Visual Motion Tracking for Estimation of Kite Dynamics

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Figure 3: Overlay of the tracked kite positions. Full video can be found at http://control.ee.ethz.ch/~awe/vmt.avi.

ABSTRACT

We present a visual motion tracker, capable of long-term real-time object tracking. The presented visual motion tracker (VMT) is applied to the state estimation of an airborne wind energy (AWE) system to assess the performance of new estimators. Further, the approach is suitable to significantly improve the quality of the state estimation in experiments without additional on-board sensors.

VISUAL MOTION TRACKING

By combining recently developed algorithms for motion tracking [1] and object detection [2], long-term real-time object tracking with low failure rate and good recovery capabilities is achieved (Figure 1). For inevitable localization failures by the tracker, the detector re-detects appearances of the target, and reinitializes the tracker. In case of target absence, failure handling strategies (including motion models) are included in the VMT scheme (Figure 1). An additional quality measure evaluates the overall localization performance of the VMT.

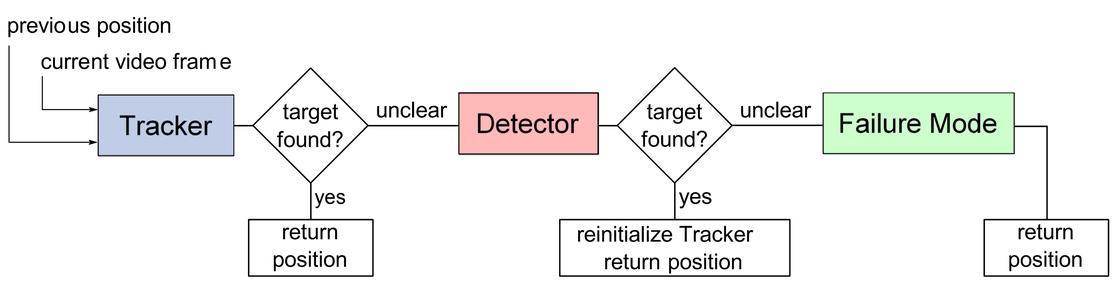

Figure 1: Flow chart of the presented VMT.

Tracker: The internal tracker is a kernelized correlation filter. It exploits the structure from overlapping sub-images in the training and evaluation of a non-linear classifier [1].

Detector: The detection method is based on more complex image features. In comparison to the tracker, it is able to detect changed object appearances profiting from pre-labelled data [2].

APPLICATION TO AIRBORNE WIND ENERGY

The developed tracking algorithm is applied to a ground-based AWE system developed by Fachhochschule Nordwestschweiz (FHNW). It has two purposes:

- **Quality assessment of existing estimators** (based on line angles)
- **State estimation in real-time application** (based on VMT)

The incorporation into the AWE setup is done in a modular approach (Figure 2). In the failure mode, the VMT uses the state estimated by the ground-station (GS) for additional position measurements, implicitly benefitting from the motion models and additional sensor data that are fused in the GS. The camera is mounted to the lead-out (Figure 3). After calibration and including camera motion, we receive VMT-based position measurements (Figure 4).

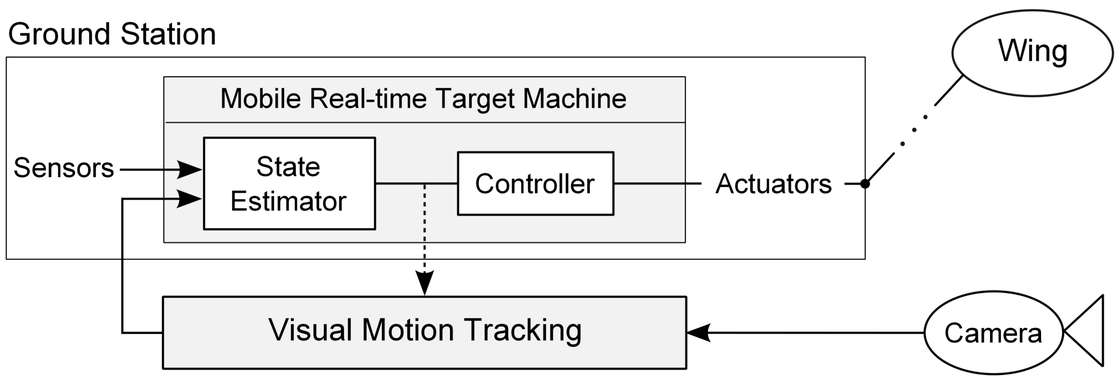

Figure 2: Computer Vision Setup: The VMT is running on a separate machine, consuming no computational resources of the GS control unit. During state estimation the tracked positions are fused with other sensor data and fed back to the VMT.

RESULTS

We have demonstrated the approach, tracking tethered wings in a series of visually challenging videos, containing: occlusions, camera motion, appearance changes, and long video duration**.**

In all videos the wing is tracked successfully with limited intermediate target losses and consequent re-detections. Comparing visual motion tracking results to measured line angle data reveals weaknesses in the line angle only based state estimators especially during retractions (Figures 4 and 5).

