Effective vibration length identification of cables from UAV video using multi-mode shape consistency constraints for cable tension estimation

Y. Qi [1], P. Lin [2]

[1] *PhD Candidate, School of Civil Engineering, Lanzhou Jiaotong University, 13240041@stu.lzjtu.edu.cn*
[2] *Professor, School of Civil Engineering, Lanzhou Jiaotong University, pzhlin@mail.lzjtu.edu.cn*

Extended Abstract

Cable force is a key parameter for the safety assessment of bridge cable-supported systems, directly affecting structural geometry, stiffness distribution, dynamic characteristics, and cable fatigue safety. Vibration-based cable force estimation is widely used in practice because it can infer cable force from measured natural frequencies. However, its accuracy is strongly affected by the cable length used in the calculation. In actual bridge cables, anchorage zones, extension sleeve, local end constraints, and cable bending stiffness can cause the effective vibration length to differ from the geometric length. Directly using the geometric length may therefore introduce systematic errors in cable force estimation. To address this issue, previous studies have introduced the concept of effective vibration length and identified it by installing multiple accelerometers along a cable to reconstruct its actual mode shapes. Although this strategy can improve the accuracy of cable force estimation, it still relies on contact-based multi-point sensor installation, which requires work at height and is difficult to apply efficiently to multiple cables in long-span bridges. Therefore, how to obtain multi-point vibration responses and identify the effective vibration length in a non-contact and efficient manner remains an important problem. In this study, UAV video is used to replace multiple contact accelerometers. By extracting multi-point displacement responses from annular markers on the cable surface, reconstructing the actual mode shapes, and identifying the effective vibration length through multi-order mode-shape fitting, the proposed method provides a non-contact approach for improving cable force estimation under practical boundary conditions.

The main difference between this study and previous research lies in the measurement strategy for effective vibration length identification. Existing methods generally rely on multiple accelerometers installed along the cable to obtain contact-based multi-point vibration responses, which makes field implementation complicated and limits inspection efficiency. In contrast, this study uses UAV video to replace multiple contact sensors, enabling the synchronous acquisition of multi-

point cable vibration responses in a non-contact manner, and further achieving actual mode-shape reconstruction and effective vibration length identification.

This study proposes a complete UAV-video-based framework for cable force identification, enabling a fully non-contact workflow from video acquisition, target segmentation, vibration response extraction, UAV drift suppression, and effective vibration length fitting to cable force calculation. As shown in Fig. 2, the field tests on four cables indicate that the average relative errors of the cable forces calculated using the identified effective vibration lengths are 1.69%, 1.07%, 3.70%, and 2.85%, respectively. Compared with the results obtained using the actual cable lengths, the errors are reduced by 7.36%, 6.79%, 9.18%, and 5.88%, respectively, demonstrating that the effective vibration length can effectively correct the cable force estimation error caused by the geometric length assumption. Meanwhile, the proposed spectrum-shape-driven SSD-CEEMDAN method can adaptively separate UAV-induced low-frequency drift without requiring a preset cutoff frequency or manual intervention, while preserving the true narrowband modal components and improving the stability of frequency identification and mode-shape extraction. In addition, the joint fitting method based on multi-order mode-shape consistency constraints can stably identify the actual mode shapes and effective vibration length using multi-point and multi-order modal amplitude information. By combining coarse grid search with Nelder-Mead optimization, the proposed method improves parameter estimation accuracy and provides an effective technical approach for accurate, rapid, and non-contact cable force identification under complex boundary conditions.

