Recovering Articulated Non-rigid Shapes, Motions and Kinematic Chains from Video

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Abstract. We propose an approach to analyze and recover articulated motion with non-rigid parts, e.g. the human body motion with non-rigid facial motion, under affine projection from feature trajectories. We model the motion using a set of intersecting subspaces. Based on this model, we can analyze and recover the articulated motion using subspace methods. Our framework consists of motion segmentation, kinematic chain building, and shape recovery. We test our approach through experiments and demonstrate its potential to recover articulated structure with non-rigid parts via a single-view camera without prior knowledge of its kinematic structure.

Keywords: structure from motion, articulated, non-rigid, motion analysis.

1 Introduction

Articulated motion has been attracting research interests for decades. It is highly relevant to human motion, one of the most interesting motions in nature. Articulated motion with non-rigid parts is a good approximation to human motion. A system that can capture and recover that kind of motion has a wide range of applications in medical study, sport analysis and animation, etc. We propose an approach to analyze and recover articulated motion with non-rigid parts under affine projection from feature trajectories.

We model articulated motion with non-rigid parts as a set of intersecting subspaces. From this model, we derive our approach to segment the motion, build the kinematic chain and recover the structure. Compared to previous works on articulated motion, which assume that the parts are rigid [20][22][1] or use a kinematic model as a prior [2][3][4][5]. Our approach uses a unified framework to deal with rigid parts and non-rigid ones. Besides, it does not require prior knowledge of the kinematic structure, instead it can automatically builds the kinematic chain from analyzing the feature trajectories.

The following sections are organized as followed: Section 2, detailed discussion of our model of articulated motions; Section 3, our approach for motion segmentation, kinematic chain building and shape recovery; Section 4, experimental results; Section 5, conclusions and future work.

F.J. Perales and R.B. Fisher (Eds.): AMDO 2006, LNCS 4069, pp. 90–99, 2006.

2 Modeling Articulated Motion with Non-rigid Parts Using Subspaces

We are going to show that under affine projection the trajectories of rigid, non-rigid and articulated motions lie in some low-dimensional subspaces. Then we discuss the extension of the articulated case to non-rigid parts. The conclusion is that articulated motion with non-rigid parts can be modeled as a set of intersecting subspaces. The intersection between two motion subspaces may imply an articulated link of either a joint or an axis.

2.1 Articulated Motion Subspaces

The rigid, non-rigid and articulated motions are described as followed with respect to the subspaces they form.

- For rigid motions, the trajectories of a rigid object forms a linear subspace of dimensions no more than 4 ([16]).

$$M_{2f\times p} = [R_{2f\times 3}|T_{2f\times 1}] \begin{bmatrix} S_{3\times p} \\ \mathbf{1}_{1\times p} \end{bmatrix} \tag{1}$$

  f is the number of frames and p, the number of feature trajectories.
- The trajectories of a non-rigid object can be approximated by different weighings of a number of key shapes ([8][9]) and, as shown below, lie in a linear subspace of dimensions no more than $3k+1$.

$$M = \begin{bmatrix} c_1^1 R_{2\times 3}^1 | ... | c_k^1 R_{2\times 3}^1 | T_{2\times 1}^1 \\ ... \\ c_1^f R_{2\times 3}^f | ... | c_k^f R_{2\times 3}^f | T_{2\times 1}^f \end{bmatrix} \begin{bmatrix} S_{3\times 1}^1 \\ ... \\ S_{3\times p}^k \\ \mathbf{1}_{1\times p} \end{bmatrix} \tag{2}$$

  c_j^i $(1 \le i \le f, 1 \le j \le k)$.
- For articulated motions with rigid parts ([20][22]),
  - If the link is a joint, $[R_1|T_1]$ and $[R_2|T_2]$ must have $T_1 = T_2$ under the same coordinate system. So M_1 and M_2 lie in different linear subspaces but have one-dimensional intersection.
  - If the link is an axis, $[R_1|T_1]$ and $[R_2|T_2]$ must have $T_1 = T_2$ and exactly one column of R_1 and R_2 being the same under a proper coordinate system. So M_1 and M_2 lie in different linear subspaces but have two-dimensional intersection.

The articulated motion can be modeled as a set of intersecting subspaces. The intersections between two subspaces are the motion subspaces of a link, either a joint or a axis, with dimensions of 1 or 2.