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ON THE USE OF ARUCO MARKERS IN LONG TERM MONITORING OF TIMBER STRUCTURES

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ABSTRACT: For research and monitoring purposes, there is a need to measure long-term displacements of parts, joints, etc. Of course, existing solutions (LVDT, Tell tales, etc.) can be used, but they are relatively expensive or inaccurate. The article describes a simple procedure based on an optical method using ArUco markers originating from computer vision applications (robotics). This technique uses not only marker tracking, but also along with it image rectification using projective transformation, and thus works well in 2D structures (beams, walls). The illustrated principle allows to take only two images (the original and another one after a certain time) and to quantify the displacement and rotation of the markers identified in the images. Reference points have to be specified. The displacement fields are then interpolated and a final map is produced. This can be of interest to anyone working in practice, conducting research on the long-term behavior of joints, monitoring the creep of wooden structures or for any monitoring purpose - including laboratory tasks. The article describes accuracy and error estimation and shows an example of use.

KEYWORDS: Monitoring of timber structures, ArUco markers, measurement of displacement, long term monitoring.

1 INTRODUCTION

The work presented in the article was created and inspired in everyday practice, both in the laboratory and in-situ. Measuring long-term displacement fields in wood joints or in wood research in general (e.g. shrinkage due to moisture changes) is a complicated matter, as expensive in-situ equipment is not preferred due to possible damage, suffering also from issues like a need of stable power supply, data storage or simply because of the fact that the device is blocked for a period of time for further activities, etc. What is then needed for reliable displacement measurement not only in the wood engineering industry? It is an inexpensive practice that can be used repeatedly, which keeps the data for further analysis and is sufficiently accurate. Such a solution can be attained when taking the advantage of computer vision algorithms. Since many algorithms in this field have been already developed [1], the users need to understand them and use them properly to ensure a reliable result of the analysis.

Optical measurement of movements or strain fields can be performed using marker tracking (e.g. the ones commonly spotted in car crash tests) or based on minimization of warping of a subset in a sequence of images leading directly to digital image correlation (DIC). Because digital image correlation is very sensitive to any moves of the camera, usually it is the choice for laboratory testing, where there is no need of repositioning of the optical device etc. Further text is thus focused on CV [1] and marker-based procedures, which allow (re)moving the camera and return it later after some time.

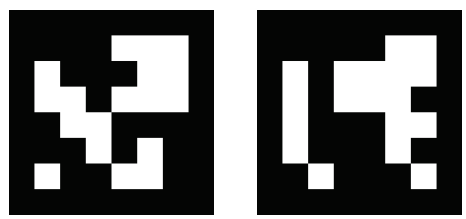

Figure 1: *Samples of two distinct ArUco markers*

The idea is to use an industrial camera (or even an ordinary one) to obtain a picture of the scene and compute the precise position of markers of known dimensions. There are more types of markers [7], but the very simple ones, the ArUco markers [2] have multiple advantages: their area and corners are relatively big to ensure good contrast. The markers have been developed for use in robotics, where cameras are serving as the eyes of the robot and let it orientate in 3D space using found points. Such a marker has simple geometry (see Figure 1) and has also an ID coded in the binary map. That allows to recognize the markers from each other and use further processes to track their relative change. It should be noted that these markers can be printed out very cheap way by a standard laser printer (whose precision 1200 DPI is expected) and glued to the surface use a glue or an adhesive gum. This setup is the starting point for further analysis.

Of course, measurement of precise point displacement can be done using standard geodetic approaches, such as total station or laser-based methods, however, this article goes

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its own way because a gap in monitoring techniques has been found, especially for rigid body motion assessment: a very cheap technique, that can be done using basic equipment without additional cost and which is relatively powerful. To attract the interest of the professionals and public, the author decided to spread and discuss it in the conference.

2 METHODS

2.1 PRINCIPLE

Theoretical starting point is the image rectification based on projective transformation [3,4]. The method uses the alignment of the image sequence to one image plane (usually to the reference one). The principle requires presence of four rigid reference points in the scene. In next step the algorithm determines the point differences in this (already aligned) reference image plane. Because of this fact the validity of the method is to 2D planar problems because projective transformation is limited to it. The number of problems where this approach can be used is high in civil engineering (beams from the side, walls, crack monitoring). Clearly enough, there is a lot of errors that can be made during the process and which are more in detail discussed later.