Keywords: *UAV photogrammetry; Cable segmentation; Vibration extraction; Drift suppression; Mode shape fitting; Tension calculation*

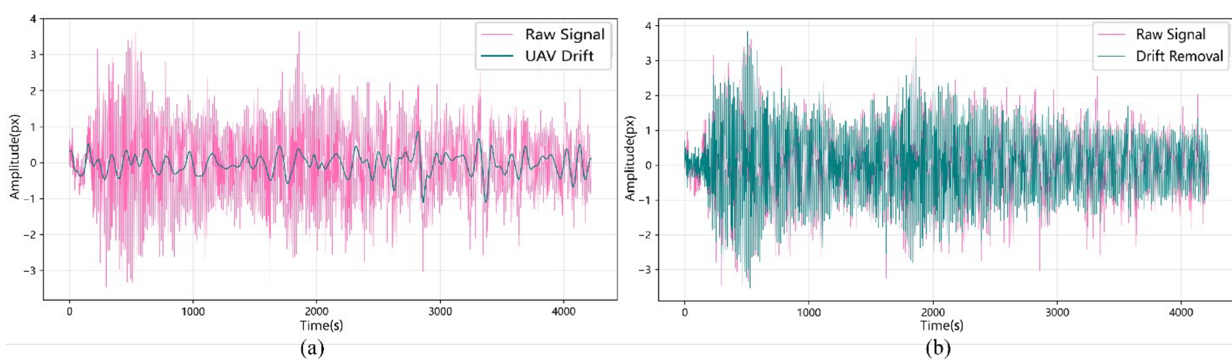

Figure 1-UAV drift signal separation

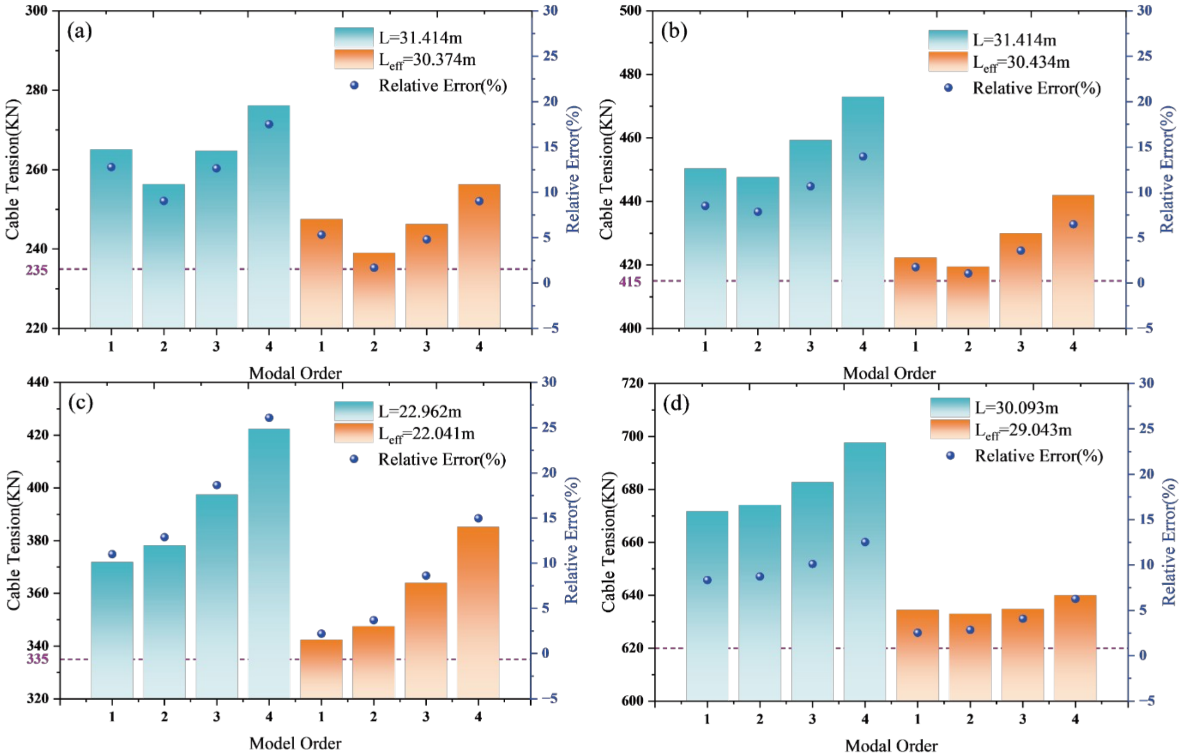

Figure 2-Comparison of cable tension calculation results for actual length and effective vibration length.