The Battle of Algorithms for Vision-based Structural Health Monitoring.

R Kromanis [a], A Hawas [a], S Taylor [b] and L Bonenberg [c]

[a] Nottingham Trent University, [b] Queen's University Belfast, [c] University of Nottingham

Introduction

Developments in technologies provide engineers with powerful sensor systems that help assess performance of civil structures. In recent years, a great progress has been made in applications of computer vision in structural health monitoring (SHM). The deployment of cameras is particularly useful when capturing deformations of bridges. Applications of vision-based technologies also reduce risks of working at height and over busy roads and traffic disruptions, which are usually associated with the bridge closure during the installation of contact sensors. In addition to the above, computer vision applications can be integrated in student experience and teaching. For example, students could film a three-point flexural test of a beam and analyse its deformations using available image processing tools. But, are there many readily available tools and algorithms?

We are *throwing* an image processing challenge and inviting researchers, especially PhD candidates, to analyse images/videos of laboratory and real-world structures subjected to loadings. We have run a set of laboratory experiments, which are captured in images and videos, and recorded a video in which the Wilford Suspension Bridge (Nottingham, UK) is subjected to forced excitations. All images and videos where captured with smartphone cameras. Data files can be downloaded from a SharePoint site. You will have to send an email to Rolands Kromanis specifying data files you would like to access (see *Data* section).

The research challenge greatly contributes to developments and applications of computer vision in SHM. The challenge will be in a form of a workshop in which we expect to introduce and compare multiple image processing techniques to analyse images/videos, demonstrate applications of smartphone technologies in SHM and show how vision-based, data driven methodologies can be implemented in SHM. The workshop findings, image processing results and data interpretation are then anticipated to be published in a collaborative paper.

Challenge tasks

You are invited to take the challenge and "make sense" of deformation measurements that you will obtain from the provided images/videos. You will present your findings and methods in a report and, if selected, in the workshop organized at Nottingham Trent University (NTU). You are invited to attempt at least one of the challenges, write a short report about what you have done, how you have done it and what you have found out/learnt about the structure and its conditions and collected data. In total there are four challenges:

1. Static load tests on a timber beam,
2. Dynamic forced excitations of a timber beam,
3. Quasi-static loads on an aluminium beam, and
4. Wilford suspension bridge forced excitations.

You can find more about each challenge below.

Static load tests on a timber beam

A simply supported timber beam is considered for this challenge (see Figure 1). The left support is pinned allowing for lateral rotations only, while the right support allows for movements in the longitudinal direction and lateral rotations. The length between supports is 1100 mm. The cross-section of the beam is $20\,mm \times 27\,mm$, width and depth respectively. The structure is subjected to a series of static load tests, in which 30 N load is applied and removed manually five times at the middle of the beam (see Figure 1). A typical load cycle is as follows: no load for 30 s, load is applied and left for 30 s then removed. The beam is known to be in good conditions during the application of the first static load cycle. What happens next, is for you to find out and tell.

Images of the structure during the tests are collected every second using Samsung A5. Artificial markers with a uniform pattern are painted on the beam. Marker dimensions are provided in Figure 1. The markers are drawn to simulate structural features such as bolts or connections in steel bridges. As will be seen from the images provided in the data set, a paper sheet is glued to the beam. This is to hide damage locations, and make the damage detection more challenging.

Your task is to estimate the deformation from provided images and comment on what is happening to the structure. Please use any image processing approach that you find to be the most suitable.

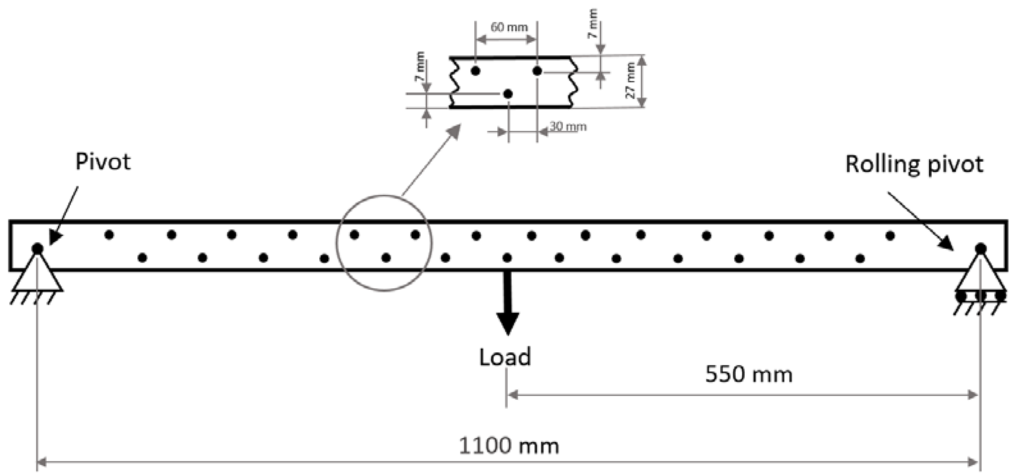

Figure 1: The experimental layout of simply supported beam.

