

# Uncalibrated Non-Rigid Factorisation by Independent Subspace Analysis

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## Abstract

*We propose a general, prior-free approach for the uncalibrated non-rigid structure-from-motion problem for modelling and analysis of non-rigid objects such as human faces. We recover the non-rigid affine structure and motion from 2D point correspondences by assuming that (1) the non-rigid shapes are generated by a linear combination of rigid 3D basis shapes, (2) that the non-rigid shapes are affine in nature, i.e., they can be modelled as deviations from the mean, rigid shape, (3) and that the basis shapes are statistically independent. In contrast to the majority of existing works, no statistical prior is assumed for the structure and motion apart from the assumption that underlying basis shapes are statistically independent. The independent 3D shape bases are recovered by independent subspace analysis (ISA). Likewise, in contrast to the most previous approaches, no calibration information is assumed for affine cameras; the reconstruction is solved up to a global affine ambiguity that makes our approach simple and efficient. In the experiments, we evaluated the method with several standard data sets including a real face expression data set of 7200 faces with 2D point correspondences and unknown 3D structure and motion for which we obtained promising results.*

## 1. INTRODUCTION

The estimation of structure and motion from image streams is a fundamental problem in computer vision. As an extension to the regular structure-from-motion (SFM) problem, the non-rigid structure-from-motion (NRSFM) problem takes the non-rigidity of the object in consideration in the recovery of structure and motion. The NRSFM problem has received considerable attention during the last two decades and encouraging results have been obtained.

The approaches for NRSFM can be categorised in several ways. From the algorithmic point of view, there are *direct* and *iterative* methods. Starting from the direct methods, the work of Bregler *et al.* [8] can be seen as the starting point for NRSFM research. They proposed an approach where the shape deformations are modelled as a linear com-

Figure 1. We propose a method that infers the 3D reconstruction, basis shapes, and the underlying affine camera geometry from the 2D projections of a non-rigid object by only assuming an uncalibrated affine camera and *statistically independent* basis shapes.

bination of rigid shape basis that leads to a low-rank model; a heuristic 1D factorisation together with orthogonal constraints were used to recover the camera matrices. This pioneering work was thereafter succeeded by the work of Brand *et al.* [6], who used the heuristic of minimising deformations. Del Bue and Agapito applied additional constraints arising from a stereo rig [11]. Xiao *et al.* constrained the shape basis by assuming that each basis shape is visible unmixed in some frames [26]. Hartley and Vidal proposed a solution for perspective non-rigid structure from motion problem by factoring a multifocal tensor [16].

Regarding the iterative methods, one category is alternation-based methods, such as the trilinear method by Torresani *et al.* [25], the bilinear methods by Paladini *et al.* [22] and Del Bue *et al.* [13] which include projections onto the metric manifold, and the method by Torresani *et al.* [24] which is based on Probabilistic PCA and Expectation Maximisation. Bundle adjustment has been applied, for instance, in [1, 12, 5]. Moreover, Bartoli *et al.* [5] used a coarse-to-fine problem formulation to obtain a robust result. Various works have applied either statistical or physical priors to regularise the non-rigid structure from motion problem. These include priors such as rigidity [12, 5],



















