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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSI*net*

Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Stereo Matching for Dynamic Programming on TRIZ

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Abstract: To solve the contradiction between matching precision and matching speed in stereo matching for dynamic programming, TRIZ theory was introduced. After locating the contradiction in 39 contradiction matrix and getting the solutions for the matrix, we get the TRIZ advice. With this guidance, we apply the pyramid algorithm on low resolution images and adopt bidirectional dynamic programming strategy on disparity space image to speed DP process and then the ground control points were attained. Experimental results showed that the proposed method in the paper has higher matching precision with less time.

Key words: TRIZ Theory, stereo matching, dynamic programming, ground control points

INTRODUCTION

Stereo matching has been concerned extensively with a wide range of applications such as virtual reality, 3D measurement and medical imaging (Haseeb and Khalifa, 2006; Zhixiang *et al.*, 2011; Jiang *et al.*, 2011). Among the techniques, stereo matching is the most fundamental. According to the type of the matching element, stereo matching can be divided into phase matching feature matching and region matching. There are some deficiencies in stereo matching: The phase singularities for the phase matching (Ito *et al.*, 2006; Zigh and Belbachir, 2010), the sparse disparity field for the feature matching (Yong-He *et al.*, 2011) and the stray points in the dense disparity map for the region matching (Yu *et al.*, 2011) and these restrict the applications in practice. Hence, many global optimization strategies have been introduced to attain matching results with high quality, including Dynamic Programming (DP) (Kopylov, 2008; Latha *et al.*, 2007; Lohmander and Limaiei, 2008; Zhu *et al.*, 2010), Graph Cuts (GC) (Bleyer and Gelautz, 2007) and Belief Propagation (BP) (Liang *et al.*, 2011; Yao *et al.*, 2012) methods. With the introduction of global optimization strategies, the quality of the disparity map has been obviously improved while the computation efficiency is slightly decreased (De-Maezhu *et al.*, 2011). The contradiction between matching precision and matching speed has been a pair of nasty problems even the technological bottleneck in

stereo matching. Meanwhile, it is very difficult to conceive new solutions from the conventional view in this field. TRIZ, Theory of Inventive Problem Solving in English, was conceived by Soviet scientists G.S. Altshuller. It provides a combination of tools and methods for problem solvers to access the good solutions to technical problems (Hsia and Huang, 2011). Based on the contradictions for specific problems, a generic problem-solving framework is been used to seek for instructive solutions as a suggestion.

In this study, a new stereo matching algorithm for dynamic programming on TRIZ is proposed. Here we analyze the main contradiction in stereo matching and then find the best solution to the problems.

THE METHODOLOGY: TRIZ

The methodology TRIZ (Theory of Inventive Problem Solving) was conceived by the former Soviet scientist G.S. Altshuller and his colleagues with painstaking effort since the year 1946. It has evolved into a system of several effective tools for problem analysis, understanding and solution in scientific, technological or administrative field. It includes Technical Evolution Theory, Inventive Principles, ARIZ (Algorithm for Inventive Problem Solving) and Standard Techniques, which are helpful for the designers to shorten the error correction process and inspire personal creative potential in problem solving.

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Improving parameters \ Depravation parameters		1	----	18	----	39
		Mobile weight		Illumination		Productivity
1	Mobile weight					
:						
20	Immobile energy			9, 2, 32, 35		
:						
39	Productivity					

Fig. 1: The 39 contradiction matrix

In the application of TRIZ, specific problems are first classified as administrative, physical or technical problems. For the technical problems, the 39 contradiction matrix and 40 inventive principles are the most accessible TRIZ tools.

In the contradiction matrix, 39 parameters that would be improved in the contradiction are arranged as the column titles and same 39 parameters are as the row titles to represent the performance would be deteriorated. At the cross is the inventive principle numbers suggested to solve the contradiction, which has been proved the most effective in practice. With the help of the matrix, more detailed solutions can be further proposed. The structure of the contradiction matrix is shown in Fig. 1.

