Stereo Matching on Low Intensity Quantization Images

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Abstract

This paper addresses the problem of how the image intensity quantization affects the stereo matching algorithms. We compute the disparity using the stereo images represented by various intensity quantization levels. It is shown that, depending on the stereo matching algorithms, even the image pairs with low intensity quantization are able to produce fairly good disparity results. Experiments on Middlebury datasets demonstrate that the global algorithms such as GC and BP are suitable for stereo matching using low intensity quantization images.

1 Introduction

Stereo matching is considered as one of the most challenging and unsolved problems in computer vision. Due to the broad applicability to many application domains such as multimedia, 3D display and robotics, it has attracted the researchers' attentions for over several decades. In the past few years, a fairly large amount of computational algorithms has been proposed to cope with the stereo matching problem [3]. The objective is usually to obtain an accurate disparity map from a pair of images. Based on the well-studied camera and scene geometry, the 3D structure of the scene can then be derived using the image formation parameters.

In the early development of stereo algorithms, the block matching techniques exploiting local constraints have been extensively investigated [4]. Recent advances on stereo matching, in contrast, are mostly based on the energy minimization framework for global optimization [11]. Some well-known techniques include graph cuts [5], belief propagation [10], and dynamic programming [6], etc. Those methods and the variations have been shown to provide significant disparity estimates on the Middlebury stereo evaluation datasets [8]. However, the computational cost is fairly high, in terms of processing time and data allocation.

In this work we address the problem of stereo matching using the images created with various intensity quantization levels. While the images represented by more bits per pixel contain more detailed texture for stereo matching, processing the low intensity quantization images generally requires less memory usage. Thus, it is interested to know whether the full intensity depth of the images is required for stereo matching algorithms to obtain good disparity results. The idea is similar to the analysis of perceived depth quality if compressed stereo images are used [9].

To the best of the authors’ knowledge, the effects of image intensity quantization on stereo matching algorithms have never been presented before. It is shown in this paper that the quality of disparity estimates does not drop significantly when the incomplete information with low intensity quantization is provided. Thus, the data usage overhead can be reduced by taking the low bit-rate image pairs as input for the hybrid recursive matching strategy [1]. Furthermore, the trade-off between performance and data bit-rate for stereo matching is also worth investigating.

We validate the feasibility of stereo matching with low intensity quantization images, and evaluate the performance in terms of bad matching rate and image bit-rate. In addition to the applicability on 8-bit images (per channel), the proposed technique will also greatly benefit the stereo matching on the images with higher bits per pixel. In this paper we are interested in the relationship between the data bit-rate and stereo matching results. Thus, it is not our primary objective to improve the computation cost.

2 Low Bit-Rate Matching

Given a pair of images for stereo matching, most existing algorithms take the image intensity values as
raw data input for disparity computation. For a general grayscale image with 256 quantization levels, each pixel is represented by an 8-bit integer. Stereo matching is carried out on the images with full 8-bit intensity depth. However, as the number of bits per pixel increases for high quality image representation, it might be unnecessary or impractical to perform stereo matching using the full intensity depth. The investigation on how to use the reduced intensity depth for stereo matching has become an important issue. More precisely, if an \( n \)-bit stereo image pair is given, is it possible to derive a comparable or better disparity map using only the \( m \)-bit information where \( m < n \)?

To deal with the problem of stereo matching on the image pairs obtained from various quantization levels, we investigate a stereo matching technique based on a variate bit-rate image representation. For an \( n \)-bit grayscale image, the intensity value of any pixel can be represented by

\[
I = \sum_{i=1}^{n} a_i \cdot 2^{i-1}
\]  

(1)

using bit-plane decomposition, where \( a_i \) is the \( i \)-th bit of the intensity value. If the image is to be approximated with an intensity depth less than \( n \) bits, then the higher order bits should be used since they contain more significant information. Based on these facts, the variate bit-rate representation for a \( k \)-bit image approximation is given by

\[
I(k) = \sum_{i=n-k+1}^{n} a_i \cdot 2^{i-1}
\]  

(2)

where \( k = 1, 2, \ldots, n \). An image represented by \( I(k) \) can be thought as the one with \( 2^k \) quantization levels on the intensity value.

Using the image representation given by Eq. (2), a variate bit-rate stereo matching technique can be carried out for disparity computation from a pair of \( n \)-bit images. Instead of the full intensity depth, we can use only the \( k \) most significant bits of the \( n \)-bit image pair for stereo matching. If the derived disparity estimate does not meet some predefined criteria, then stereo matching is performed again on either the entire or certain parts of the image using \( I(k+1) \), the \( k+1 \) most significant bits of the pixels. This process may continue until the disparity is satisfactory. It is clear that the worst case happens when \( k = n \) and the entire image is processed. In this case, the result is identical to the one computed from the original \( n \)-bit image pair.

One major advantage of the proposed variate bit-rate stereo matching technique is its capability on bitwise processing of the image data stream. Once the image pair of bit-plane \( n \) is obtained, stereo matching can be performed immediately for disparity computation. The quality of disparity estimates can then be gradually improved by providing lower order bit-planes “upon request”. Thus, the data rate for disparity computation in terms of the number of bits per pixel is generally less than \( n \) when processing the \( n \)-bit images. Furthermore, the framework using the variate bit-rate image representation does not involve any specific stereo matching algorithms.

