A Graph-Based Approach to Optical Flow Estimation

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Abstract — *A vector field which describes the apparent motion between two images of a video sequence is commonly known as optical flow. The accurate estimation of these displacement vectors is crucial for several computer vision problems, including video object segmentation and tracking. In this work we propose a new algorithm for computing a dense optical flow field that tackles the inherent problems of optical flow algorithms, namely the estimation of flow vectors in regions of low texture as well as the precise identification of motion boundaries. We try to overcome these problems by taking advantage of color segmentation and robust optimization via graph-cuts. Experimental results show the good performance and robustness of our method.*

I. INTRODUCTION

The task of a motion algorithm is to automatically compute a dense field of two-dimensional displacement vectors that transform one image into the next in an image sequence. This array of vectors is commonly referred to as optical flow. The accurate estimation of optical flow plays a key-role in several computer vision problems, including motion segmentation, 3D scene reconstruction, robot navigation, video shot detection, mosaicking and video compression.

Major challenges in optical flow estimation are twofold. Firstly, matching often fails in the absence of discriminative image features that can be uniquely matched in the other frame. This is the case in untextured regions as well as in the presence of texture with only a single orientation (aperture problem). Secondly, a pixel's matching point can be occluded in the other frame. Those occlusions often occur at motion discontinuities, which make it specifically challenging to precisely outline object boundaries. Nevertheless, accurate identification of motion discontinuities is often required for applications such as motion segmentation. A large number of optical flow algorithms fail in this respect, since the fact that there are occlusions is simply ignored. In this work, we propose an algorithm that explicitly addresses those problems taking advantage of two recent developments in the computation of dense correspondences, which are robust optimization via graph-cuts [1, 2] and the incorporation of color segmentation [3].

II. ALGORITHM

The proposed algorithm starts by segmenting the reference image into regions of homogenous color. The color segmentation incorporates the assumption that the motion inside regions of homogeneous color varies smoothly and motion discontinuities coincide with the borders of those regions. The affine motion model is used to describe the motion inside a segment. To initialize the model parameters, we estimate a sparse set of correspondences. Layers are extracted from the initial segments, which represent the dominant motions likely to occur in the scene. Every color segment is then assigned to exactly one layer. This assignment is optimized by minimizing a global cost function with a graph-cut-based technique. The cost function is defined on the pixel level, as well as on the segment level. On the pixel level, a data term measures the pixel similarity based on the current flow field. Furthermore, occluded pixels are detected symmetrically. The segment level is connected to the pixel level in a way that the segmentation information is enforced on the pixel level. Additionally, a smoothness term is defined on the segment level. Moreover we allow our algorithm to use multiple input frames in order to discriminate the motion of different layers when the inter-frame motion is small.

III. EXPERIMENTAL RESULTS

We demonstrate the performance of the proposed algorithm using the well-known Mobile & Calendar MPEG test sequence that is shown in Figure 1a. In this sequence, the camera pans to the left, while there are moving objects (calendar, train and ball) in the scene. Since no ground truth is available, we have to focus on a qualitative discussion of the results. To present the computed flow values on the segment level, we draw the flow vectors for some pixels in Figure 1b, where we also outline the layer boundaries. We superimpose the layer borders on the reference image in Figure 1c to show their agreement with actual object boundaries. The object outlines seem to be well preserved. Finally, we demonstrate the robustness of our approach by segmenting the complete Mobile & Calendar sequence. The segmentation results for every fifth frame of the Mobile & Calendar sequence

