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A Survey on Stereo Matching Techniques for 3D Vision in Image Processing

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Abstract

Extraction of three-dimensional scene from the stereo images is the most effective research area in the field of computer vision. Stereo vision constructs the actual three-dimensional scene from two stereo images having different viewpoints. Stereo matching is a correspondence problem, that means it ascertains which part of image corresponds to which part of another image ,where variations inside two images is due to the movement of camera or elapse of time. Many stereo matching algorithms have been developed in order to construct the accurate disparity map. This paper presents a review on various stereo matching techniques. The comparison among existing techniques has clearly shown that none perform optimistically every time. This review has shown that the existing methods in stereo matching involve median filtering. But median filter is not effective for high density of noise. Besides mean-shift segmentation is being used for disparity refinement in existing methods, which can be enhanced by using improved mean-shift segmentation, available now days. In addition, guided filter has been used by many algorithms, but this can be replaced by joint trilateral filters.

Index Terms: Stereo Matching; Disparity Map; Guided Filter.

1. Introduction

Digital Image Processing is one of the key fields of the digital signal processing that involves the use of methods or algorithms to manipulate the digital image. A digital image is two-dimensional function of x and y i.e. f(x, y), where x and y are spatial coordinates and the rate of amplitude f at any point in the plane is known as gray-level or intensity of the image at that point. The amplitude values of f in digital image are finite and discrete quantities. Digital image processing employs the principles from various fields like Optics, Mathematics and Physics. In fact, fields that use images include Computer Graphics, image processing and

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computer vision. Computer graphics deals with the creation of images. Image Processing deals with enhancement or other manipulation of the image – the result of which is usually another images and Computer Vision deals with analysis of image content. The various operations performed on the images are enhancement, restoration, analysis, compression and synthesis.

Image synthesis is the essential image processing task that produces images based on the model of a scene. It uses some description of the image in order to create an image. Computer graphics, text patterns and image noise are the various images that can be synthesized. The fields under the images synthesis are visualization and stereo matching. The work in this paper focuses on stereo matching aspect of computer vision.

In stereo reconstruction, we attempt to produce the dense depth maps from uncalibrated images, which in turn is among the key as well as challenging job in computer vision. It serves as an essential task in numerous 3D applications, for example, the fields of virtual reality, robot navigation and machine vision [3]. It was well-known from the primary inquiries that depth will be perceived by simply us using the differences inside appearance relating to the left as well as the right eye [4].Stereo matching is the process of taking two or more images along with estimating 3D model of a scene by finding matching pixels images and transforming 2D positions to 3D depths. Stereo matching is a correspondence problem, i.e. the problem of ascertaining which part of image corresponds to which part of another image, where differences in the two images is due to the movement of camera or elapse of time .Stereo matching algorithms are widely-used to obtain the correspondence points between two or multi-view images [3].The correspondence methods can be classified into two classes: those producing the dense output and the ones producing the sparse end results. Most of the algorithms used today focus on dense correspondence [4]. It's been observed the process stereo matching will be decomposed inside four measures:

(1) Matching cost calculation
(2) Cost aggregation
(3) Disparity computation
(4) Disparity refinement [3].

According to detailed review [1], stereo related algorithms are generally broken down into two main classes: global and local algorithms.

Local or the window-based method trade accuracy for speed [6].These algorithms compute disparity for a given point based on intensity values in just a finite as well as pre-defined window. These methods are efficient but they are sensitive to the occluded regions and some other ambiguous regions. These kinds of procedures belong to a few wide-ranging classes: block matching, gradient methods and feature matching [51].

Global methods are time consuming but very accurate. These methods explicitly incorporate smoothness assumption into an energy function and aims to minimize the cost function. They formulate the problem as the energy-minimization framework. The disparity maps are determined by getting a solution that diminishes the global energy [5].Even though global methods produce best results; almost all the global algorithms use image segmentation to ensure the sharp edges [7]. The smoothness term that exists in the global algorithms makes the disparity smooth everywhere; this results in poor detection of the object boundaries. It is known that the quality of edges influences the disparity map. So this problem needs to be addressed, a method based on guided filter was introduced by Zhou and Hou [4] to resolve this issue. But this method uses median filter which is not effective for high density of noise.

This paper represents a taxonomy regarding recent stereo-matching algorithms in order to compare the individual algorithms design decisions. Section 2 reviews the different stereo matching techniques and classifies them on the basis of some issue that is being resolved by particular technique. This section summarizes the various algorithms with the help of the table that defines the algorithm category, issues, benefits and limitations of the various techniques. Along with this comparative analysis, various challenges have been described in Section 3 .Section 4 compares some recent approaches for stereo matching on the basis of some parameters.

