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Test installation of a Marker-based Framework for Structural Health Monitoring of Bridges

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Abstract. Regular health monitoring of bridges is a vital process to prevent serious structural damage. Marker-based systems, which follow the trajectory of objects by placing a well-characterized pattern on their surface and identify them on photos or videos taken of these objects, have proven to be a cheap and flexible alternative for such tasks. In this work, we extend our previous laboratory implementation with a low-cost, fully automatic on-site installation at the bridge at Arosa Island, Galicia, Spain. Preliminary results presented in this paper show that our system is highly robust for the harsh climate of the installation site.

Introduction

High forces due to wind, traffic, fluctuation of temperature or other sources cause bridges to deteriorate, which must be monitored in order to prevent serious damage or even catastrophes. Automatic structural health monitoring systems determine the level of safety based on data provided by different types of sensors installed on the bridges and aim to replace traditional on-site inspection by human experts. It has been shown that computer vision based systems offer a flexible and low-cost solution for a specific type of health monitoring, tracking of the movement of structural elements [1][2]. In a previous work [1], we proposed a marker-based system that uses planar, well-characterized patterns called fiducial markers [3] painted on the surface of the tracked objects. Standard computer vision algorithms [4] can determine the three dimensional position and orientation (with respect to the camera) of planar markers present on a photo and thus, by taking photos regularly from a fixed camera position, we can obtain the trajectory of objects with the desired sampling rate. The system can be made fully automatic using IP cameras that are accessed via internet. Thus, measurement data is collected remotely and markers are located, i.e. object trajectories are obtained off-line, independently of the data acquisition (Fig. 1). In this paper, we present our results and experiences of an on-site installation.

Application to elastomeric supports

Our system was installed at the bridge connecting the Arosa island with the mainland at the Atlantic Coast of Galicia in Spain. The bridge was constructed using elastomeric supports that connect pillars with the deck. When the deck expands or shrinks due to fluctuation of the temperature, it can slide on the support, preventing the structure to be damaged by the changes in its volume (Fig. 2). The high forces arisen during sliding cause damage in the elastomeric support making it less and less capable of sliding, i.e. losing its functionality. The health of the elastomeric support can be characterized by the total distance it has moved so far, if this reaches a certain threshold, the support has to be replaced. Thus, by tracking the trajectory we can minimize the frequency of costly reparations while maintaining safety of the structure.

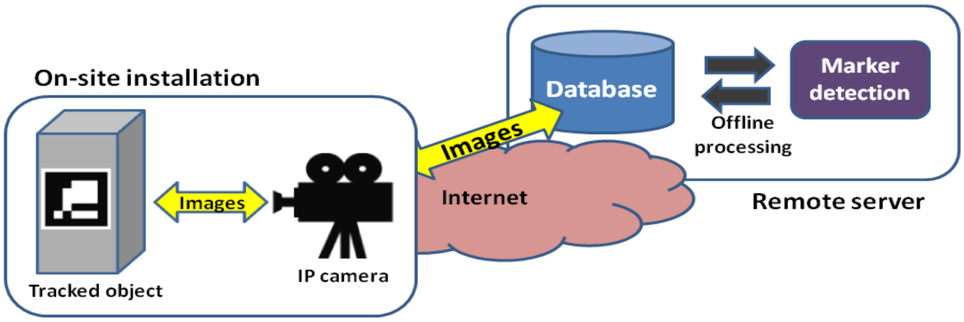


Figure 1: System overview. A marker is placed on the tracked object, which is followed by a camera. Captured photos are downloaded into a database via internet and processed offline.

Figure 2: Elastomeric support. The left image shows its location on the bridge, while the right image shows how the bridge is sliding on the support. Note that at the time of construction, the support was placed at the middle, while when the photo was taken it was shifted by around 30 cm.

Installation

We built our system using an Apexis APM-J0233-WS-IRC [5] camera, a low-cost 3G router and a 3G USB modem, all parts excluding the modem integrated into a protective metal box. Although the camera has infrared mode, for the protecting cover we used plexiglass which reflects infrared light, making it impossible to take night measurements (see Fig. 6). However, this could be solved by using a more expensive material that is completely transparent to both infrared and visible light. The total cost of the sensor was less than 300$. Fig. 3 shows the installation setup. The marker was placed on the deck, while the camera was put onto the pillar approximately 50 cm from the marker, resulting in a 2 mm detection error [1]. We note that the camera's horizontal axis may not coincide with the movement direction of the structure, any directions could be tracked, even in depth.