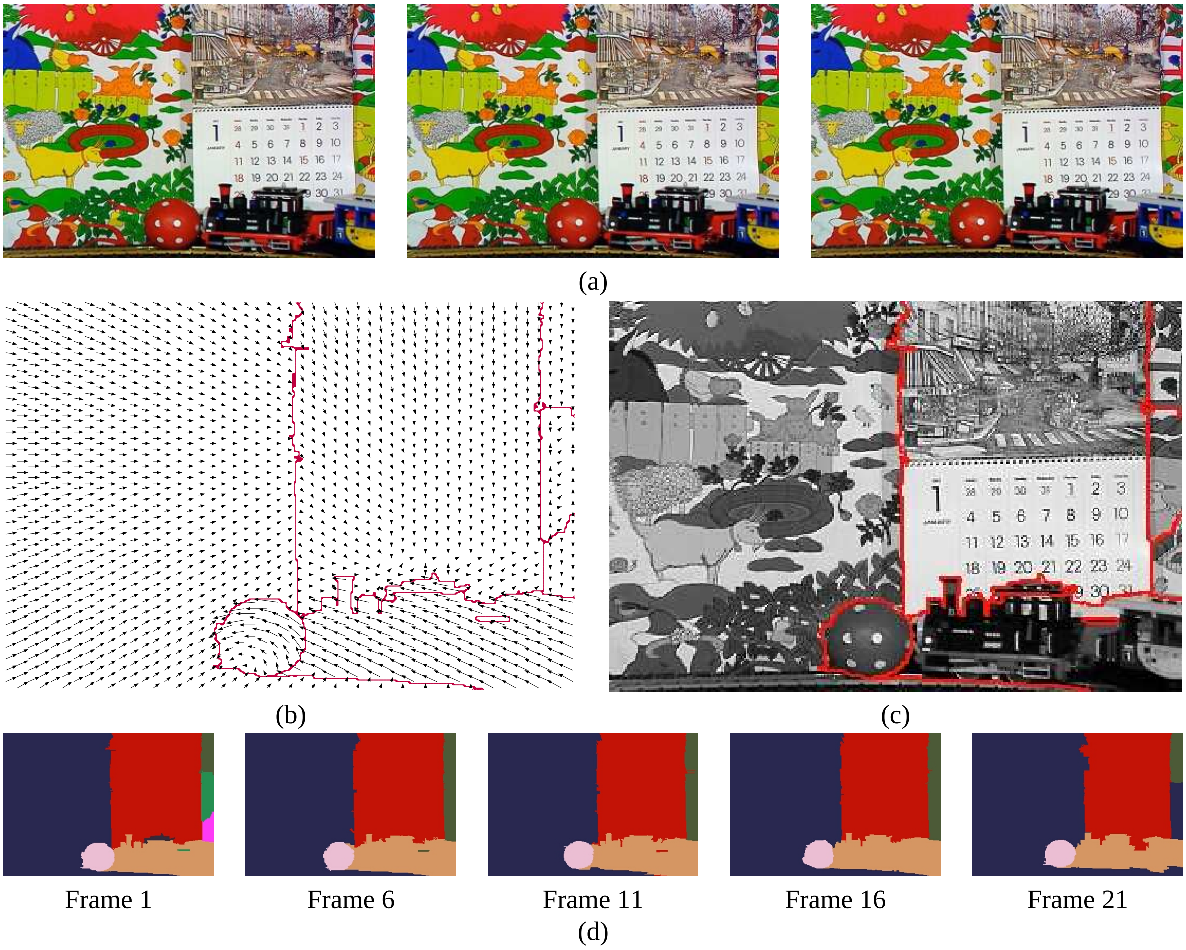

Figure 1: Results for the Mobile & Calendar sequence. (a) Frames 1, 3 and 5 of five input frames. (b) Flow vectors with layer boundaries. (c) Layer boundaries (red) superimposed on input frame 1. (d) Motion segmentation.

are presented in Figure 1d.

IV. Conclusions

In this work, we presented a new algorithm for computing a dense optical flow field between two or more images of a video sequence. The algorithm uses color segmentation to improve the quality of flow estimates in untextured regions and for the accurate detection of motion boundaries. The proposed method uses a layered representation and employs the affine motion model to describe image motion. The tasks of layer extraction and assignment are formulated as energy minimization problems. In order to approximate a minimum of the energy functions, a graph-cut-based optimization scheme is applied. Our method is capable of estimating correct flow information in traditionally challenging regions such as areas of low texture and close to motion discontinuities and can as well be applied to derive a motion segmentation of a complete video sequence. Further research will concentrate on improving the algorithm by defining criteria for splitting segments that overlap motion discontinuities and by using a more sophisticated motion model.

References

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