Assessment of the bachelor thesis by Petr Hrubý

Two-Body Structure from Motion
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The goal of the thesis was to develop a practical system for reconstruction an object moving w.r.t. a background from sequences of images by extending existing Structure from Motion (SfM) paradigm. This is a step towards a long-standing problem of Multi-Body SfM that has been addressed by many of works in past, yet there still has been no reconstruction pipeline producing useful results in practice. In full generality, Multi-Body SfM is a very hard, perhaps intractable, problem. It is a general segmentation problem with additional difficulties are caused by ill conditioned 3D reconstruction from small data sets and numerous degenerate situations. The goal for the theses was to make the smallest possible generalization of Single-Body SfM for multiple objects, which would be practical and could extend capabilities of existing SfM pipelines.

The thesis presents an extension of one of the most popular SfM pipelines, COLMAP, which allows to reconstruct an object moving in front of a static background. It is assumed that the object is taken by multiple image sets (takes), each take capturing the object and the background in a static configuration. The object moves from one take to another. The thesis describes the complicated situation of multiple possible coordinate system choices, and hence many possibilities how relative motions can be expressed. It proposes techniques for transforming all into a single coordinate system by a robust method based on RANSAC and cycle consistency. It addresses and solves removal of nuisance motions, which are close to identities by spectral clustering. Relative motions are extracted by another RANSAC based method and more advance cycle consistency, using chordal completion, is applied to discover the relative motions. Based on motions, which are further refined by averaging, point tracks are constructed and 3D points initialized. All is finally optimized in a bundle adjustment and inconsistent tracks are filtered out.

Experimental validation brings a new set that is specifically constructed for this new problem. It is shown that using background can improve reconstruction quality when foreground objects possess repetitive structures or are degenerate (e.g. planar). Experiments with bundle adjustment, interestingly, show that coordinate-wise alternation outperforms classical gradient descent.

The thesis presents perfect mathematical formulation of the problem as well as very professional engineering solution. All engineering choices are meaningful. Experiments demonstrate functionality as well as the advancement w.r.t. the state for the art. Many different techniques have been mastered and used to provide a working and practical solution.

The thesis is written in clear and understandable language with appropriate use of formalism. Nevertheless, it is not very easy to understand since it has to deal a complicated problem generating a large number of phenomena (many different coordinate systems, many possibilities of forming relative motions, different techniques for clustering, etc.). I believe that

it would be very helpful to have a grand plan of all coordinate systems and motions on one figure that would help to keep track of what has to be done and what has been done.

Petr Hrubý was a very motivated, capable, and hard-working student. He started our collaboration already during the first year of his studies by experimenting with SfM pipeline COLMAP and investigating how it could be extended to reconstructing multiple moving objects. His results supported the idea to look at the minimal extension towards two objects and known takes. He picked this idea and developed, in my opinion, the first practical extension of single-body to multi-body SfM.

Petr Hrubý presented a very professional research work, which by large exceeds the level of a Bc. thesis. He fulfilled all the goals set in the assignment. He mastered advanced techniques in the field and contributed by truly new result.

I believe that this work is *excellent (A)*.

Prague, 9 June 2019

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