Dynamic forced excitations of a timber beam

Forced dynamic excitation tests are carried out on the same timber beam shown in Figure 1. The beam is excited by a sudden removal of the force from its mid-span (the same location where the load is applied for the static test). Similarly to the static test, a dynamic test, which itself included three repetitions of sudden removal of the applied force, is carried out five times. Tests are carried out one after other. Samsung S8 phone is used for the experiment. HD (1280×720) 240 frames per second (fps) video is recorded for each test. The order of the tests can be recognized from the time-stamps (file names) indicating when the start of the test. For example, the video file name of the first test, in which the structure is assumed to be undamaged, is 20180621_164241.mp4.

Your task is, again, to make sense of data. For example, you could find the natural frequency of the beam and check if it changes over the tests and if there is a clue leading to which part of the structure is damaged. You can use any image/video processing approach that you find to be the most suitable.

Quasi-static loads on an aluminium beam

For the quasi-static test, a simply supported aluminium C-beam, which is coated with a black matt paint, is chosen. The support on each side is pinned in two points. The setup should prevent beam from rotations and movements (especially in the longitudinal direction). The length between supports is 1120 mm. The C-beam cross-section is a square with 38 mm depth/width. The section thickness is 3 mm. The structure is subjected to artificially simulated daily temperature cycles. Two 500 W thermal heaters are set 200 mm away and above the mid-span of the beam. In total three simulated cycles are considered. A simulated cycle is as follows: only ambient temperature is applied for 30 min, then the heaters are turned on for 45 min and then 30 min ambient temperature before the cycle is repeated. (Images corresponding to three simulated cycles are made available.) The beam setup with relevant information is provided in Figure 2. Markers are drawn on the surface of the beam at its mid-span. A regular pattern is used. Five thermocouples (TCs) are installed to collect distributed temperature. Their approximate locations are shown in Figure 2. TC-5 measures ambient temperature in the lab. TC-1 to TC-4 are installed in the inside of the C-beam (see section A-A in Figure 2). Thermocouples collect measurements every 10 sec. Samsung A5 is use to take an image every 30 sec. The smartphone is placed very close to the structure and only the region with the markers is captured.

The structure is in healthy conditions during the first simulated cycle. Your task is to obtain thermal response of the beam and analyse it for anomaly events. The provided temperature data might help. You may consider using the regression-based thermal response prediction methodology (see the paper by Kromanis and Kripakaran (2014) "*Predicting thermal response of bridges using regression models derived from measurement histories*").

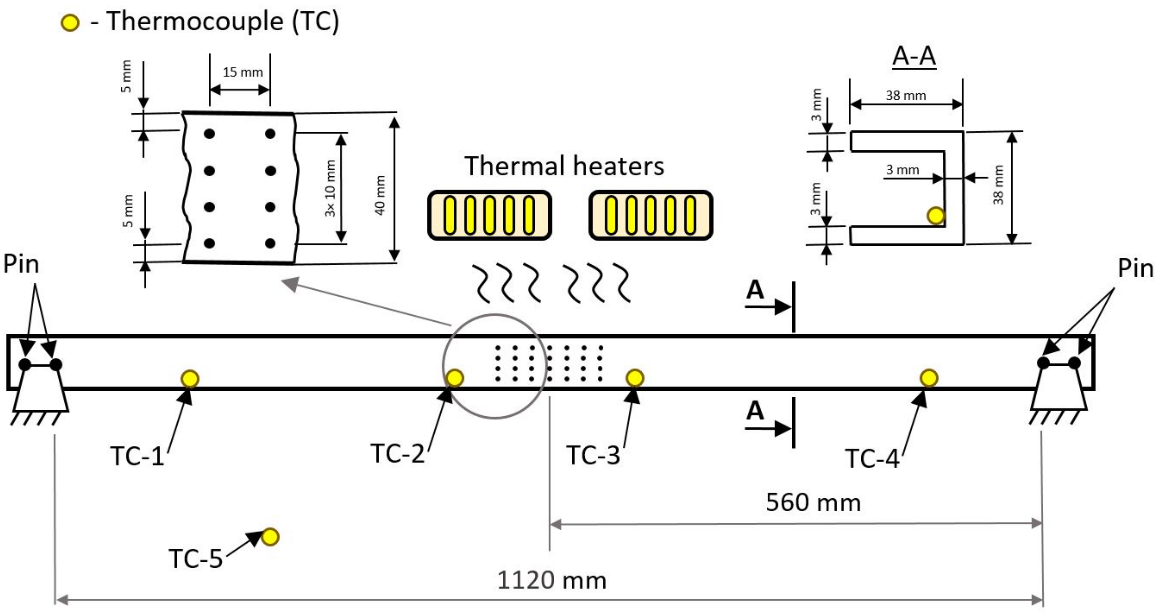

Figure 2: The experimental layout of quasi-static test.