2. Stereo Matching Techniques and Related Work

This section provides a review of the various algorithms available in the field of stereo vision. In order to represent an exhaustive survey of algorithms, a categorization scheme for such algorithms is presented. The study of the stereo matching problem has continuous evolution. The problem of the stereo correspondence concentrates on matching of points, or any other primitive, between a pair of images of the same scene. Considering the stereo system setup for being calibrated, these matching lie on similar horizontal line. After that disparity is calculated as the distance of these points when one of the two images is projected onto the other. Disparity map is comprised of the disparity values for all the image points. After solving the correspondence problem, the depth of the scene can be estimated [6]. Stereo related algorithms are generally broken down into two main classes: global and local algorithms.

One of the core problems of the stereo correspondence is to get an accurate dense disparity map. Techniques that produce dense end result gain popularity for the reason that computational power grows. A framework has been provided in order to categorize the various two-frame dense algorithms [1]. According to this review, dense algorithms are divided into two categories that are local and global algorithms. The particular categorization of various algorithms is actually presented inside next section.

2.1 Methods that are Sensitive to Depth Discontinuity

Depth discontinuity is the one of the important issue in stereo matching. It arises when matching window cover the pixels that lie over different depth Methods that are sensitive to depth discontinuities basically include area-based correspondence methods. Many traditional methods like block matching blur the depth edges. Block methods computes disparity at a point in an image through coordinating a small area about that given point with a sequence of small regions removed from the other stereo image. Block matching uses three metrics i.e. correlation, rank and intensity difference [51]. Muhalmann *et al.* [28] represents an algorithm that uses SAD correlation metric for color images. This method utilizes left to right reliability check in order to uniqueness difficulties. It can achieve high speed and reasonable quality. Stefano *et al.* [29] presented a fast stereo matching algorithm called Single Matching Phase (SMP).This proposed method rejects prior matches once better ones are detected as it is based on the uniqueness constraint. This method produces reliable dense disparity maps that can be implemented in real-time using a PC. Binaghi *et al.* [30] represents a more advance method that uses zero mean normalized cross correlation i.e. ZNCC metric that is integrated with the neural network. For each support region, this neural network is decided on the basis of proper window shape and size. Gradient-based methods [52], tends to compute small local disparities among two images by forming a differential equation relating movement and image brightness. This method will depend on the assumption that this image brightness of a point in the scene is usually constant throughout two various views [51].

2.2 Methods That Handles Depth Discontinuity

The aforementioned methods usually are sensitive in order to depth discontinuities and elements of uniform texture from the image. You can find methods often known as Feature dependent methods that solve this matter by constraining the elements of support in order to specific functions in photos like edges [51]. Dhond and Aggarwal [53] represent an overview on the actual feature dependent algorithms. A pair of classes regarding feature-based techniques includes segmentation matching [4] along with hierarchical feature based method. Birchfield along with Tomasi [42] have got proposed an algorithm in order to detect discontinuity throughout stereo match images. This offered algorithm matches individual pixels throughout equivalent scanline pairs while enabling occluded pixels to incomparable, and subsequently spreads the knowledge between scanlines by way of a quick postprocessor.

2.3 Global Optimization Based Methods

Global methods produce explicit smoothness assumptions and solve the optimization difficulty. Global approaches perform a bunch of their work during disparity computation and quite often skip this aggregation step. Global approaches produce exact results but they are very frustrating. They are generally iterative inside nature, so that they are computational demanding also. Torra along with Criminisi [34] presents a framework which involves the integration associated with partial information about disparities, for instance known surfaces inside the scene. This process combines the final results from edges and matching algorithm to impose constraints and offers fully automatic stereo system with quicker runtime. The different global strategies are referred to below:

- *Dynamic Programming*

Dynamic programming is really a mathematical method that reduces the computational complexity of optimization problems simply by decomposing these individuals into more compact and much easier sub problems [51]. Veksler [17] re-examine the use of dynamic programming in stereo correspondence problem by utilizing it to some tree structure instead of individual scanlines. The offered algorithm is actually a global optimization method, as disparity estimates in each pixel depends on the inequality pixels at all the other pixels. The experimental results on benchmark Middlebury datasets have shown that the algorithm is fast and can produce better results.

- *Graph Cuts*

The major drawback of dynamic programming is its inability to firmly incorporate the two horizontal as well as vertical continuity demands. An alternative approach that exploits these constraints is usually to cast this stereo coordinating problem seeing that that of picking out the maximum flow within a graph [51]. Daolei and Lim[3] offers an formula of segment-based stereo matching for extracting depth map from stereo image pair employing graph cuts. The proposed algorithm formulates a new energy function with the use of graph cuts to be able to label each and every segment. Finally, depth information is extracted from the last disparity map. This method uses plane to match the region with regular disparities and is effective in improving the existing methods.

