Vision-based methodologies for the motion tracking and parameter identification of flexible multibody mechanisms

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EXTENDED ABSTRACT

1 Introduction

In this work we present a methodology for the time-domain motion tracking and parameter identification in the case of flexible multibody systems. The methodology exploits vision-based measurements for which previous research [1, 2, 3] already showed the added value in the identification of structural components due to its spatial overdetermination. With this research we want to explore the use of vision-based measurements towards flexible multibody mechanisms. The motion of these mechanisms is characterized by the motion of its different components which undergo, in general, both a large rigid body motion and a much smaller deformation motion. This motion is difficult to track with conventional sensing systems (e.g., accelerometers) due to mass or cable loading and time or cost constraints. In this research it is shown that vision-based tracking algorithms can overcome the limitations of conventional sensing systems and make it possible to extract measurement data that would be hard to extract for conventional sensing systems. This opens up the potential to develop new experimental identification methods for these flexible multibody mechanisms.

2 Methodology

The approach presented in this work is able to extract the total motion of a multibody mechanism by vision-based data only. As such, the motion measurement method is contactless and no mass or cable loading effects need to be taking into account. Furthermore, the motion of multiple components can be tracked with a limited number of cameras which makes the experimental setup relatively time and cost effective. One only needs to make sure that the components are visible within the field of view of the cameras and are not occluded by other components during their motion.

The Lucas-Kanade optical flow method [4] is employed in order to obtain sub-pixel accurate motion results needed to track the small deformation motion. This tracking technique uses an image intensity based tracking by solving the optical flow constraint:

$$\frac{\partial i}{\partial u}\Delta u+\frac{\partial i}{\partial v}\Delta v+\frac{\partial i}{\partial t}\Delta t=0\,. \tag{1}$$

In this equation, i is the image intensity, u and v are the image coordinates in horizontal and vertical direction respectively and t is the time. Equation (1) is solved for Δu and Δv and for every point to track and every time instance. A spatial image window is used to create an overdetermined set of equations and resolve the aperture problem.

However, in the case of multibody systems special attention must be paid to the use of this method for large inter-frame motion resulting from the rigid body motion. The Lucas-Kanade method can lose track of the points when their motion is larger then the spatial window used and their feature descriptors are undistinctive for a image pyramid approach. In this research, this is solved by providing initial guesses for the point locations based on the tracked locations of some keypoints (e.g., component joints). This can be done as the flexible motion will be much smaller than the rigid body motion and fall within the spatial window used.

The tracked motions are then used in a Procrustes method [5] in order to separate the rigid body motion from the deformation motion. With $\boldsymbol{X}$ a set of 3D points and $\boldsymbol{X_0}$ a set of undeformed reference points, the rigid body translation $\boldsymbol{t}$ and rotation $\boldsymbol{R}$ of $\boldsymbol{X}$ can be determined as:

$$\boldsymbol{t}=\overline{\boldsymbol{X}}\ (\text{with}\ \overline{\boldsymbol{X_0}}=0)\,, \tag{2}$$

and

$$\boldsymbol{R}=(\boldsymbol{U}\boldsymbol{V}^\top)^\top\ (\text{with}\ [\boldsymbol{U},\boldsymbol{S},\boldsymbol{V}]=svd((\boldsymbol{X}-\boldsymbol{t})\boldsymbol{X_0}^\top)\,. \tag{3}$$

The extracted rigid body and deformations motions of the components can then be used in a parameter identification scheme. The identification scheme employs the recently developed flexible natural coordinate formulation (FNCF) in combination with the adjoint variable method (AVM) to retrieve sensitivity information [6].

3 Results

The presented approach is experimentally validated on a slider-crank mechanism as seen in Figure 1. The motion was recorded with a synchronized stereo camera pair (JAI SP-12000M-CXP4 and Ximea xiB-64 CB120RG-CM-X8G3). Several markers

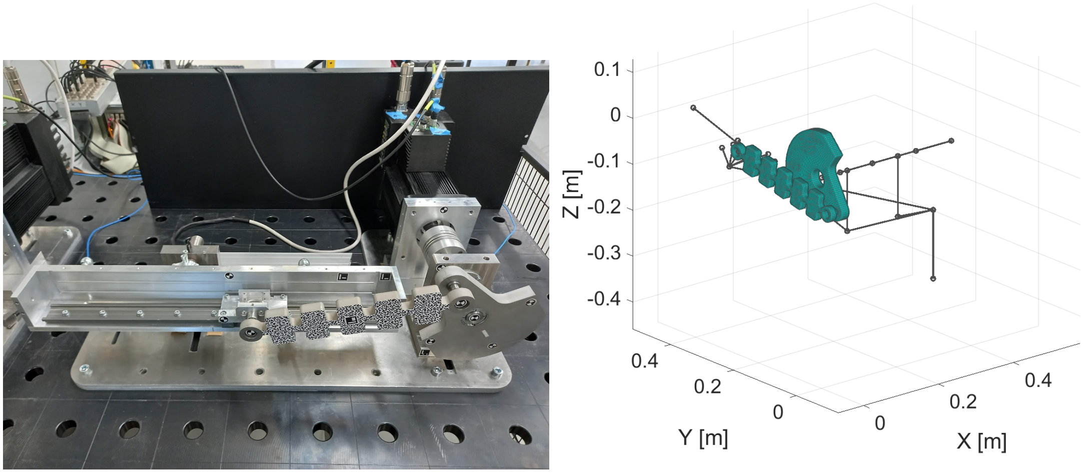

Figure 1: Slider-crank setup used for experimental validation (left) and its flexible multibody model used for parameter identification (right)

were attached on the different components of the slider-crank and the connecting rod was covered with a speckle pattern as this component was expected to show the largest deformation. These markers allow for a more accurate motion tracking with the image intensity based Lucas-Kanande optical flow algorithm. Running the proposed Procrustes method, it was able to extract a flexible deformation of the connecting rod smaller than 1 mm while having rigid body motions ranging up to 100 mm. This shows the multi-scale tracking ability of the proposed motion tracking methodology. Next, an identification of the bearing stiffness of the main axle is aimed in comparison with an identification through accelerometer measurements to assess the influence of full-field vision-based measurements on the identification accuracy.

4 Conclusion

The results of this work show that a vision-based approach has the benefits of providing full-field measurements and extract measurements that are hard to extract for conventional sensing systems. This enables us to rethink experimental testing techniques for flexible multibody systems. Future research will aim to expand the identification capabilities towards the structural mass and stiffness matrices of the flexible multibody formulation.

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