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Recovering Euclidean Deformable Models from Stereo-motion

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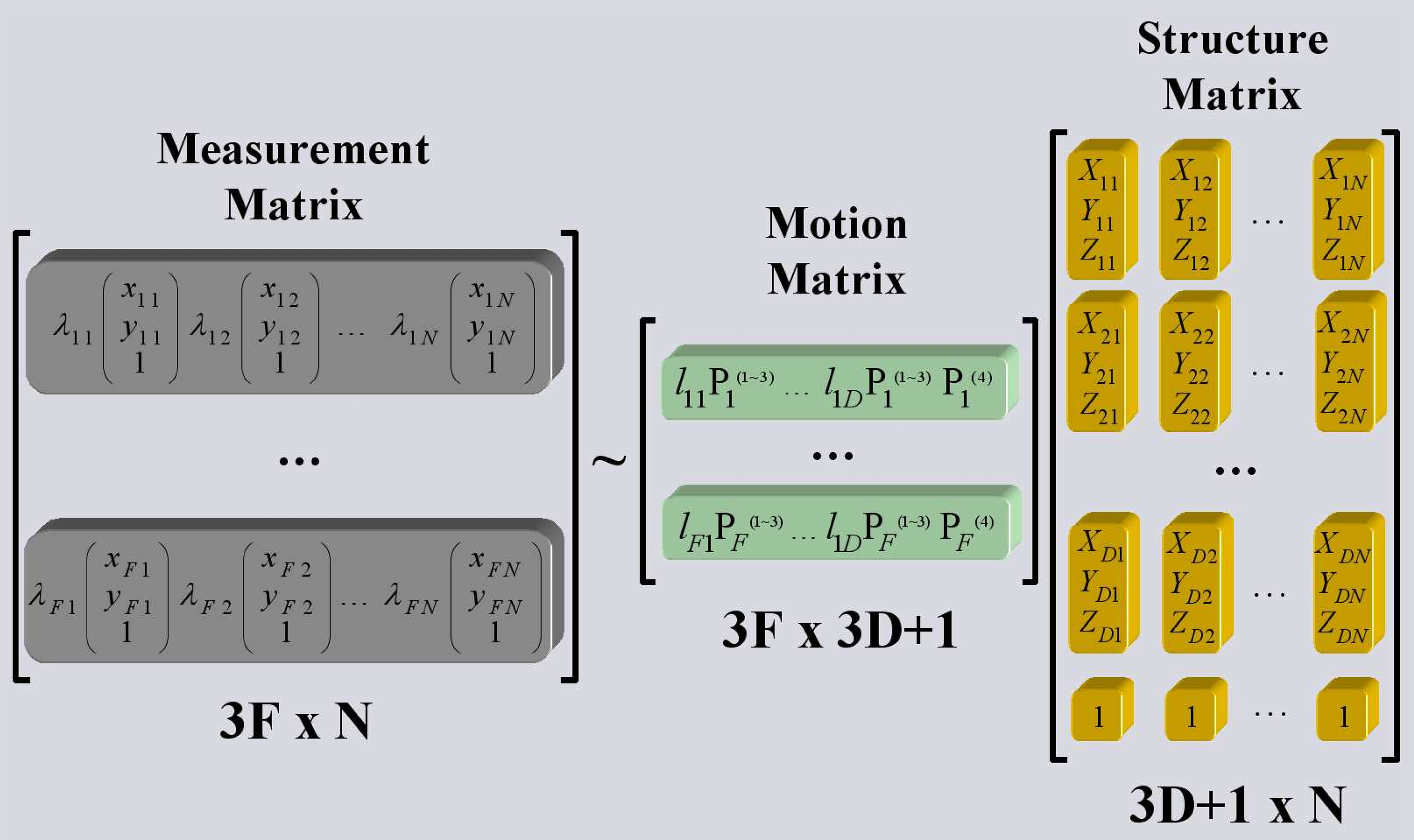
1 Introduction

In this paper we present a novel Structure from Motion approach able to infer 3D deformable models from uncalibrated stereo images.

The stereo setup dramatically improves the 3D model when the object is mostly deforming without undergoing strong rigid motion.

2 The Factorization Framework



- D is the number of 3D basis shapes B_d which provide a description of the modes of deformation.
- P_i are the 3×4 camera matrix such that $P_i = K_i[R_i|\mathbf{T}_i]$ with $i = 1 \dots F$.
- l_{id} with $d = 1 \dots D$ are the configuration weights which linear combination gives the non-rigid shape at frame i such that $X_i = \begin{bmatrix} \sum_{d=1}^{D} l_{id} B_d \\ \mathbf{1} \end{bmatrix}$.

