Simultaneous Vision System Calibration and Full-motion Estimation Using a Sequence of Noisy Images from a Stereo Affine Cameras*

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Abstract— **The paper describes a kinematic model-based solution to estimate simultaneously the calibration parameters of the vision system and the full-motion of an object using a sequence of noisy images captured by a set of stereo affine cameras. Assuming a smooth motion, an Iterated Extended Kalman Filter (IEKF) is used to recursively estimate the cameras projection matrices and the object's full-motion over time. The estimator was developed having in mind the structure health monitoring of large structures of civil engineering domain, observed at long distance, in particular, of long deck suspension bridges.**

Results related to the performance evaluation, obtained by numerical simulation and with real experiments, are reported.

I. INTRODUCTION

The Structural Health Monitoring (SHM) is an emergent powerful diagnostic tool which can be used to identify and to prevent failures of the various components that comprise an infrastructure. In the case of large structures, and in particular of a suspension bridge, knowing the motion (displacement and rotation) over time is of utmost importance for their safety assessment. However, the traditional displacement transducers cannot be used because there is not a fixed point in the neighborhood of the part to be monitored and the displacements amplitude can achieve a couple of meters. A common solution is to measure the acceleration or the velocity and integrate the measured values in time domain. While in principle it is possible to recover the time history of the bridge deck displacement, it is well known that this method has several drawbacks [1, 2]. An enhanced solution comprises a non-contact measuring system with dynamic response, accuracy and amplitude range well-suited to the physical phenomenon to measure [1]. By now, only a few measurement systems satisfy these requirements, albeit partially. This set includes the systems based on: i) GPS (*Global Position System*) [3]; ii) radar technology [4]; and iii) optical devices [1, 2, 5, 6, 7, 8, 9, 10].

The GPS-based systems are well established in the health-monitoring field from long time ago. Using differential positioning techniques (RTK—Real Time Kinematic), these systems provide measurements with an accuracy of 10 mm in the horizontal direction and 20 mm in the vertical direction at a sampling rate of 20 Hz [3]. However, these systems are particularly sensitive to the signal multipath effect with a direct influence on the position accuracy.

Another non-contact measurement system is based on the radar principle [4]. A single measuring system is capable to measure the distance to multiple targets, up to 500 m away from the targets, and achieving an accuracy ranging from 10 μm to 100 μm at 40 Hz of sampling rate. Nonetheless, to identify clearly the targets the minimum distance between any two targets must be higher than 0.5 m. Otherwise the reflected signal from the targets will appear scrambled at the receiver, making it impossible to identify each target.

Laser systems constitute other category of non-contact devices used to measure displacements. This type of system may operate at a distance up to several hundreds of meters and providing a sampling rate up to a few hundreds of Hz [11]. Despite of that, its small range amplitude does not satisfy the usual requirements of long deck suspension bridges.

Amongst the set of non-contact measurement systems the vision-based systems are the more advantageous solution for tracking the motion of large structures, namely those built with steel material [1]. However, the number of vision-based measurement systems reported on the literature is very limited and most of them use very simple camera and motion models, which quickly fail when the structure displacement occurs in a plane not parallel to the image plane [2, 5, 6, 7, 8, 9, 10]. Most of these systems use only a single camera to track the motion of the structure, which does not allow recovering the full motion. Usually, the calibration follows an inadequate procedure, limited to the determination of the scale factor and in some cases also the aspect ratio parameter, which is clearly scarce to modeling the camera. Further, in general, the assessment of these vision-based systems was carried out at very short distance and, in some cases, using accelerometers as reference, which does not represent the real conditions.

Bearing in mind the measurement of the displacements of the deck of the bridge 25 de Abril, over the river Tagus, in Lisbon, (P25A), a vision-based measurement system was developed. The system aims to measure the displacements with an amplitude up to a couple of meters and a standard accuracy better than 10 mm. Though, to obtain measurements with the aforementioned accuracy an adequate vision system calibration and motion estimation procedures are required. Usually, the vision system calibration and the object's motion estimation procedures are performed independently, in separated steps, with the calibration being carried out in offline mode [1]. In this paper we will present a recursive algorithm that allows performing the vision system calibration and, simultaneously, estimate the full mo-

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