- *Belief Propagation*

Sun and Zheng [2] presented a method to resolve the stereo matching problem by means of Belief propagation. It represents the challenge of stereo matching as a markov network and this network contains three coupled markov random fields. This proposed work further extends the two-view stereo to multi-view stereo. Image segmentation can be integrated together with basic stereo model that is proposed in this paper as a soft constraint in order to produce better results. Wang *et al.* [12] extends the traditional belief propagation method that is not very effective for solving the stereo matching, by utilizing the Census measure and pixels-based intensity measure into the data term of belief propagation.

2.4 Methods that Handles Occlusions

One of the several important problems that need to be handled in stereo matching process is occlusion. Generally speaking, occluded pixels in one image mustn't be matched while using the pixels inside other image. Luo *et al.* [8**]** introduces the disparity consistency in order to handle the occlusions in complicated scenes, which provide the benefit of integrity along with illusion sensitivity. A method while using the disparity

uniformity is displayed. All difficulties are put in the disparity consistency and in addition they exploit how pixels are represented inside disparity space and the nature of imaging and occluding. Here we are using immediate clue involving imaging along with occluding, that is why, and integrity and illusion sensitivity will be achieved.

Summary of Major Stereo Correspondence Approaches

This section summarizes the methods reviewed above by explaining the benefits, issues and limitations of various stereo matching techniques. The summary is represented in the following table.

Table 1. Summary of major Stereo correspondence approaches

Stereo Correspondence approach	Algorithm Category	Matching cost	Issues	Benefits	Limitations
Muhlmann *et al.*[28]	Local	Sum of Absolute Difference (SAD)	Uses left-to right consistency check and uniqueness constraint.	High speed & accuracy. Detect occlusions.	Does not work well for images with high texture.
Stefano *et al.*[29]	Local	Sum of Absolute Difference (SAD)	Based on left-to-right matching phase & incremental calculations	Fast and Suitable for real time applications	Does not take advantage of filtering.
Binaghi *et al.*[30]	Local	Zero mean normalized cross correlation(ZNCC)	ZNCC integrated with neural network	Solve the global matching problem	Not suitable for real time application
Ogale and Aloimonos[31]	Local	Absolute intensity difference	Consider the shape of object depicted	Minimum segmentation	Does not involve filtering.
Yoon *et al.*[32]	Local	Correlation based	Consider the properties of half-occluded areas.	Minimum systematic errors and increased performance	Do not provide good results under adverse environment.
Yoon *et al.*[33]	Local	Adaptive support weight	Adjust support weight of a window in order to reduce image ambiguity.	Does not involve initial disparity estimation and is highly robust.	Expensive
Torra and Criminisi[34]	Dense	Squared difference	Uses dynamic programming	Faster run time and increased accuracy	Do not provide good results under adverse environment.
Bleyar and Gelautz[35]	Global	Sum of Absolute Difference (SAD)	Uses planer layers to describe the scenes	Provides high quality results	Does not use superior edge detection operators.
Veksler[36]	Sparse	Absolute difference	Use graph cut for dense feature extraction	Robust and does not require parameter tuning.	Does not work well with textureless and occluded portions.
Gong and Yang[37]	Sparse	Squared difference	Based on reliable dynamic programming	Provides efficient and better results.	Not suitable for real time implementations.
Zitnick and Kanade[38]	Cooperative	Normalized correlation	Detect occlusions	Improves efficiency	Not suitable for real time implementations.
Sun *et al.[*39]	Global	Squared difference	Formulate the problem as markov random fields	Improves result	Can be improved with generalized approach.
Komolgorov and Zabbih[40]	Global	Squared difference	Works well for detecting occlusions.	Fast approximation algorithm	Need to be generalized
Birchfield and Tomasi[42]	Dense	Shifted absolute difference	Detect depth discontinuities	Fast computation	Brittleness of algorithm needs to be replaced with principle approach.
Boykov *et al.*[41]	Global	Squared difference	Solves the problem of minimizing energy functions	Effective for image restoration, stereo & motion.	Do not deal with occlusions.

Boykov *et al.*[43]	Dense	Threshold absolute difference	Uses an arbitrarily shaped connected window.	Can be applied to image restoration problems and Linear runtime.	Does not use superior edge detection operators.
Ishikawa and Geigar [44]	Global	Squared difference	Computes disparity by solving global optimization problem.	Polynomial runtime and gives valid results.	Does not involve filtering.
Scharstein and Szeliski[45]	Global	Robust square difference	Based on diffusion	Outperforms the existing techniques	Does not involve filtering.
Gutiarrez and Marraquin[46]	Global	Robust square difference	Based on Bayesian approach.	Provides reliable disparity estimation in untextured regions.	Does not involve filtering.
Zhou and Hou [4]	Global	Sum of Absolute Difference (SAD)	Maintains discontinuity of object edge and continuity of non-edge area	It provides a high accurate and superior algorithm.	Not efficient for high density of noises.