As is shown in Fig. 1, in the design of lamps with the power saving mode and good lighting effect, the features to be improved and deteriorated are 20 (energy consumption) and 18 (illumination depravation) in the contradiction matrix, respectively. At the cross there are four accessible principles suggested to solve the conflict, including periodic action (9), extraction (2), property changes (32) and color changes (35). With the principle of periodic action on a device, the contradiction can be solved.

It can be seen that with TRIZ theory, the technical innovation problem will have reasonable theoretical evidence and shorter development cycle. In stereo matching, how to locate its inherent technical contradictions accurately has been a nasty problem, whereas TRIZ theory makes the appropriate and effective solutions possible.

In this study, we discuss the application of TRIZ on stereo matching for dynamic programming and present the whole process.

Stereo matching based on dynamic programming: Stereo matching algorithms based on Dynamic Programming (DP) are essentially a stereo matching method that integrates dynamic programming global optimization with region matching.

Region matching: The main task of region matching is to get the similarity by comparing the intensity statistic of

the reference image blocks and the ones to be matched. We can calculate the similarity by the formula as follows:

$$v_{match} = I_R - I_L \quad (1)$$

where, I_R and I_L are the intensity statistic for the blocks to be matched of the left image and the right image, respectively and v_{match} is the similarity for the blocks.

In the process of region matching, the best match is the one when the similarity v_{match} is minimized. Therefore, the best match we get only take account for the matching quality at specific points rather than at other points. That is, it is a local optimization strategy of stereo matching. Once it is occluded, there is no corresponding match in the left image and the right image and the error matching pixels arise, resulting in the un-continuity of the disparity map.

Dynamic planning optimization: DP algorithm implements the global optimization with a multi-stage decision-making mode. Let x_k and μ_k represent the state and decision for each stage, respectively and the value for the decision is evaluated by the cost function $V_{k,n}$, as the formula (2) shown:

$$V_{k,n} = \sum_{j=1}^n v_j(x_j, \mu_j) = v_k(x_k, \mu_k) + V_{k-1,n} \quad (2)$$

where, $v_k(x_k, \mu_k)$ is the cost for the kth step.

When the optimal $V_{k,n}$ is globally determined, the DP process is finished.

When DP is applied in stereo matching problem, the cost function $v_k(x_k, \mu_k)$ will become the form as Eq. 3:

$$v_k(x_k, \mu_k) = v_{data}(x_k, \mu_k) + v_{smooth}(x_k, \mu_k) \quad (3)$$

where, $v_{data}(x_k, \mu_k)$ is the matching cost function calculated from the formula (1), v_{smooth} is the occlusion function and will increase obviously in the occluded areas.

Given various factors such as the occlusion, the method can achieve global optimal stereo matching. However, influenced by the Markova property in DP, the disparity map obtained by this method has obvious fringe