Problem: Recovering the deformable models without strong rigid motion.

3 Our Stereo-motion SfM Approach

1. **Stereo Calibration** and reconstruction of metric rigid structures per frame.
   - Automatic calibration using fundamental matrices and Kruppa equations. Estimation of K_i (focal lengths), R_{rel}, and $\mathbf{T}_{rel}$.
   - Triangulation using Epipolar geometry. Recovery of the rigid metric shape for each frame.
2. **Segmentation of Rigid/Non-rigid points** from the 3D views.
   - The aim is identify a set of rigid points over a deforming surface to later on estimate the frame-wise motion.
     - Firstly, all the 3D shapes are registered via RANSAC to a reference view, computing also the mean shape (B_1).
     - Afterwards, the segmentation is done analyzing the 3D registration errors per point (like in [1]).
3. **Frame-wise motion estimation**.
   - With the good set of rigid points we do the frame-wise registration using RANSAC to robustly extract the motion parameters R_i and $\mathbf{T}_i$.
4. **Global optimization stage** to recover the Non-rigid model and to refine the initial solution.

4 Global Optimization with Bundle Adjustment

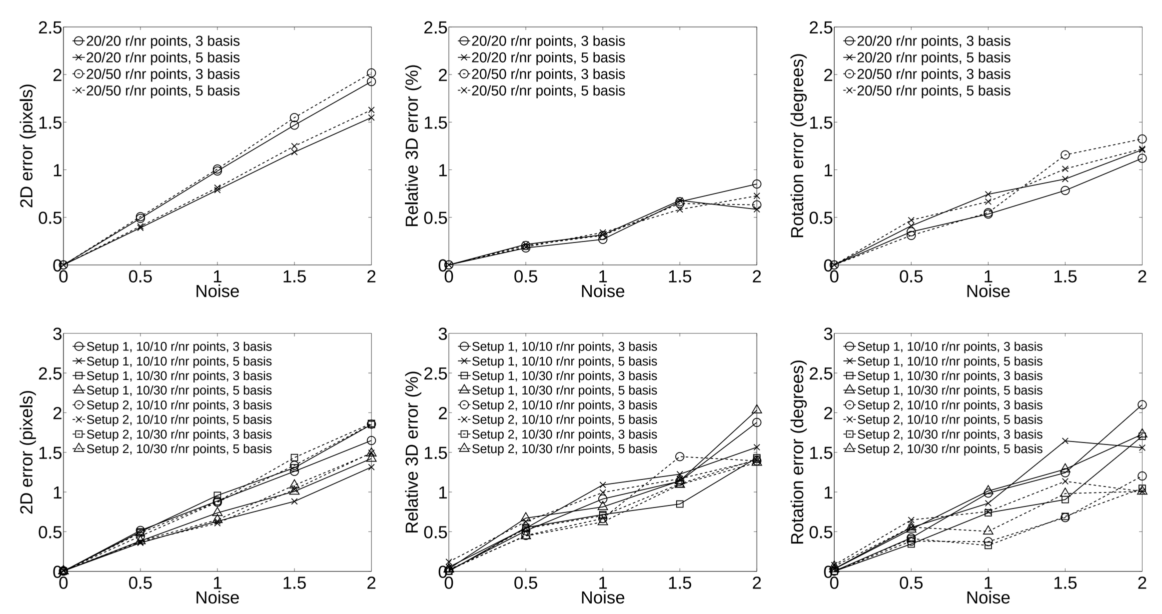
The parameters previously estimated provide a reliable initialization for the following non-linear optimization:

$$\min_{K_i R_i \mathbf{T}_i R_{rel} \mathbf{T}_{rel} \mathbf{B}_d l_{id}} \sum_{i,j} \| \mathbf{x}_{ij}^{L} - K_i[R_i|\mathbf{T}_i] \begin{bmatrix} \sum_{d=1}^{D} l_{id} \mathbf{B}_{dj} \\ 1 \end{bmatrix} \|^2 + \| \mathbf{x}_{ij}^{R} - K_i[R_{rel}R_i|\mathbf{T}_i + \mathbf{T}_{rel}] \begin{bmatrix} \sum_{d=1}^{D} l_{id} \mathbf{B}_{dj} \\ 1 \end{bmatrix} \|^2 \quad (1)$$

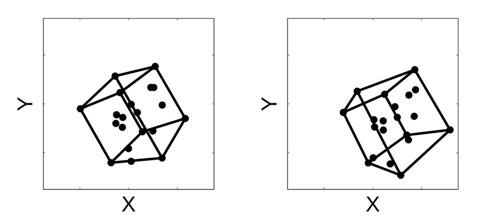
The goal is to refine and correctly estimate the left and right camera matrices, the intrinsic parameters K_i, the coefficients l_{id} and the basis shapes $\mathbf{B}_{dj}$.

