More Efficient Method for Determination of Match Quality in Adaptive Least Square Matching Algorithms

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Abstract

For the accurate generation of DEMs, the determination of match quality in adaptive least square matching algorithm is significantly important. Traditionally, only the degree of convergence of a solution matrix in least squares estimation has been considered for the determination of match quality. It is, however, not enough to determine the true match quality. This paper reports two approaches of match quality determination based on adaptive least square correlation : the conventional if-then logic approaches with scene geometry and correlation as additional quality measures; and, the fuzzy logic approaches. Through these, accurate decision of match quality will minimize the number of blunder[1] and maximize the number of exact match. The proposed methods have been tested on JERS and SPOT images and the results show good performance.

1. INTRODUCTION

The generation of digital elevation models(DEMs) using satellite images becomes more and more important in particular with the emerging high resolution spaceborne sensors. In the process of DEM generation, stereo matching, a general notion to select corresponding phenomena in two or more observation sets, is an essential process, and however, a bottleneck for a DEM generation.

Generally, stereo pairs from satellite images include a lot of noises such as clouds and brightness differences, etc. and several factors which make the correspondence problem difficult such as occlusions, photogrametric distortions and figural distortions. These cause blunders and holes for stereo matching and hinder the generation of accurate DEMs. Hence more efficient stereo matching algorithm is needed for the generation of accurate DEMs from spaceborne stereo images.

Experiments have been carried out using an adaptive least squares correlation algorithm proposed by Gruen(1985), further developed by Otto & Chau (1989) and implemented and modified at the author's affiliations. This algorithm is an iterative process and at each iteration, decision is made whether matching is a "success" or "failure" or iterations should "continue". Since the algorithm is known to have a problem of blunder propagation, such a decision should be made very carefully not to conclude any wrong estimation as a "success" or right one as a "failure".

This paper reports two approaches tried for accurate decision of match quality which minimizes the number of blunder and maximizes the number of exact match. In the first approach, the conventional if-then logic were used. Traditionally, only the degree of convergence of a solution matrix in least squares estimation has been considered for match quality determination. But this constraint is not enough to model decision boundaries. It was found that better performance was achieved by using the scene geometry such as the shape of patch and normalized cross correlation as additional quality measures. In the second approach, the fuzzy logic decision

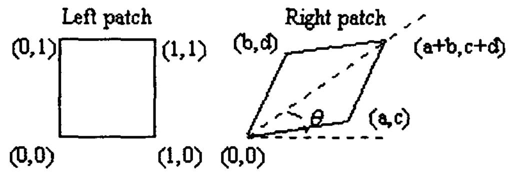
[1] Grossly inaccurate match

models based on the scene geometry and the degree of convergence of a solution matrix were used. Fuzzy logic can be very useful to model unknown or poorly defined decision boundaries. Also, the fuzzy logic provides continuously-valued fuzzy outputs which represent the "possibility" of match success. These outputs can also be used as an index indicating how well an output match pair is matched. It was found out that this model work better when the decision boundaries were not linear or when the exact shapes of the boundaries were unknown(Kim at el., 1998).

Section 2 explains the conventional if-then logic decision making system with the scene geometry and normalized cross correlation. Section 3 will then explain the fuzzy logic decision making system. Experimental results obtained using the two approaches and discussions are shown in Section 4.

2. CONVENTIONAL IF-THEN LOGIC APPROACHS

The adaptive least squares correlation algorithm used in this paper defines patches of a pre-defined size around match candidate points in the left and right images. The left patch and the right patch initially have a rectangular shape. As matching progresses, the left patch remains unchanged but the right patch changes its shape at each iteration according to an affine transformation. Parameters for the affine transformation are derived through the least squares estimation. Since this algorithm is an iterative process, a decision for the termination of iteration, i.e., the determination of match quality, should be made very carefully not to match any wrong pairs of point. If the determination of match quality is wrong, this algorithm has a problem of blunder propagation.



Affine Transformation : $\begin{pmatrix} x_r \\ y_r \end{pmatrix} = \begin{pmatrix} a & b \\ c & d \end{pmatrix} \begin{pmatrix} x_l \\ y_l \end{pmatrix} + \begin{pmatrix} s_x \\ s_y \end{pmatrix}$

Scene Geometry : Size = $\det \begin{pmatrix} a & b \\ c & d \end{pmatrix}$

Distortion = $\dfrac{\|(a+b, c+d)\|}{\|(a,c)-(b,d)\|}$

Rotation = $\theta - 45°$

Normalized Cross Correlation

$$\frac{\sum_{(u,v)\in W} I_1(u,v)\cdot I_2(x+u, y+v)}{\sqrt{\sum_{(u,v)\in W} I_1^2(u,v)\cdot \sum_{(u,v)\in W} I_2^2(x+u, y+v)}}$$

Figure1. Scene geometry and Correlation

Traditionally, for the determination of match quality, only the degree of convergence of a solution matrix in least squares estimation - the position change of the estimated match pair before and after one iteration - was considered as a quality measure. But this measure is not enough to model decision boundaries. Therefore, the use of the scene geometry and normalized cross correlation are proposed here as additional quality measures.

