Efficient Recursive Factorization Methods for Determining Structure from Motion

Yanhua Li, B.Comp.Sci.

Department of Computer Science
The University of Adelaide

Cooperative Research Center for
Sensor Signal and Information Processing

A thesis submitted for the degree of

Doctor of Philosophy

in the Department of Computer Science

The University of Adelaide

July 2000

Abstract

This thesis addresses the *structure from motion* (SFM) problem in computer vision. We study recursive algorithms for efficient shape and motion recovery at each frame of a sequence of images. In real-time applications where image data is extensive, efficiency of an SFM method becomes very important for estimating shape and motion at each frame. The proposed recursive method in this thesis improves the efficiency, both in computational cost and in storage, of a class of innovative SFM methods — the *factorization methods* (FMs).

Our work in this thesis may be viewed as an extension of the original [71], the sequential [55] and the paraperspective [60] factorization methods. A critical aspect of these factorization approaches is the estimation of the *shape space*, and their computational complexity is dominated by their shape space computing algorithms. If P object feature points are tracked through a sequence of F frames, the shape space updating complexity at each frame is $O(P)$ in the recursive least-squares (RLS) method proposed in this thesis, while that in the sequential FM is $O(P^2)$. In contrast, the batch-mode original and paraperspective FMs, which are not intended to be used frame by frame, compute the shape space at a cost of $O(FP^2)$ after all F frames are tracked. Further, the RLS shape space updating algorithm is an adaptive data driven algorithm. Hence it does not require storage of a large measurement or covariance matrix, while other FMs usually do.

The proposed recursive method uses the general affine camera model, while the original and the sequential FMs assumed an orthographic model. Like the paraperspective FM, we give Euclidean shape and motion recovery from the estimated shape space under one of the three specific affine camera models — orthography, weak perspective and paraperspective, in order to apply the recursive method to a wider camera motion

range.

We also extend the recursive method to accommodate the situation in which some feature points are occluded or leave the field of view during the sequence. The extended recursive method still retains the low computational complexity of $O(P)$ and is simpler than the occlusion solutions proposed in other FMs.

Experiments with real and synthetic image sequences confirm the recursive method's low computational complexity and good performance and indicate that it is well suited to real-time applications.

Contents