Winter school project: Non-Rigid Structure from Motion

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Problem description: The Non-Rigid Structure from Motion (NRSfM) aims at recovering the depth information lost in the image formation process by estimating the 3D structure of the object of interest from multiple image observations. This is an ill-posed problem due to its inherent unconstrained nature. Any solution thus require priors, such physical models of the deformation. Applications of NRSfM include medical imaging and computer aided surgery, virtual and augmented reality.

Purpose: The scope of this project is to introduce a NRSfM solution and provide an overview of the challenges posed by this problem, as well as create an opportunity for exploring different ways of improving various aspects of the implementation.

Main reference: Paper [1], available here.

Code: Our solution is written in Matlab, using the Bicubic B-Splines toolbox available here, and the GloptiPoly solver for Matlab, available here. Also, one of the tasks requires the Matlab Optimization Toolbox.

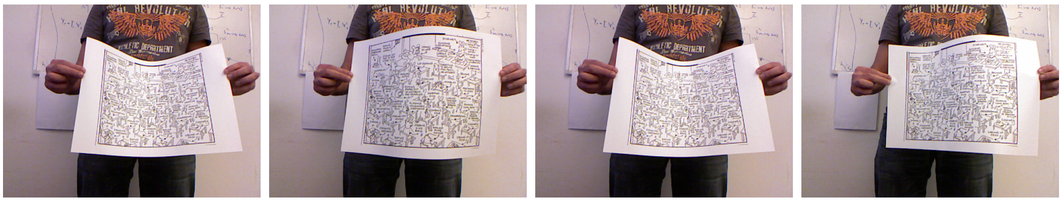

Figure 1: The Kinect Paper dataset

Dataset: The dataset used is the Kinect Paper dataset, available here (Figure 1). A copy will be provided along with the project.

Solution: The expected outcome of the project will be an extension of an implementation of the NRSfM [cite] algorithm. At the core of this reconstruction algorithm is a system of bivariate bicubic equations obtained by imposing isometric constraints, whose solution gives the surface normals. The up to scale reconstruction is obtained by integrating these normals.

Project step: The participants will be asked to complete the following exploration steps based on the provided code, including:

- **Faster way of solving.** In the proposed implementation, we have used GloptiPoly, a Matlab add-on that can solve non-convex global optimization problems. A different solution can be obtained via a non-linear least squares optimization. Therefore, the participants are asked to replace the GloptiPoly solver with a non-linear least squares optimization and to compare the two approaches (time performance, accuracy). Care must be taken at choosing a good initialization point for the optimization.

- **Accuracy Analysis.** The proposed solution requires the estimation of an image warp transformation based on the sparse keypoint matches available in the dataset. For good stability, it requires that the image warps respect the Scwarzian constraint. Therefore, we use a refinement procedure which imposes the Schwarzian constraint [2] on the image warps. This is a very time consuming process (over 1 second per frame). Investigate the impact of removing the Schwarzian refinement on accuracy for both the GloptiPoly and the non-linear least squares solutions. Also, try changing the number of keypoints through uniform sampling, and see how the accuracy is impacted.

- **Reference frames (Optional).** The proposed solutions picks the first frame as a reference frames, pairs it with every other frame and computes the image warp and obtains two bicubic equations from each such pair. However, the final accuracy is sensitive to the choice of the reference frame - you can convince yourself by running the algorithm with different frames as reference. One simple approach to mitigate this issue is to run the reconstruction algorithm multiple times, using a different frame as reference, and then combine the resulting normals (e.g. using mean or median). Can we automatically detect possible candidates for the reference frame without an exhaustive computation?

Final evaluation: The marks for these four steps are respectively: Different way of solving (60), Accuracy Analysis (30), Reference Frames (10). The total marks are 100. Each part will be evaluated by combining the code and the final report.

References

[1] Parashar, S., Pizarro, D and Bartoli, A.: "Isometric Non-Rigid Shape-from-Motion with Riemannian Geometry Solved in Linear Time," in IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 40, no. 10, pp. 2442-2454, 1 Oct. 2018, doi: 10.1109/TPAMI.2017.2760301.

[2] Pizarro, D., Khan, R. and Bartoli, A. Schwarps: Locally Projective Image Warps Based on 2D Schwarzian Derivatives. Int J Comput Vis 119, 93–109 (2016). https://doi.org/10.1007/s11263-016-0882-9