The basis shapes B_d which encode the $(D-1)$ non-rigid components are initialized to small random values. A similar initialization has previously been used in [2, 3].

5 Experimental Results: Synthetic Data

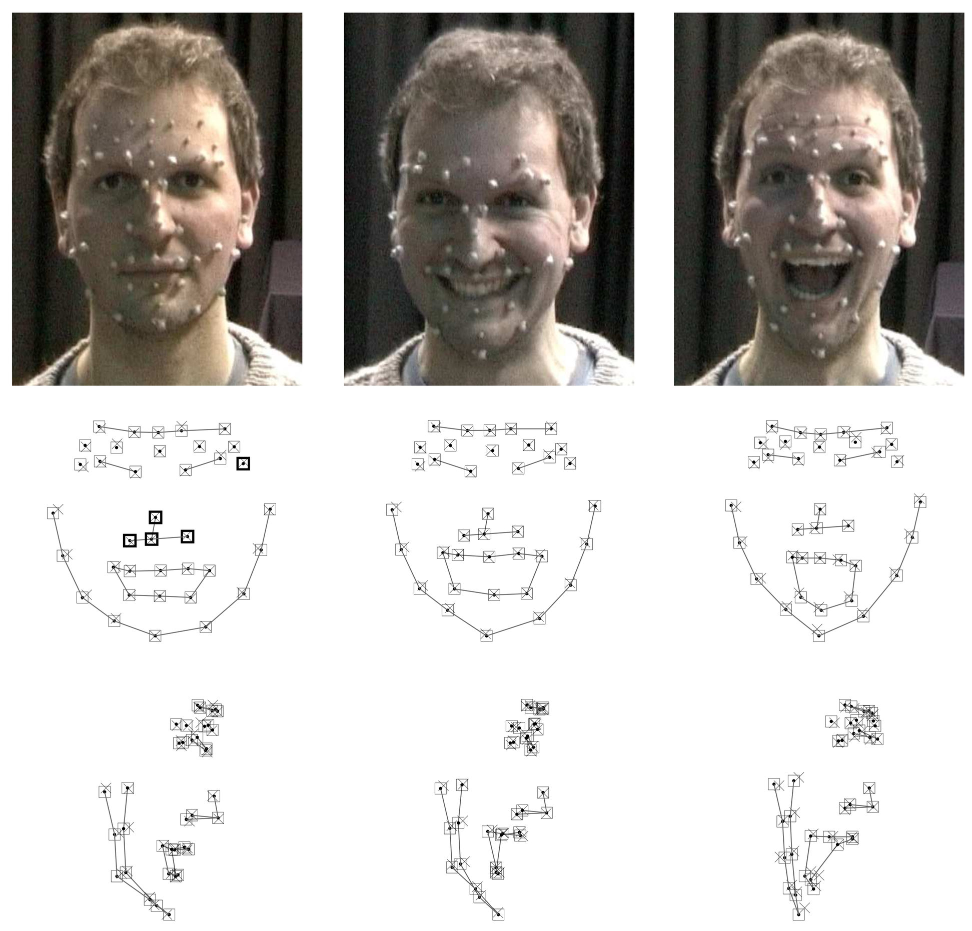


2D, 3D and rotation error curves. First row: results when not rigid motion was applied. Second row: results when the object was deforming while doing a rigid motion transformation.



Stereo view of a synthetic sequence frame.

6 Experimental Results: Real Data



7 Conclusions

We have proposed an approach for the 3D Euclidean reconstruction of deformable objects from a stereo-motion system.

The experiments have proven the performance even when there is no rigid motion in the original sequence and with a minimal set of rigid points.

[1] G. Wang and Q. M. J. Wu. Stratification approach for 3-d euclidean reconstruction of nonrigid objects from uncalibrated image sequences. *IEEE Trans. Syst., Man, Cybern.*, 38(1):90–101, February 2008.
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