Wilford suspension bridge forced excitations.

The Wilford Suspension Bridge crosses the River Trent and is both a footbridge and aqueduct bridge. A sketch of the bridge with its principal dimensions is shown Figure 3. Some of the given dimensions can be used to generate a scale factor to convert pixel information to engineering units. Samsung S8 is placed at an angle approximately 40 m away from the mid-span of the bridge, at which it is focused. A 4 K (3840×2160 pixel) video at 24 frames per second is recorded. The bridge is exposed to periods of forced vibrations (students jumping on the bridge).

Your task is to extract displacement information of the bridge and comment on it. Two example can be found on YouTube, see *"Capturing forced excitation of the Wilford Suspension Bridge using Samsung S8"* and *"DeforMonit - Capturing dynamic movements of a bridge using a smartphone"*. You can address issues related to the stability of camera, camera drift etc. You can also derive natural frequencies of the bridge.

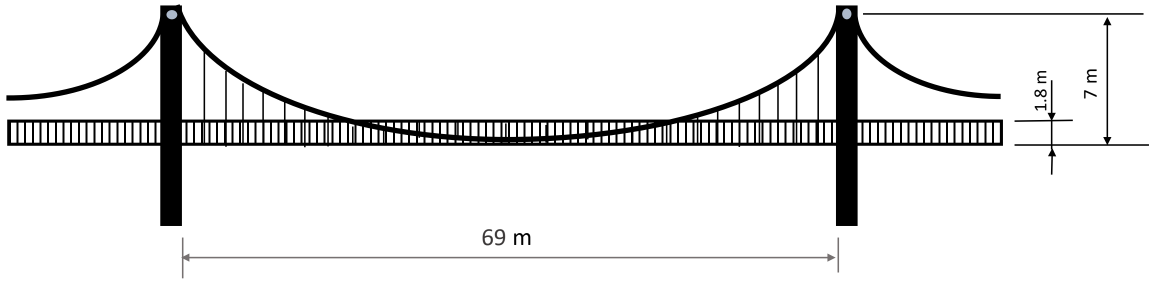

Figure 3 A sketch of the Wilford Suspension Bridge

Data

In total four data files are made available. Please send a request to Rolands Kromanis and we will share the data files via SharePoint. Please be specific which data you would like to access. You can request an access to all four data files, however, it is not anticipated that you will analyse all of them (this can be very time consuming). The following data files are available:

(1) Static tests. A *.zip file with images of a beam subjected to five cyclic load tests. The name of an image is times when a photo was captured. (File size: 423 MB).
(2) Dynamic tests. Five videos of the dynamic tests. In each video the structure is excited tree times. The name of a video is time when it was recorded. (File size: 268 MB).
(3) Quasi-static test: A folder with a *.zip file with images, their names are times when images were captured (file size: 1.64 GB), and a *.xlsx file with temperature measurements.
(4) Wilford Suspension bridge: A 4K video which contains some activities on the bridge. You will see them in the video. (File size: 2.56 GB).

Report on findings

The deadline for submission of the report is 3rd September at 12 noon. The report is expected to provide evidence of appropriate image processing approaches, analysis of measurements and discussions/findings/results. You do not have to write lengthy introduction with a literature review. You should introduce reader to the problem, explain what method you are using to obtain structural movements from images/videos and show what you do then to analyse time-histories of measurements. Discussions, conclusions and future recommendations are much appreciated. Successful candidates will be invited to present their findings at the workshop. The workshop findings, image processing results and data interpretation is then anticipated to be published in a collaborative research paper.

Workshop attendance

PhD candidates are eligible to receive contribution towards their travel expanses to/from the workshop location, which is in NTU, Nottingham, UK. The contribution towards travel expenses can be up to £50 for UK students. The contribution amount depends on the location from which the applicant is traveling and number of received applications. For example, students traveling from Northern Ireland or Scotland could receive up to £100 towards their travel expenses. PhD candidates outside the UK are also encouraged to apply. The budget is limited therefore we cannot guarantee that all applicants will receive support with travel expenses. Therefore, you should express your interest to participate in the workshop as soon as possible. Once you will receive the confirmation of your attendance and access to the data files, you should provide an estimate of your travel expenses. Once your travel expenses and the amount that will be reimbursed after you have visited the workshop are confirmed, you can proceed with booking bus, train or plane tickets. Please seek the discounted tickets. This will allow more participants to take part.

The workshop will take place on Thursday 20th September 2018 in Newton building (room will be specified when it will come closer to the day), Nottingham Trent University, Nottingham, UK. The registration will start from 9:30 AM and the workshop will start at 10:00 AM. Drinks and meals will be provided.

Best presentation and paper awards

There will be awards for your reports/findings and also presentation. Therefore, please try to prepare a good quality report and presentation (if invited to give one).

Information

For any further information, please contact:

Dr Rolands Kromanis: rolands.kromanis@ntu.ac.uk

Dr Allan Hawas: allan.hawas@ntu.ac.uk