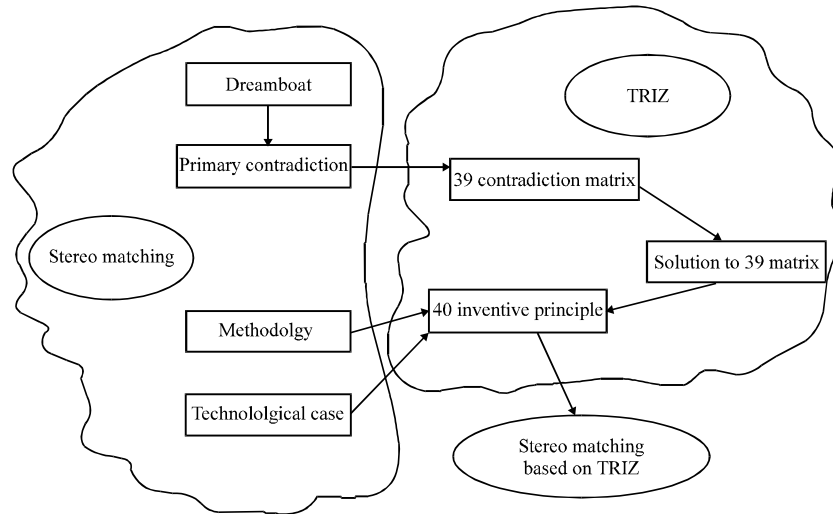


Fig. 2: Scheme of introducing TRIZ to stereo matching

effect, that is, mismatch at one pixel may propagate the error to the following pixels along the same epipolar. Thus, the technique of control points is introduced.

Refinement of the control points: The application of DP in stereo matching is to find a global optimal path in disparity map that consist of those pixels with lowest cost $v_k(x_k, \mu_k)$ during path finding process. If some of the pixels have already been acquired accurately, we can set $v_k(x_k, \mu_k)$ of the pixels to be the lowest, so the final optimal path will go through them. The pixels we use to find the path are called control points. In the case, even if the pixels along one epipolar cause mismatch, the refinement of the control points will make sure that the path formed by the following pixels will be still correct and thus significantly suppress the fringe effect.

We can see that the introduction of the control points have significantly improved the performance of DP stereo matching method. However, the implement of left-right consistency check technique we apply to acquire the control points is equivalent to twice the region matching process, resulting in more time consumption. The unbalance between the matching precision and matching speed is still not solved.

STEREO MATCHING ALGORITHM ON TRIZ

Framework of stereo matching on TRIZ: The scheme of introducing TRIZ to stereo matching is illustrated as Fig. 2.

Main contradictions and TRIZ solutions:

- Set the desired goal for stereo matching

The desired goal for stereo matching is to acquire the best matches or the dense disparity map within the least time.

- Locate the contradiction pairs in the 39 matrix

From the analysis above, we can see that the main problem in DP stereo matching is the contradiction between the matching precision and the matching speed. It can be transformed to the contradiction between the information loss and the speed by TRIZ theory. It can be located in the 39 contradiction matrix Fig. 3.

As is illustrated in Fig. 3, the contradiction in stereo matching can be solved by the innovative principles (13, 26) in TRIZ theory.

Get the solutions of the contradiction matrix: The 13th principle is to do it reverses and the given solutions are as follows:

- Do it in the other way round rather than offering the conventional solution
- Make part of the object or the external medium from movable to unmovable or the reverse
- Put the object upside down

The 26th principle is copying and the given solutions are as follows:

Improving parameters \ Depravation parameters		1	----	24	----	39
	Mobile weight			Information lossing		Productivity
1	Mobile weight					
:						
20	Speed			13.26		
:						
39	Productivity					

Fig. 3: Locating for the contradiction in stereo matching in the 39 contradiction matrix

- Use simple and cheap substitute instead of the complex and expensive or unavailable ones
- Use optical copies (image) instead of the object or the system and change the scale of the images if necessary
- Use infrared or ultraviolet rays instrument if available

Design of stereo matching algorithm on TRIZ: The given solutions to the contradiction pair in DP stereo matching on TRIZ is to do it reversely and copy it. Now taking them into account, we can reconsider stereo matching for dynamic programming as follows:

- The time for dynamic programming algorithm is mainly for getting the control points, in which process it use the left-right consistency checking technique
- If the consistency check is taken on the image with a smaller scale, the time cost will be greatly reduced (The 26th principle)
- Good dynamic programming optimization may also be achieved with less control points
- The dynamic programming optimization along two directions may greatly reduce the time cost and suppress the fringe effect to some extent (The 13th principle)

Application of the innovative principles on stereo matching: Instructed by TRIZ theory, here we make two improvements for DP stereo matching.

Firstly, to reduce the time cost for calculating the control points, we try to get the control points on small images or under solution images. Here the pyramid algorithm Fig. 4 is need.