If one assumes that a stereo pair is acquired from the same sensor, the correlation between left patch and right patch should be high and the size and shape of the left and right patch similar. Furthermore the distortion and rotation of a right patch can be limited. Figure 1 shows the definition of the patch size, distortion, rotation and normalized cross correlation. It is assumed that the affine transformation be an identity matrix and the size and shape of right patch identical to the left one. Based on this assumption, patch size, distortion, rotation and normalized cross correlation are used as match quality measures.

Using these match quality measures, the following procedures can be applied.

1. Get initial match candidate and initial affine transformation;
2. Perform the ALSC matching, update affine transformation and right patch and calculate an estimated match pair;
3. Calculate match quality measures;
4. Apply a conventional if-then logic decision making process based on the scene geometry and correlation;
5. If the output of a decision making process is a "success", report so and finish matching;

6. If a "continue", go to step 2:
7. If a "failure", report so and finish matching

Based on the scene geometry, convergence and correlation, the following three conventional if-then logic decision making systems were modeled as shown in Figure 2.

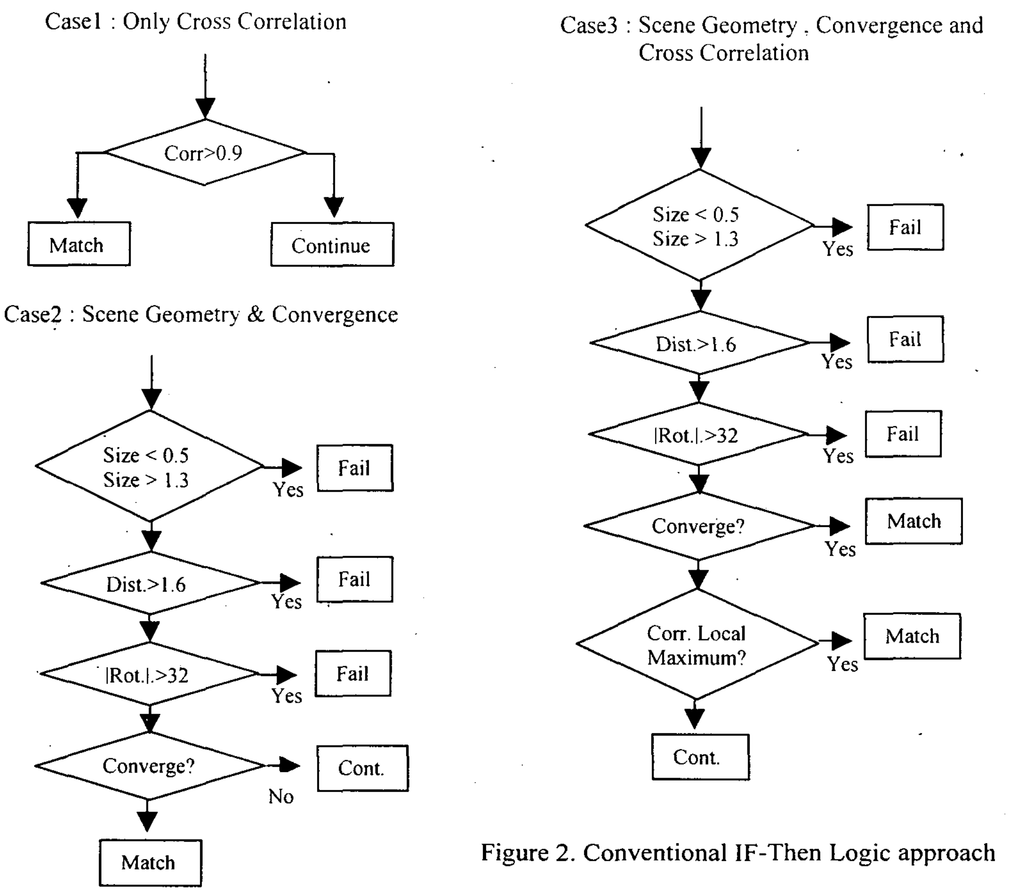


Figure 2. Conventional IF-Then Logic approach

In the first decision making system, for the match quality measure, only normalized cross correlation was considered. If the correlation between left patch and right patch was over a pre-defined threshold, the estimated match pair was assumed as exact match. In the second decision making system, only the scene geometry and the degree of convergence of a solution matrix were considered. If the left and right patch were similar and a solution matrix in least square converged, the estimated pair was assumed as match. In the last decision making system, the scene geometry, the degree of convergence of a solution matrix and normalized cross correlation were considered for match quality measures. If the left and right patch were similar, and a solution matrix in least square converged or the correlation between left and right patch were local maximum over a certain threshold, the estimated pair was assumed as match.

