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AN EXPERIMENT TO MATCH RADAR IMAGES

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ABSTRACT

Matching of images is a fundamental tool of automated vision. Therefore numerous algorithms have been proposed, and many experiments conducted to perform and assess matches of optical images. Radar images, in contrast, have rarely been the object of image matching work. We report on a recent experiment in the context of NASA's Magellan mission to map planet Venus. At issue is the proof that automated matching of radar images is feasible in a meaningful manner, and that the matches can serve various purposes. We show that match errors are in the range of $\pm$ 2 pixels, and that this differs from errors in the optical domain of perhaps only $\pm$ 0.6 pixels. We also report that machine matches at $\pm$ 2 pixel uncertainty compare with manual matches by an experienced operator with an uncertainty of only $\pm$ 0.6 pixels.

INTRODUCTION

Hardly any work has been reported in the literature that would permit one to assess the likelihood of making only small errors in matching side-looking synthetic aperture radar images. Past efforts have been based on manual stereo measurements in overlapping pairs of radar images (Leberl, 1991; Leberl et al. 1992) and in looking for well-defined objects in radar images such as ground control points (Guindon, Maruyama, 1986). Image matches by machine were reported by Ramapriyan and Strong et al. (1986) and by Welch et al. (1992). However, the quality of the matches was not the object of these studies. Therefore there exist no data points for the student of radar images to predict how matching errors may depend on various factors.

Yet it is fairly obvious that matching is an important tool for a variety of tasks which go well beyond the realm of stereo reconstruction of terrain surfaces. If this were the only object, then perhaps the scientific effort may better be spent on developing the most promising technology of topographic shape reconstruction from radar images, namely interferometry. However, Table 1 is an attempt to list typical tasks which must rely on matched radar images and it shows the breadth of the applicability.

While there may be numerous factors to affect the outcome of an image match, there often exists the expectation that it is the matching rule itself which has the biggest significance. We doubt this view and express the suspicion that there are many different factors to affect our succes in matching as shown in Table 2. This table derives from observations in numerous manual image matching efforts.

As a particular feature of the radar image matching problem we must cope with an inherent radiometric dissimilarity of overlapping images. This may be the most serious differences from the well-studied problem of matching optical images. It is also the reason why we believe that such previous studies on optical data are irrelevant for radar images.

It is the purpose of this paper to summarize an experiment on matching a variety of radar images both by machine and by an experienced human, and of comparing these matches with those obtained from optical SPOT and aerial photographs. A full account of this experiment is being reported in a forthcoming paper (Leberl et al., in print). We will show that radar images of reasonable similarity can be automatically matched with differences between machine matches and those obtained by an experienced stereo operator of $\pm$ 2pixels.

Table 1: Why Radar Image Matching ?

For Parallax Detection and Stereo Mapping
For Image Mosaicking
For Image Time Series Analysis
For Incidence Angle Signature Studies
For Backscatter Calibration Purposes

Table 2: Factors Suspected of Significant Influence on the Ability to Match Two Radar Images

Sensor Type
Geometric Resolution
Signal to Noise Ratio
Object/Surface Shape
Type of Object/Surface
Look Angle Geometry
Look Angle Disparities

We do this work because of a need to proof that radar images can be matched automatically for the data of planet Venus, as obtained in NASA's mission Magellan. That mission was planned to produce only one set of images to cover the planet; however, an Extended Mission created additional images for a second and third coverage. As a result a large set of images now exits that needs to be processed and analyzed. This can only be accomplished by machine, if at all.

We believe that our study demonstrates that automated image matching is feasible with some loss of accuracy when compared to matches by a human, but that the errors will be acceptably small and not make use of the matches impossible.

MATCHING ALGORITHMS

Our focus is on data and a coarse assessment of matching quality. It is not on developing a best matching algorithm, nor even to judge which of a great variety of matching strategies may be optimum for radar images. Generally we believe that the major factors to look for in a matching method are those listed in Table 3.

Table 3: Issues of an Algorithm to Affect Matching Result

Ability to Predict a Match Location
Matching Criterion
Size of Window
Shape of Window
Ability to Warp Images
Gross Error Detection
Coping with Dissimilarities

We select 5 different simple matching methods that all are area-based. Table 4 describes them. None of them accounts specifically for the fact that radar images taken from different vantage points will not only be geometrically different (a difference we seek for reconstruction of topogaphy), but also radiometrically, since illumination will vary (a difference we commonly do not seek and for which we typically have no use). Therefore rather than developing radar-specific matching and surface/backscatter reconstruction methods, we simply use the most common generic image matching techniques and look to assess their performance on radar images.