3 Implementation and Discussion

In this section, we describe the implementation and experiments of the stereo matching technique using the images with various intensity quantization levels as input. Two local algorithms—sum of absolute difference (SAD) and normalized cross correlation (NCC)—are used for disparity computation.
(SAD) and normalized cross correlation (NCC), and two global algorithms—graph cut (GC) [2] and belief propagation (BP) [10] are used to analyze the effects of intensity quantization on stereo matching. Eight standard Middlebury stereo datasets, Tsukuba, Venus, Teddy, Cones, Bowling, Lampshade, Midd and Wood are used in our experiments [7]. The evaluation details on the percentage of bad matching pixels versus the pixel bit-rate are presented using the Tsukuba dataset.

To compare the performance of stereo matching on different bit-rate image pairs, bit-plane slicing is first used to generate the image pairs with a fixed bit-rate. The four stereo matching algorithms are then carried out to compute the disparity maps associated with the fixed bit-rate image pairs. Figure 1 shows the disparity estimates of Tsukuba dataset, from the top to the bottom, derived using the image pairs with $2^2$, $2^3$, $\cdots$, $2^8$ quantization levels. The percentage of bad matching pixels compared to the ground truth disparity is illustrated in Figure 2 for the stereo matching algorithms performed on different bit-rate image pairs.

As shown in Figures 1 and 2, the local algorithms SAD and NCC give poor disparity estimates for low bit-rate stereo matching. The mismatches are mainly due to insufficient quantization in image intensity. However, the performance is improved as the image bit-rate increases. The SAD and NCC curves in Figure 2 indicate that the disparity map derived from the 6-bit image pair is almost the same as those derived from higher bit-rate image pairs (in terms of the percentage of bad matching pixels). This result suggests that, for the local matching algorithms, the images with less quantization levels can still give comparable performance with the 8-bit images.

For the global algorithms GC and BP, it is surprising that even low bit-rate image pairs give good disparity estimates, as shown in Figures 1(c) and 1(d). The global optimization stage provides the additional smoothness criterion on the disparity results. Moreover, Figure 2 illustrates that the performance gain is not guaranteed when the image bit-rate is increased for stereo matching. The disparity maps obtained from low bit-rate image pairs using the global matching algorithms can outperform those computed using the local matching algorithms with high bit-rate image pairs.

The evaluation of fixed bit-rate matching is also carried out on other stereo datasets. The percentages of overall bad matching pixels for eight Middlebury stereo datasets, Tsukuba, Venus, Teddy, Cones, Bowling, Lampshade, Midd and Wood obtained from different stereo matching algorithms are tabulated in Table 1. The results illustrate that the above discussions on local and global algorithms are also applicable to various types of images. Figure 3 shows some of the disparity maps obtained using 8-bit (the odd number columns) and 6-bit (the even number columns) images with SAD, NCC, GC and BP algorithms. There is no clear difference between the results obtained from 8-bit and 6-bit input images for the GC and BP algorithms. For the SAD and NCC algorithms, 6-bit input images tend to generate additional mismatches in the flat image regions.

Table 1. The averages of bad matching pixels (in percentage) obtained by performing fixed bit-rate matching on 8 Middlebury stereo datasets using SAD, NCC, GC and BP algorithms.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>SAD</th>
<th>NCC</th>
<th>GC</th>
<th>BP</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-bit</td>
<td>55.5%</td>
<td>45.1%</td>
<td>53.7%</td>
<td>48.7%</td>
</tr>
<tr>
<td>7-bit</td>
<td>57.4%</td>
<td>55.1%</td>
<td>53.4%</td>
<td>49.7%</td>
</tr>
<tr>
<td>6-bit</td>
<td>58.3%</td>
<td>57.6%</td>
<td>54.9%</td>
<td>49.4%</td>
</tr>
<tr>
<td>5-bit</td>
<td>59.9%</td>
<td>60.4%</td>
<td>57.3%</td>
<td>51.0%</td>
</tr>
<tr>
<td>4-bit</td>
<td>62.2%</td>
<td>64.1%</td>
<td>56.1%</td>
<td>51.7%</td>
</tr>
<tr>
<td>3-bit</td>
<td>68.2%</td>
<td>70.2%</td>
<td>59.5%</td>
<td>54.2%</td>
</tr>
<tr>
<td>2-bit</td>
<td>76.6%</td>
<td>78.1%</td>
<td>65.6%</td>
<td>59.4%</td>
</tr>
</tbody>
</table>
Figure 3. The results obtained using SAD, NCC, GC and BP algorithms for Cones, Teddy, Venus and Bowling datasets. The left and right columns are the disparity maps computed from 8-bit and 6-bit input images, respectively.

4 Conclusion

In this paper, the problem of how the image intensity quantization affects the stereo matching algorithms is addressed. We have computed the disparity using input images with various intensity quantization levels. It is shown that even the image pairs with low intensity quantization are able to produce fairly good disparity results. Experiments on Middlebury datasets demonstrate that, even with low intensity quantization levels, the global algorithms such as GC and BP are able to give good results compared to the conventional full bit-rate matching.

References