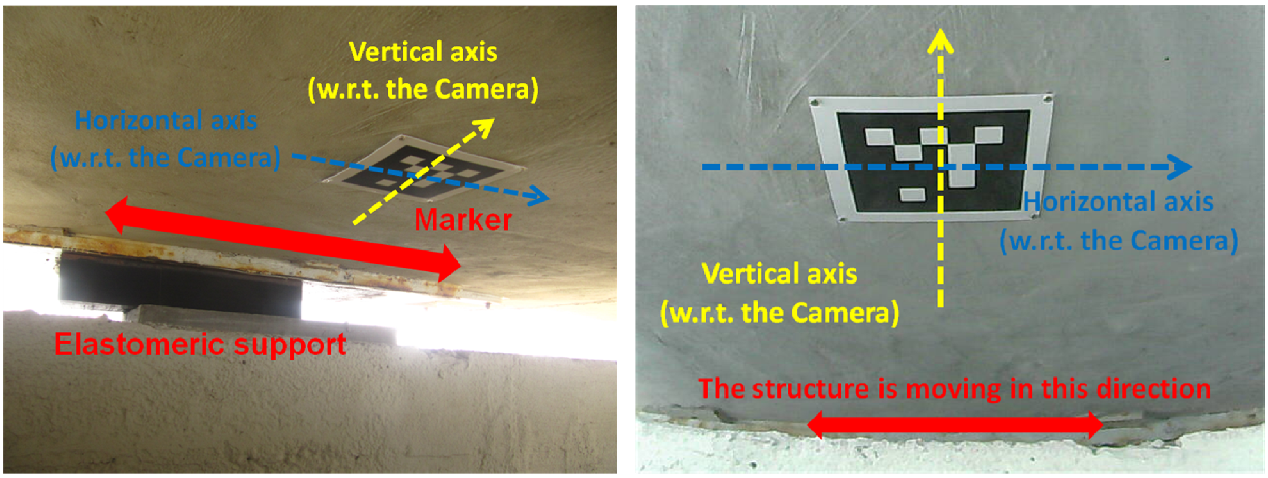
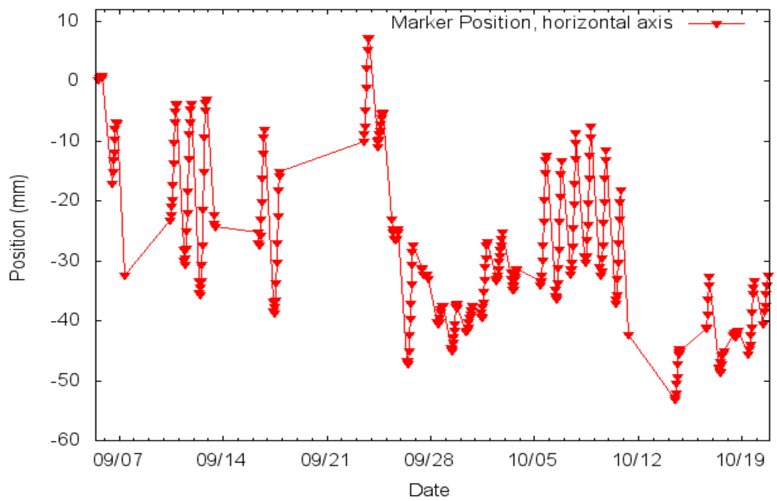


Figure 3: Camera coordinate-system from an outer (left) and the camera's (right) viewpoint

Measurement results

Measurements were collected for 6 weeks, with a photo taken at every daylight hour. Fig. 4 (left) shows the measured dilations of the marker along the horizontal axis of the camera in millimeters. Since movement along the vertical axis were at most 1 pixel (approx. 2 mm) and in depth no movement was detected, the depicted values well approximate the 3D trajectory. Note that in certain days, the deck moved almost 4 cm. However, we expect higher values during summer when the daily temperature fluctuations are much higher. The lack of measurements between September 18 and 22 was due to system maintenance of our database server. The rest of the outages were due to network and electricity issues, discussed in the next section. In order to illustrate how the marker moves during a single day, Fig. 4, right shows the border and center of the detected markers.

We also compared the dilations of the support to the daily temperature fluctuations measured by nearby meteorological stations at Tremoedo and Corón, which lie approximately 4 and 10 km away from the bridge, respectively. As Fig. 5 shows, there is a noticeable correlation between the temperature and the dilation (note that we scaled the dilation curve to match the scales of the temperature curves), however, since the bridge was built over a reach and the stations are located in the mainland we cannot expect perfect correlation. Still, it is obvious that the larger the daily fluctuation in temperature, the higher the structure position oscillates and additionally, the daily mean of the position tends to follow the mean temperature.