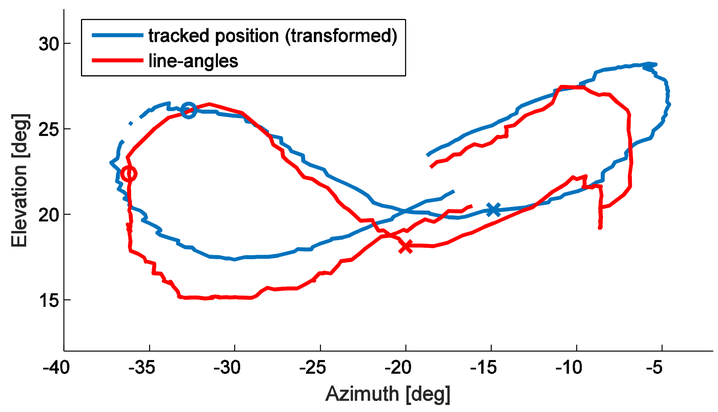

Figure 4: Tracked image positions are mapped to GS coordinates after calibration and correcting for the relative motion of the camera. Markers illustrate the instantaneous tracked positions at two different time instances.

Line dynamics introduce a varying lag, especially at low line tension during up-loop curves and retraction. Additionally, line sag causes a mismatch in the estimated position of up to 50m during retraction and 30m during traction phase for line length of 200m (Figure 5).

The continuous reinitalization of the internal tracker by target re-detections of the detector renders the presented VMT feasible for long-term real-time motion tracking. In the AWE state estimation, it improves existing estimators by visual measurements that are not affected by line dynamics (Figure 5).

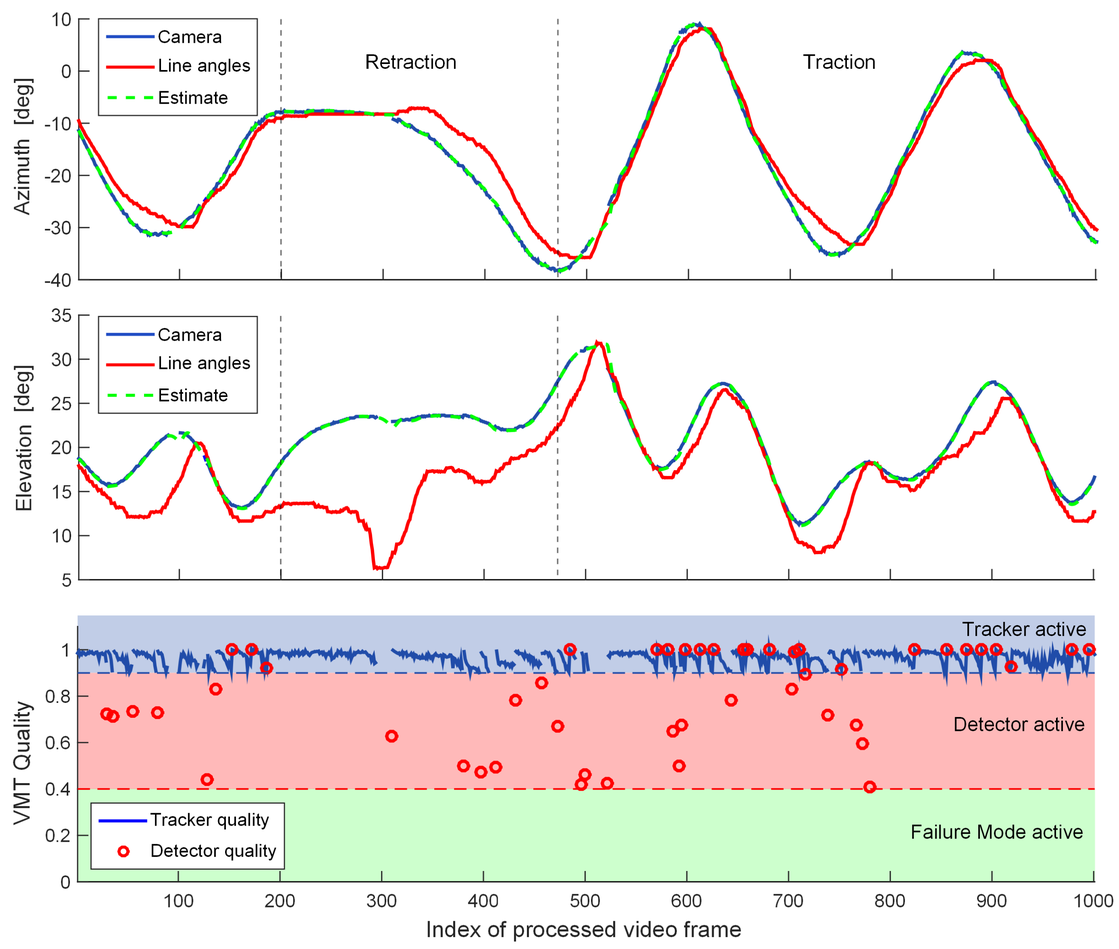

Figure 5: A full pumping cycle of a tethered wing with line lengths between 130m and 200m tracked at 24fps. In the upper two subfigures, the tracked position (blue), the measured line angles (red), and the Kalman filter based state estimate (green), that fuses line angles and VMT positions, are shown. The lowermost subfigure shows statistics for the VMT. Corresponding to colors in Figure 1, activity and quality of the internal tracker (blue) and detector (red) are plotted.

REFERENCES & ACKNOWLEDGEMENTS

[1] Henriques J., Caseiro R., Martins P., Batista J.: High-Speed Tracking with Kernelized Correlation Filters. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 37(3), 583-596 (2015).

[2] Dollar P., Appel R., Belongie S., Perona P.: Fast Feature Pyramids for Object Detection. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 3(8), 1532-1545 (2014).

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