In the pyramid, there are 3 layers of image, of which the original image is in the first layer. The resolution gets lower as the number of the layer rise. We take the image in the third layer or the second pyramid image (about 1/16 of the scale of the original image) as the input for the consistency check and thus get enough control points to suppress the fringe effect in a very short time.

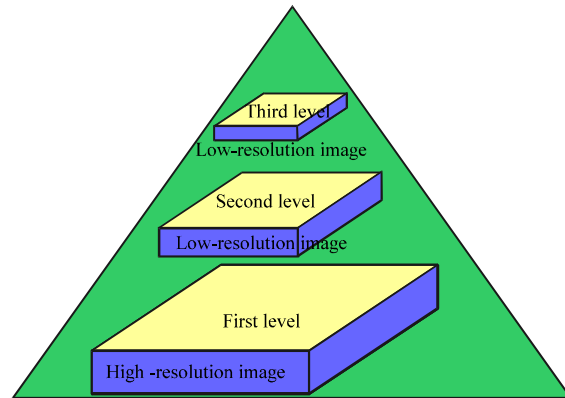


Fig. 4: Multilevel resolution images built by the pyramid algorithm

Furthermore, to speed up the dynamic programming process, we conduct the optimization along the two directions for each epipolar Fig. 5.

Figure 5 describes the process of finding the path on a disparity space image. It initiates from the starting points along two directions and goes along two different paths. In this way the search speed is decreased and the fringe effect is suppressed obviously.

EXPERIMENTAL RESULTS

To verify the proposed algorithm, we carry on experiments on a synthesis stereo image Fig. 6a Tuskuba. The real disparity map is as show in Fig. 6b. The results from the DP stereo matching and the proposed method on TRIZ are as shown in Fig. 6c and d, respectively. The original resolution of the test image is 384×288 and the platform is a self-research test platform for the stereo matching algorithms.

From the result (Fig. 6), it's easy to see that:

- The disparity map we got with the two algorithms is preferable and the information of the original scenes that is identical with the real disparity map has been reserved. By comparison, the later with the proposed method is closer to the real disparity map