3. FUZZY LOGIC APPROACHS

In this approach, adaptive least square correlation algorithm works similar to that in the conventional if-then logic. In the above-mentioned match procedures, fuzzy logic replaces the step 4 to assess the quality of the estimated match pair. If the quality is low, the match pair is rejected and if high, accepted. If not high enough, iterations continue. The proposed fuzzy logic decision making system consists of three parts, i.e., input fuzzy membership functions, fuzzy rules, and fuzzy output membership functions as shown in Figure 3 and Table 1.

For fuzzy membership functions, the scene geometry shown in Figure 1 and the degree of convergence of a solution matrix were considered. Fuzzy rules are defined based on linguistic descriptions. For example, a linguistic description for "failure" criteria is "if the right patch size is LARGE compared to the left one, position change before and after an iteration is LARGE, the patch distortion is HIGH, and the patch is HIGHLY rotated, then the estimation is a "failure" ". Similarly, linguistic descriptions can be made for other circumstances. According to such descriptions, fuzzy rules are constructed (see table 1).

The output of fuzzy logic is a "possibility". If the output value is high, the estimated match pair is highly likely to be a "true" one and match is a "success". If low, the estimated match pair is likely to be a "wrong" one and match is a "failure". For the experiments presented here, the output value higher than 1.7 (in 0 to 3 range) is considered as a "success" and lower than 1.2 a "failure". For the value in-between, iterations "continue"

In addition, the fuzzy logic output can be used to reduce the number of iteration required for match "success". If the output values of fuzzy decision making system monotonically decrease at two successive iterations, the estimation can be regarded as a "failure".

In this approach, firstly, Only fuzzy logic decision making system was applied. And secondly normalized cross correlation was added as an additional quality measure.

Table 1. Fuzzy Rule Table

Patch Size	Distortion	Rotation	Convergence	Match Quality
SMALL	LOW	LOW	SMALL	FAIL
SMALL	LOW	LOW	LARGE	FAIL
SMALL	LOW	HIGH	SMALL	FAIL
SMALL	LOW	HIGH	LARGE	FAIL
SMALL	HIGH	LOW	SMALL	FAIL
SMALL	HIGH	LOW	LARGE	FAIL
SMALL	HIGH	HIGH	SMALL	FAIL
SMALL	HIGH	HIGH	LARGE	FAIL
MED	LOW	LOW	SMALL	MATCH
MED	LOW	LOW	LARGE	CONT
MED	LOW	HIGH	SMALL	FAIL
MED	LOW	HIGH	LARGE	FAIL
MED	HIGH	LOW	SMALL	FAIL
MED	HIGH	LOW	LARGE	FAIL
MED	HIGH	HIGH	SMALL	FAIL
MED	HIGH	HIGH	LARGE	FAIL
LARGE	LOW	LOW	SMALL	FAIL
LARGE	LOW	LOW	LARGE	FAIL
LARGE	LOW	HIGH	SMALL	FAIL
LARGE	LOW	HIGH	LARGE	FAIL
LARGE	HIGH	LOW	SMALL	FAIL
LARGE	HIGH	LOW	LARGE	FAIL
LARGE	HIGH	HIGH	SMALL	FAIL
LARGE	HIGH	HIGH	LARGE	FAIL

4. RESULTS AND DISCUSSIONS

The proposed conventional if-then logic and fuzzy logic decision making system were tested using a JERS image and a SPOT image. Images were extracted from the full scenes to have the size of 512x512 pixels. To each image, the proposed conventional if-then logic and fuzzy logic decision making system were applied.

Table 2 summarizes match results. In the table, "match" are presented as the ratio of matched points to the maximum number of match candidate points. For the if-then logic system considering only normalized cross correlation, its threshold was set as 0.9. For the if-then logic system considering only scene geometry and convergence of a solution matrix, scene geometry's thresholds were set as in Figure 2 and convergence threshold as 0.001. For the if-then logic system considering scene geometry, convergence and correlation, scene geometry and convergence's threshold were set equal to the previous experiment and correlation's threshold was setup as 0.95. For the fuzzy logic system, its membership functions were shown in Figure 3. For the fuzzy logic system with correlation, its correlation threshold was set as 0.9.

