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Research on Non-rigid Structure from Motion: A Literature Review ⋆

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Abstract

Non-rigid Structure from Motion (NRSfM) is a classical computer vision problem. And the main methods used to solve it are in general based on shape models or trajectory models. This paper will provide an overview over kinds of solutions proposed in these researches. It not only gives out the theoretical insights proposed by researchers in recent years, but also discusses them with their pros and cons. At the same time, the progress of the research about this topic is described in detail and its long-term trend is introduced at the end. This paper is very easy to understand, which mainly introduces two practical, everyday models for the NRSfM problem, namely trajectories based model and shape based model. Both of them are based on matrix factorization technology. Inevitably, some relevant optimization methods are mentioned to solve the projection matrix and corresponding coefficients effectively.

Keywords: Non-rigid Structure From Motion; Optimization Methods; Shape Models; Matrix Factorization; Trajectory Basis; Discrete Cosine Transform

1 Introduction

Non-rigid structure from motion plays a very important role in some computer vision applications [1–5], such as tracking, motion-capture, human computer interaction, 3D face reconstruction to augmented reality [7, 8], etc. So it's very useful to learn from previous experience. This paper aims to introduce some well-known methods for NRSfM problem. Most of the solutions for solving NRSfM problem were based on Matrix factorization technology [10,12]. The factorization framework for NRSfM was a significant extension from rigid scene to non-rigid scene as the well-known Tomasi-Kanade factorization, originally proposed by Bregler et al. in [10]. They argued that the structure of motion object could be regarded as an approximate linear combination of basis shapes. The shape model was widely used in this field, though it appeared to be very hard because the inherent basis ambiguity of the non-rigid problem must be overcome. To resolve this ambiguity, Xiao et al. [13] proposed to add extra "basis constraints" besides the orthonormality

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constraints. For the same reason, Torresani et al. [14] introduced a Gaussian prior to constrain the solution by reducing the coefficients. Del Bue introduced to use special shape priors [15]. Later, Dai et al. [17] proposed a simple prior-free method to solve the NRSfM problem for the first time in 2010. Although they did not assume any additional prior knowledge except the low-rank constraint, the method recovered the non-rigid shape reliably. And the shape based model became more mature. The methods mentioned above were based on shape basis. Until Akhter et al. [18] made a great improvement, who introduced trajectories based model for solving NRSfM problem instead of shape basis. This approach, representing the 3d point trajectories as a model in the domain of the Discrete Cosine Transform (DCT) basis vectors, provided better results on complex shapes. It's ripe with meaning [19]. With the appearance of trajectory basis model, the methods for recovering non-rigid shape from motion were greatly improved. Later, for the reason of the duality between shape basis and trajectory basis, the solution for solving NRSfM problem was not limited to use shape models or trajectory models individually. Some new ideas were proved very effective.

This paper is an extension of the earlier studies and is divided into four quarters as follows: Section 2 delineates the matrix factorization proposed by Tomasi, Section 3 and 4 introduces the shape based model and the trajectory based model separately. Finally, the conclusion introduces the trend in development of this issue in the Section 5.

2 Matrix Factorization

Tomasi et al. introduced the factorization method at first time in their paper, which was based on a rigid matrix. They considered the structure from motion problem with F frames and P feature points, and obtained trajectories of image coordinate $\{(x_{fp}, y_{fp}) \mid f = 1, ..., F; p = 1, ..., P\}$, and then stacked all the points in a matrix form as follows:

$$W = \begin{bmatrix} X_{11} & \cdots & X_{1P} \\ \vdots & \ddots & \vdots \\ X_{F1} & \cdots & X_{FP} \end{bmatrix} = \begin{bmatrix} X \\ - \\ Y \end{bmatrix} \in R^{2F \times P} \tag{1}$$

W was the measurement matrix. Then, the rows of the matrices X and Y were regulated to simplify the calculation by subtracting the mean of the entries from each entry in the same row. Such that,

$$\tilde{x}_{fp} = x_{fp} - a_f; \tilde{y}_{fp} = y_{fp} - b_f; \tilde{W} = \begin{bmatrix} \tilde{x} \\ - \\ \tilde{y} \end{bmatrix}; a_f = \frac{1}{P}\sum_{p=1}^{P} x_{fp}; b_f = \frac{1}{P}\sum_{p=1}^{P} y_{fp} \tag{2}$$

The matrix $\tilde{W}$ which had been solved with above approach was called the registered measurement matrix. And then Factorization method could be used to get the camera motion (projection) matrix R and the non-rigid shape matrix S from an image measurement matrix W, such that $W = RS$. Generally, Singular Value Decomposition (SVD) was used in this step. For example, if $W = U\Sigma V$, then $R = U * \Sigma^{\frac{1}{2}}$ and $S = \Sigma^{\frac{1}{2}} * V$, the measurement matrix was factorized into two low rank matrices in a stable and well-behaved manner. This would reduce the calculation