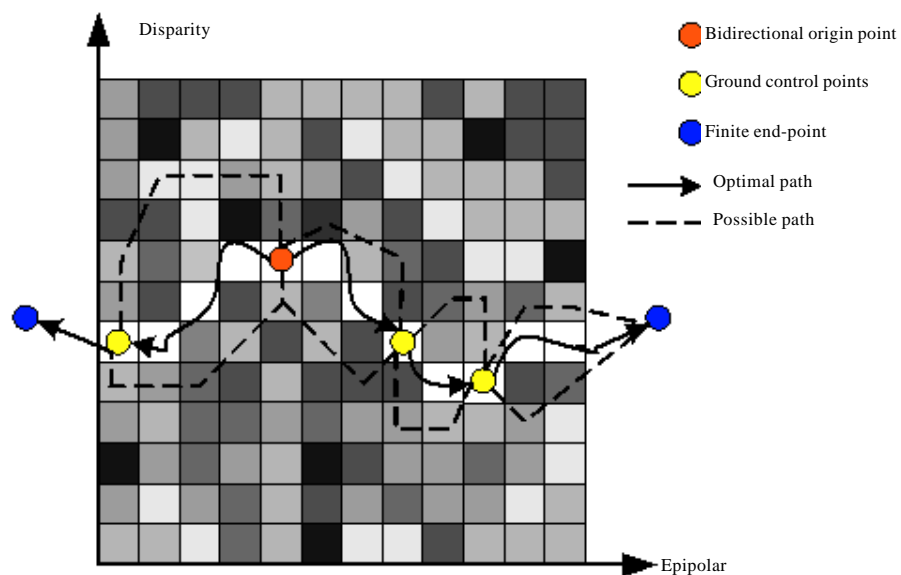


Fig. 5: Bidirectional dynamic programming diagram

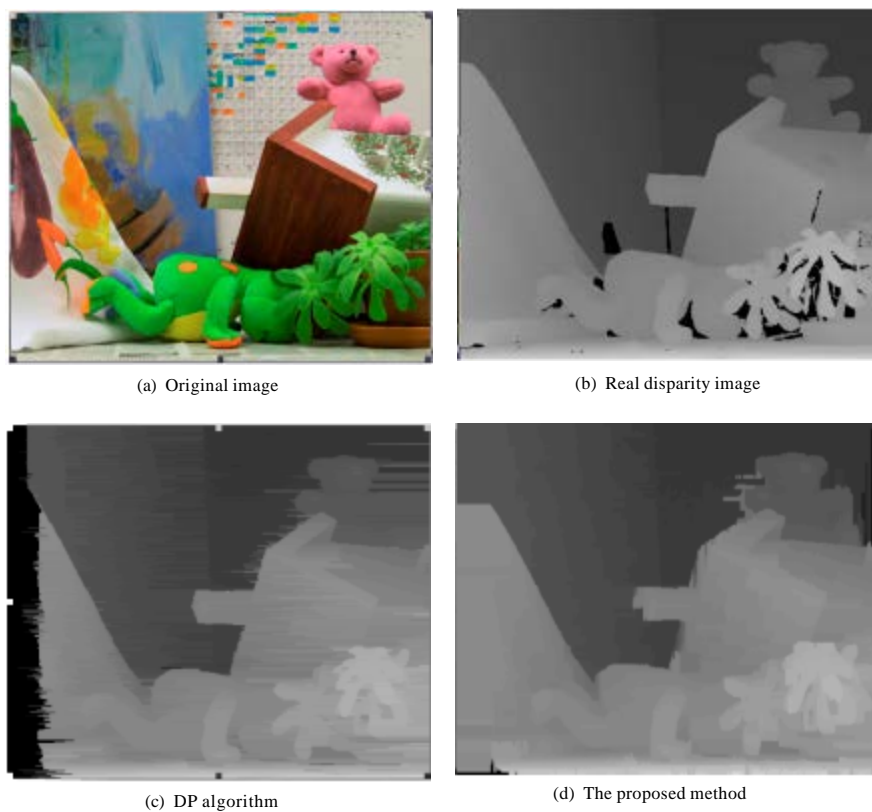


Fig. 6(a-d): Experimental result

Table 1: The quantitative comparison of the matching performance

Parameter	Stereo matching based on DP	Stereo matching based on TRIZ
Precision	88.5%	92.4%
Time (in sec)	590	173

- There are some obvious stripe flaws in the former map, while it's significantly improved in the later one with the proposed method

Figure 6 gives the qualitative comparison results of the two methods and the quantitative comparison is illustrated in Table 1.

From the data in Table 1, we can conclude that the proposed method in this paper can improve the matching precision and reduce the consumption time at the same time. By comparison with DP stereo matching, the time has decreased by about 60%. It lies in that the new algorithm takes the images with low resolution as the input for getting control points and implements the global optimization with bidirectional dynamic programming strategy.

CONCLUSIONS

The contradiction between matching precision and matching speed has been the technological bottleneck in stereo matching and it is very difficult to conceive new solutions from the conventional view in this field. In this paper we first introduce TRIZ theory to locate the main technical contradictions in DP stereo matching and get the related TRIZ solutions. Then calculate the control points with the pyramid algorithm on low resolution images and adopt the bidirectional dynamic programming strategy to speed the DP process. Finally the contradiction is well solved. The experimental results demonstrate the proposed method in the paper can keep high matching precision and significantly reduce the execution time.

ACKNOWLEDGEMENTS

This research was supported by the Scientific and Technological Project of Education Department of Heilongjiang Province with grant number (12521083), 2011 Postgraduate Innovation Science Fund Project of Heilongjiang Province with grant number (YJSCX2011-053HLJ) and Undergraduate Innovation Experiment Project of Harbin University of Science and Technology.

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