Table 4: Image Matching Methods for the Experiment

	Method	*Reference*
1	Normalized Cross Correlation (CORREL)	Anuta (1970)
2	Sum of Mean Normalized Absolute Differences (MNAD)	Ramapriyan et al. (1986)
3	Sum of Mean Normalized Squared Differences (SQUARE)	Rosenholm (1987)
4	Stochastic Sign Change (SSC)	Herbin et al. (1989)
5	Outlier Minimal Number Estimater (OMNE)	Herbin et al. (1989)

ABOUT THE IMAGES FOR THE EXPERIMENT

We select a set of images all displaying both smooth and rugged terrains. They originate from Magellan's radar sensor, from aircraft radar, from SPOT and from aerial photography. Regarding radar, we selected data with different imaging geometries both concerning look-angle off-nadir and look-angle disparities to provide different scenarios for the dissimilarities between images.

We present in Table 5 a summary of some essential facts about the images and their imaging geometries. For a look at the images themselves we refer to the full paper (Leberl et al., in print).

Table 5: Description of Test Images for the Matching Experiment

Radar Images	Pixel Size (m)	Look-Angle Off-nadir θ' (°)	Look-Angle Off-nadir θ'' (°)	Intersection Angle $\Delta\theta$	Typical Stereo Parallax for Terrain Elevation h = 100 m	Comments
Magellan radar, Set 1	75	40	21	19	140 m	2° S, 75°E
Magellan radar, Set 2	75	25	14	11	187 m	39° S, 79°E
Magellan radar, Set 3	75	15	11	4	141 m	59° S, 86°E
Aircraft radar	6	73	55	18	39 m	Brazeau, Canada
SPOT stereo-images	20	2	27	25	47 m	Boulder, Colorado
	Pixel Size (m)	**Flying Height (m)**	**Photo Scale**	**Base-to-Height Ratio**	**Stereo Parallax for Terrain h = 100 m**	
Digitized National Aerial Photography Program (NAPP)	2	6,000	1:40,000	0.6	60 m	Boulder, Colorado

MANUAL REFERENCE DATA

The experiment is based on a comparison between a human stereo operator of many years of experience using aerial photography and radar image stereo measurements. What is the quality of human image matches?

To assess this question we set up repeat measurements on two different days for two test persons, one being the experienced operator, the other an inexperienced trainee. First, a grid of match points was measured by each operator by removing the parallaxes observed in two overlapping images. Then, on another day, the machine set the left measuring mark on the same points that were previously observed, and the operator had to remove the parallax again.

Differences between the two sets of observations produced the conclusion that the experienced operator compared well with an inexperienced trainee as follows:

$\pm$ 0.6 pixels for the experienced operator on radar images,

$\pm$ 3.0 pixels for the inexperienced operator.

Following this test, we then proceeded with the collection of manual reference match points in all test images from various sensors over terrain of rugged and smooth character. This was then followed by the computed matches which used the manual measurements as "approximate values" or match predictions. From these "predictions", the algorithm proceeds with the search for the best match.

RESULTS OF THE MATCHING EXPERIMENT

Figure 1 illustrates the evaluation of the considerable amount of computational results. The x,y coordinates of the location of the "best machine match" was subtracted from the location of the human manual match and stored in a table of results for each image pair and type of terrain. Then the differences were subjected to a set of statistical assessments regarding four topics:

mean coordinate difference;

standard coordinate difference;

number of observations (in %) with less than 1 pixel match error;

effect of size of the reference window to search for best window size.

Of course the best matching method and itserrors as a function of image type was at issue as well. We refer again to the full paper for a discussion of the experiment's results and report at this point only a summary in the form of Table 6.

Figure 1: **Assessment of Matching Accuracy by Comparing of Manual with Machine Matching**