3. Various Challenges In Stereo Correspondence Problem

This section summarizes some important challenges in the problem of stereo vision. Though a large number of methods have been developed for calculating disparity so far, the problem is still ill-posed and a satisfactory solution has not yet been reached. Major challenges are:

- *Photometric Variations*

One of the major challenges in stereo correspondence problem is absence of the photo consistency between the two stereo images to be matched. This inconsistency is caused due to the fact that the intensity and the color vary according to the viewpoint. These intensity and the color variations can be caused by the different camera sensor characteristics. So this issue is required to be solved in order to obtain accurate matching results [53].

- *Untextured regions and repetitive regions*

Other important challenge in stereo matching is to uniquely match the two points. This is caused by the large regions with the constant luminance. Muhlmann *et al.* [28] provides an algorithm that does not work well with regions of high texture. The proposed method in this paper uses SAD correlation and left-to-right consistency check.

- *High Density of Noise*

Noise is the outsider element of image that causes variations in the image quality like brightness, color intensity etc. Mostly all the existing methods in the stereo matching uses median filter ,which do not produce good results if density of noise is high[4]. So the problem of high density of noise needs to be addressed in order to get accurate matching results. Youlian and Cheng [24] present an improved median filter algorithm in order to solve the contradictions of the standard median filter algorithm. The proposed algorithm combines the median filtering with the averaging filtering.

4. Parameterized Comparison of Stereo Matching Techniques

Here, we present a parametric comparison of various stereo matching algorithms. The table shown below clearly represents the various parameters of the methods and the performance that is being enhanced by that

method. It is clear from the table that the some methods are linear [4] that works step-by-step. Some methods preserve the edges while others don't. There are some methods that work pixel by pixel. On the other hand some methods operate on pixels under a specified window and are called window based methods [5].

Table 2. Parameterized Comparison

Author	Parameters / Method Used	Noise Reduction	Step-by-step execution	Edge Preservation	Pixel/window Based	Performance enhanced
Zhou and Hou(2015) [4]	Segmentation and guided filter	Yes	Yes	Yes	Window	Improved accuracy
Yang *et al.*(2014)[5]	Adaptive guided filtering	Yes	Yes	Yes	Window	Improve efficiency of the disparity maps
Daolei and Lim(2011) [3]	Segment-based Graph cuts	No	No	Yes	Pixel	High quality dense disparity map
Veksler (2005)[17]	Dynamic programming	No	No	Yes	Pixel	Improve efficiency
Luo *et al.* (2002)[8]	Disparity consistency	No	Yes	Yes	Window	Integrity and illusion sensitivity.
Sun and Zheng(2003) [2]	Belief propagation	No	Yes	No	Window	Improves result
Elias (2007)[18]	Homographic transformation	Yes	Yes	Yes	Window	Outperforms non - homographic transformations
Zhang *et al.*(2009)[22]	Edge detection and Gaussian disparity distribution model	No	Yes	Yes	Window	Less disparity fluctuations, sharped object boundaries.
Daolei and Lim(2011) [3]	Segment based approach using Graph cuts	No	Yes	No	Window	Robust disparity plane fitting and a new energy function.
Han *et al.* (2013)[15]	Gradient based method using guided filter	Yes	Yes	Yes	Window	High robustness and improved performance.
Cheng *et al.*(2013)[11]	Global edge constraint	No	No	Yes	Pixel	Improved efficiency and accuracy
Cheng *et al.*(2015)[9]	Cross-trees, edge and superpixel based cost aggregation	No	Yes	Yes	Window	Outperforms tree based non-local algorithms

5. Conclusions and Future Scope

The comparison among the existing techniques has clearly shown that the major challenge in stereo correspondence problem is the absence of photo consistency between the images to be matched. The reason behind this inconsistency is due to the fact that the intensity and the color vary according to the viewpoint.

These intensity and the color variations can be caused by the different camera sensor characteristics. So this issue is required to be solved in order to obtain accurate matching results. Many researches have been carried out to overcome this challenge. Un-textured regions and repetitive regions are other important challenge in stereo matching. It is required to uniquely match the two points. This is caused by the large regions with the constant luminance. To overcome the challenges of the existing literature in near future we will propose a hybrid model for 3D stereo vision which will integrate joint trilateral filter with some well-known fuzzy based segmentation techniques. The overall objective is to improve the disparity map for 3D image reconstruction.

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