Since JERS stereo pairs are both nadir looking and its time interval is short, stereo pairs are similar and not severely distorted. But, since SPOT stereo pairs are skewed and its time interval is long, stereo pairs are severely distorted and have many noises such as clouds and shadow.

As shown in the table, the system which considers only normalized cross correlation converges well for JERS images and its execution time is short but this measure is too sensitive to image distortion for SPOT images. The system based on the scene geometry and the convergence of a solution matrix do not converge well and its execution time is long. The system based on the scene geometry, the convergence of a solution matrix and the normalized cross correlation performs well. This system is not sensitive to image distortion and has an allowable execution time and match result. In the fuzzy logic approach considering only fuzzy logic can get a more match than the if-then logic one only considering scene geometry but take a longer time. However if correlation feature is added to fuzzy logic approach, its performance is improved. The percentage of match is larger and average iteration for match or fail is smaller.

Table 2. Comparison of match results

	JERS					**SPOT**				
	IF –A	IF -B	IF –C	FZ -A	FZ –B	IF -A	IF -B	IF -C	FZ -A	FZ -B
Match(%)	90.0	88.3	91.4	89.3	92.5	26.4	92.8	93.2	92.5	94.1
Average Time (msec/point)	12.3	32.7	20.9	43.4	27.8	35.0	40.5	34.6	54.2	46.2
Avg. Iteration for Match	1.084	8.259	5.127	8.506	5.289	1.264	12.376	10.194	12.751	10.565
Avg. Iteration for Fail	0.507	3.076	2.974	3.508	3.198	0.000	3.903	3.951	2.897	2.469

IF -A : Only Normalized Cross Correlation is considered

IF -B : Only Scene Geometry and Convergence of a solution matrix are considered

IF -C : Scene Geometry and Convergence of a solution matrix and Cross Correlation are considered

FZ -A : Only Fuzzy logic is considered

FZ -B : Fuzzy logic and Cross Correlation are considered

Based on these observations, it seems that the match quality measures based on the scene geometry and the convergence of a solution matrix and normalized cross correlation produce better match output. The match quality measures based on the fuzzy logic and correlation produce the best match output at the expense of computation time.

5. CONCLUSIONS

Generally, stereo matching using satellite images have many problems such as occlusions, photogrametric distortions and noises, etc.. Therefore in the adaptive least square correlation algorithm, naire use of match quality measures is not enough to generate an accurate DEMs. In this paper two approaches for accurate decision making are proposed and it is shown that the proposed approaches performed well.

For match quality determination, the scene geometry and correlation constraints can be used as an efficient quality measure and fuzzy logic system perform better than if-then logic system but take a longer time.

For more good match results, a patch-growing strategy can be considered. In this strategy, when match quality measures cannot decide at the last iteration whether this estimated match pairs are "success" or "fail", patch size is increased and matching is performed again. This strategy can get a more good result but must sacrifice significant execution time.

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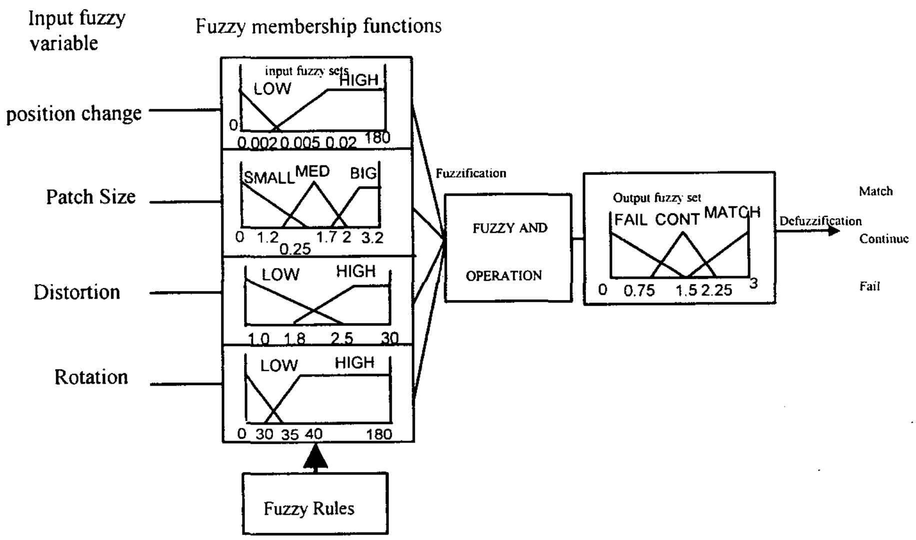

Figure 3. Fuzzy Logic Approach