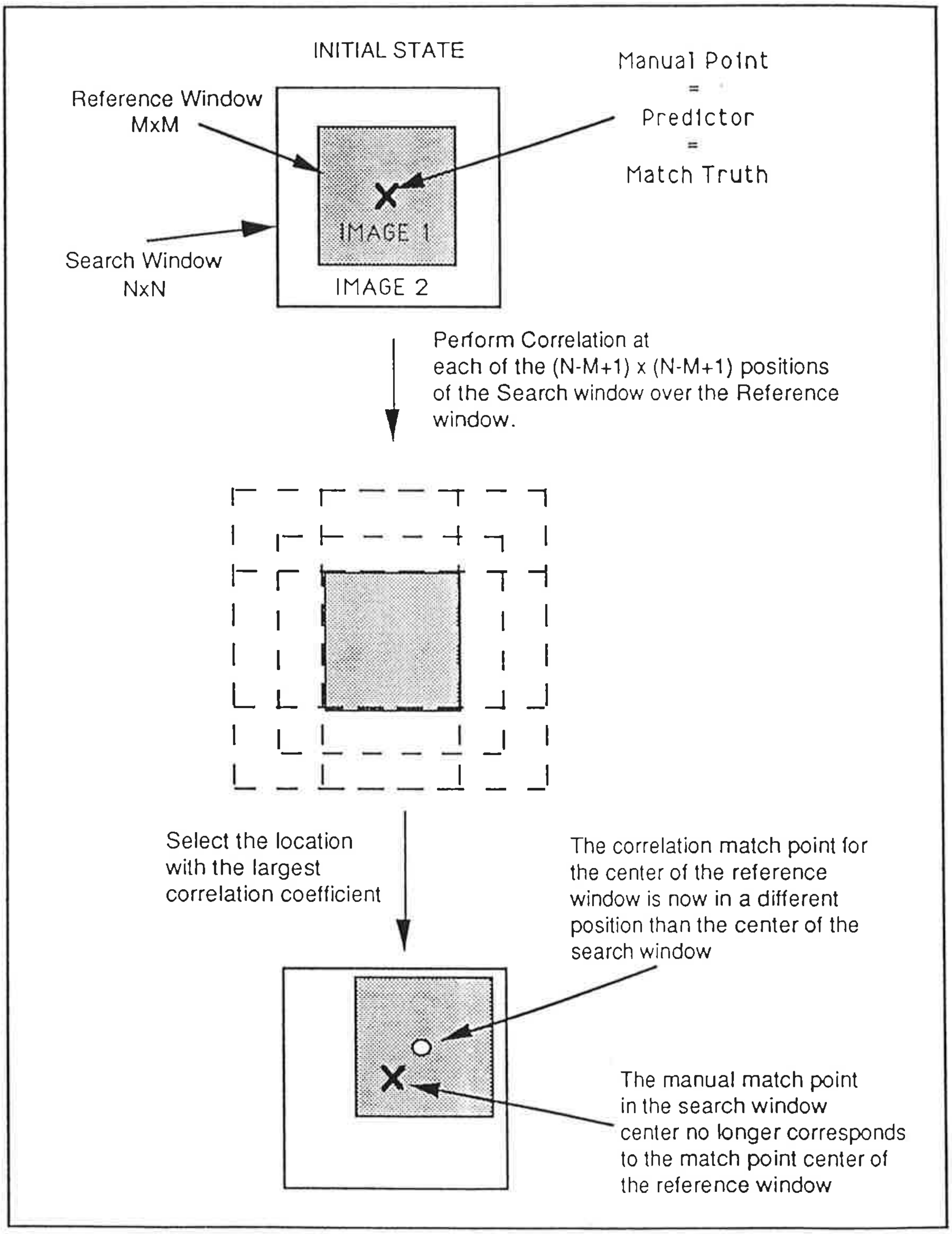

Table 6: Summary of Results from the Matching Experiment

Manual radar matching is consistent to within	± 0.6 pixels
Inexperienced operators may be in error by	± 3 pixels
Automated vs manual matching in Magellan radar images	± 2 pixels
Automated vs manual matching in aircraft radar images	± 1 pixel
Best window size at	40 pixels
SPOT automated vs manual matching (smooth terrrain)	± 0.5 pixels
SPOT automated vs manual matching (rugged terrain)	± 0.7 pixels
Airphoto automated vs manual matching (rugged terrain)	± 1.9 pixels
Airphoto automated vs manual matching (smooth terrrain)	± 0.4 pixels
Discrepancies > 1 pixel = 50 to 75% at window size of (Magellan, best case)	40 pixels
Best in all cases among investigated methods	normalized correlation

A mass of numerical data is being produced by a systematic set of 1500 computer runs with 5 methods, 25 window sizes, 6 image sets and 2 types of terrain. We had concerns with a potential distortion in the result from the use of the manual matches as "predictions" and therefore repeated some runs with a systematic displacement of the starting prediction from that of the manual match. However, the conclusions remained the same, even when starting the machine search from slightly displaced predictions.

An attempt was made to assess the effect of mismatches on the computation of topographic terrain elevations on Venus. It can be quickly shown that Magellan's geometry does permit one to convert parallax observations into elevation differences using fairly large conversion factors of 1.5 to 2.0. This is in contrast to aerial photogrammetry where such conversion factors, denoted as "base-to-height ratios", are in the range of 0.6. We find that Magellan is a good topographic elevation measurement system, resulting in elevation uncertainities from parallax uncertainities in the range of only $\pm$ 1.0 to $\pm$ 1.5 pixels.

The nature of the matching errors would be of interest to address methods of better matching. Clearly match errors may be caused by the differences in illumination. Therefore one obtains match errors that may be largest along valley bottoms. However, this issue was not addressed by this study, and its resolution must be reserved to further analyses.

CONCLUSIONS

We have created a data point for the study of matches of overlapping radar images. By simply comparing the human stereo operator with image matches obtained from machine algorithms, we conclude that radar image matching must typically count on errors of $\pm$ 1 to 2 pixels in rugged terrain and with stereo-useable geometries (thus non-excessive angle disparities).

As we look into the future we see that radar interferometry may at one point be the technology of choice for topographic terrain relief reconstruction. Yet there will continue to exist a need to match overlapping radar images to support a variety of image analysis tasks.

In particular there exists a class of tasks which address surface microwave scattering properties; these include a need to understand incidence angle effects in multiple images. Manifestations of surface slope and of surface scattering combine into a radar image grey value. Independent from this do we have elevation variations affecting image geometry. It is fairly obvious then that we must begin to combine the use of image geometry and of radiometry to resolve the effects of surface topography and surface scattering properties.

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