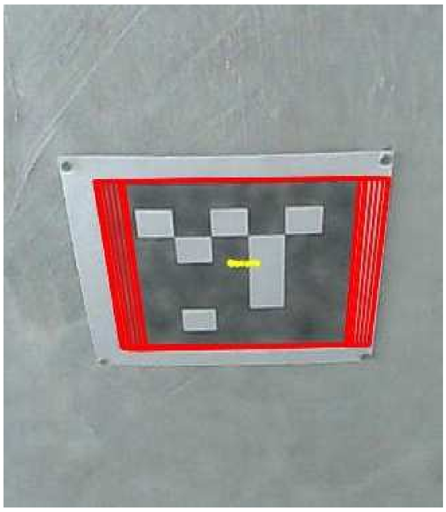


Figure 4: Dilations along the horizontal axis of the camera by time (left) and the evolution of marker positions during a single day (right)

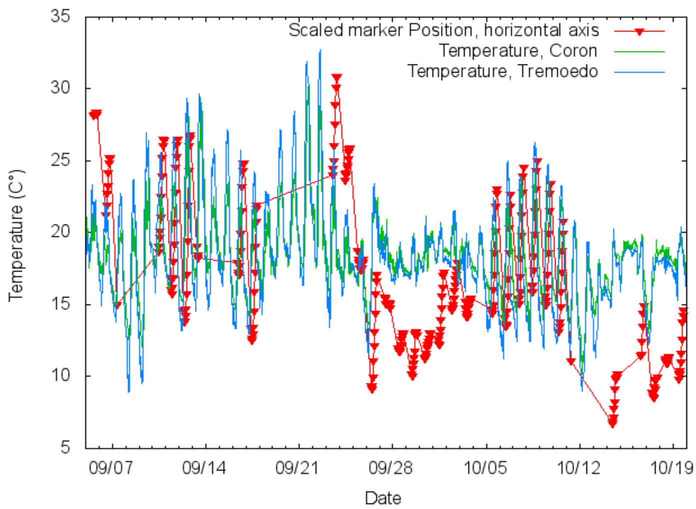


Figure 5: Correlation between the temperature curves measured at nearby meteorological stations and the dilation of the structure. The dilation was scaled to match the temperature curves.

Measurements are taken remotely, causing a limitation to our system. While the transfer of the data between the camera and the server is relatively easy, there are a few possible points of failure: temporal disconnection of the mobile telephone network due to e.g. strong storms at the installation site and outages of the dynamic domain name server (DDNS). However, our system was designed to return to online status once the problems are solved. We also note that introducing a buffer (e.g. a video recorder or hard drive) at the installation site would increase robustness, but also cost. In addition to network reliability, our system suffers from the limitations of vision-based approaches, low visibility conditions might cause the marker detection to fail (see Fig. 6). However, in our experiences, even in the harsh climate of the installation site, only 5% of the measurements failed.

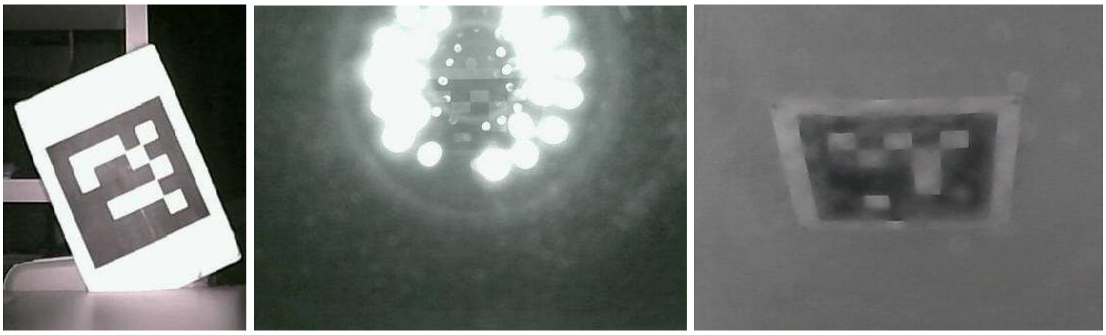


Figure 6: Image taken with infrared mode without the protective plexiglass (left), with plexiglass (middle), and a close-up of a failure case (raindrops due to lateral wind increase image noise)

Summary

This paper presented a test installation of a low-cost sensor system based on computer vision. We track the trajectory of an elastomeric support of a bridge, which is crucial in determining the lifetime of the support. Our results show that the system works well even under bad weather conditions; however, robustness may be further increased by fine tuning the marker detection algorithm to work under extreme visibility conditions and introducing a storage unit at the installation site to avoid data loss due to connection errors. As a future work, we are planning to install our system at more locations and test it for greater distances between the marker the camera.

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