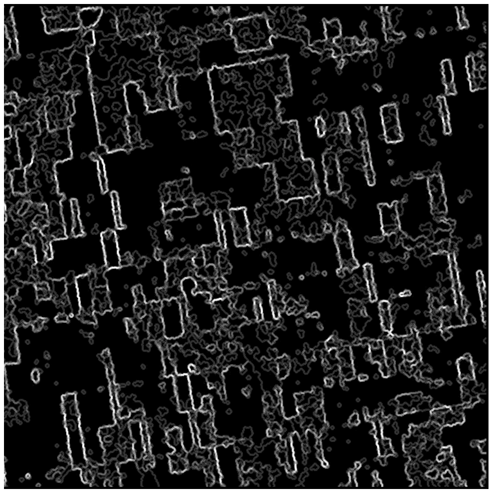


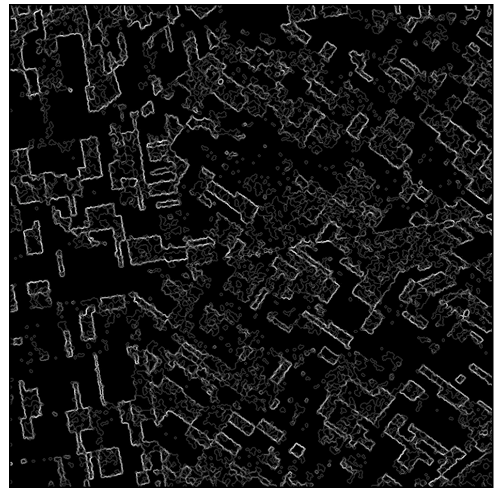
Figure 3. Schematic diagram of the hierarchical Information Fusion Approach



(a) (b)

Figure 4 Accumulated line likeness. (a) Area near Albuna. (b) Area near Tilbury.





(a) (b)

Figure 5. Accumulated boundary likeness. (a) Area near Albuna. (b) Area near Tilbury.

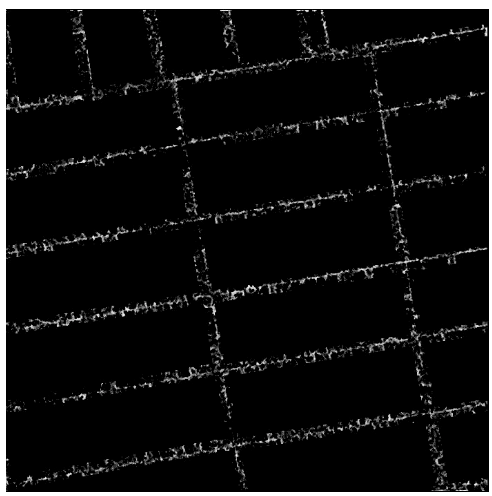


Figure 6. Input data to Hough Transform

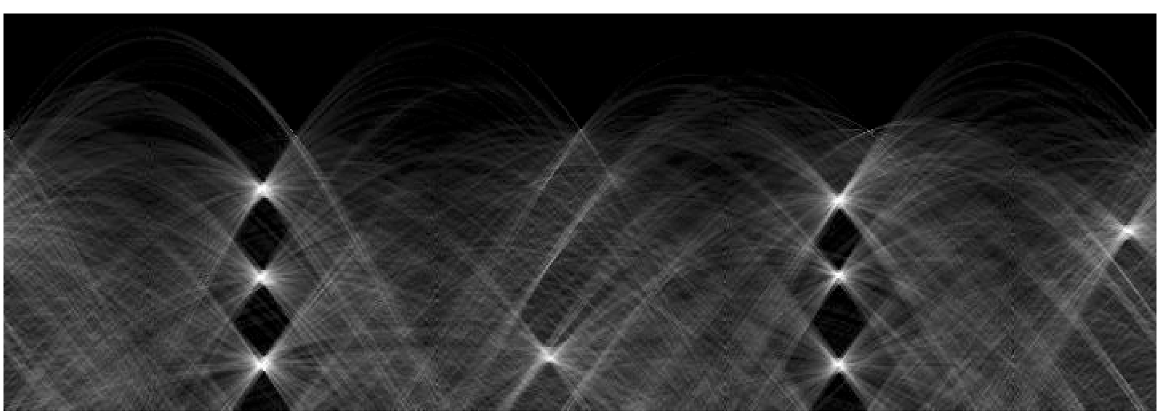


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Figure 7. Hough Transformed image of Albuna area,
where the horizontal direction represents angle and the vertical direciotion represents distance to the line.

Figure 8. Extracted sharp and high peaks in Hough space for Albuna area.

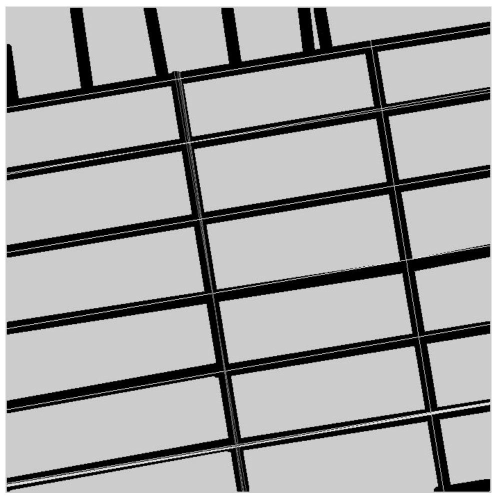

Figure 9. Road candidates of Albuna area obtained from the Inverse Hough Transform

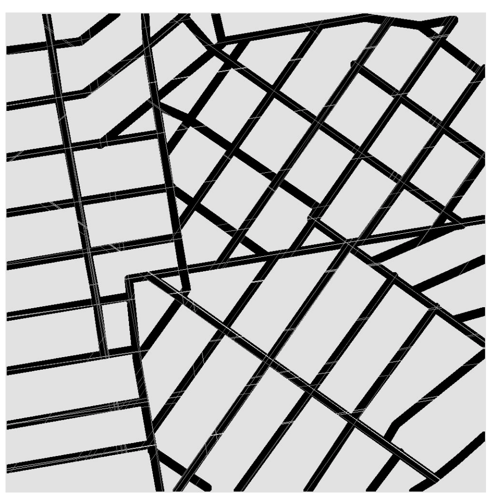

Figure 10 Road candidates of Tilbury area obtained from the Inverse Hough Transform