2.2 STEP BY STEP ANALYSIS

For clarity the methodology is outlined in following steps and commented more in detail in the paragraphs below:

1. Choose the object for monitoring
2. Print the markers in corresponding size and resolution
3. Select the 'reference part' in the scene and glue 4 markers to represent it
4. Glue the rest of the markers; the more, the better
5. Prepare the camera and perform the camera calibration (needed just once for given lens-camera system)
6. Take one reference image (t_0)
7. Come after some time and place the camera in similar place
8. Take another image (t_n)
9. Repeat step 7 and 8 as many times as needed
10. Analyze the result using the above outlined CV procedures
11. Interpolate and review the displacement field

The object dimension of course affects the precision of the process, since the precision of determination of the marker corners can be in practice considered 0.1 pixel (sub-pixel resolution up to 0.01 px is possible, but not realistic). That is also the key parameter to consider the size of the marker, as minimum 50x50 pixels representation of one marker in the whole scene can be recommended for reliable analysis. Generation of ArUco markers is included in the ArUco OpenCV-contrib package [1], and is coded using a simple Python script. Parameters of such a generation are image size and ID range to generate. The markers should be printed using a laser printer with high resolution; here the method uses the fact, that laser printer is usually the most precise mass-produced device in the office: 1200 DPI means 21 μm dot size! Markers do not have to be printed only on paper, but there exist also vinyl (PVC) sheets for printing. This is very important in the case of humid conditions when paper and timber can have significant shape changes.

The scene has to include the part which is rigid and not moving, since tiny shifts of reference points can jeopardize heavily the analysis results. That is why it is not good to measure members (or joints), which have still strong moisture-related volumetric changes, namely joints made of fresh timber. Such problems can be solved different way: using a matrix of reference points which can be after analysis of their relative displacement (distribution of strain has to be even) reduced to 4 reference points (rarely used). Highest precision is attained if the four reference points are close to four corners of the image, but this is rather an uncommon case, since the part that is monitored has to be inside the reference area. Reference points and actually the whole monitored object should be in the paraxial part of the picture, centered, which ensures lowest distortion.

Markers should be glued using a glue that does not change the shape with change of conditions and which is cheap, standard office glue is often the best one. For rough surfaces can be used an elastic adhesive gum glue.

Camera and lens should be selected carefully. Here an understanding of basic optical principles is needed. Best solution is a HQ camera with at least 5 MP resolution as is used during testing of the setup here: Basler Aca2440-20gm (see Figure 2). Global electronic (preferably not mechanic) shutter with rather bigger chip size should be selected. Field of view (FOV) is the key for proper lens selection, nevertheless, avoid fish-eye effect as much as possible, go for longer lens if the chip size allows it. Always use fixed focal length. In the test a Basler C23-1620-5M-P 16 mm lens with polarizing filter to evite reflections. Camera can be mounted to any camera stand, preferably with all DOFs adjustable.

Figure 2: *Camera and lens used in the tests*

For proper measurement, camera has to be properly calibrated [6] and its intrinsic matrix assessed. This technology allows for rectification of the images taken and remove the lens distortion (undistort them). Such a process is made using OpenCV routines described in [7] and a simple chessboard, see Figure 3.

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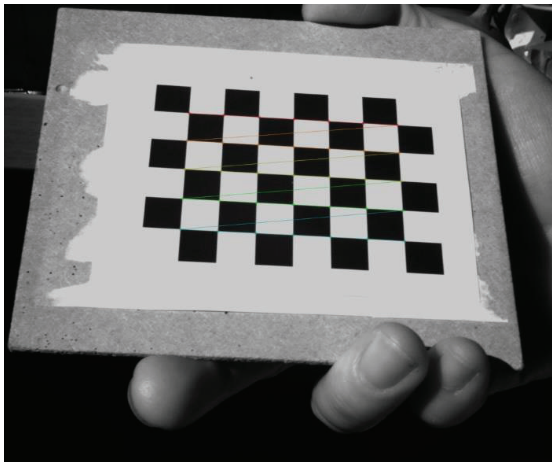

Figure 3: *Camera calibration using a chessboard*

The image acquisition is best, if the takes multiple images and computes an average out of them, since it significantly removes the noise and increases the precision of the measurement. Highest possible illumination along with highest aperture is always preferred.

The whole procedure is programmed using Python and is available for download in [5] under 3-clause BSD license. All people interested in the details can go through the code and look at the solution row by row.

Doubts arise about precision of camera repositioning when the image acquisition is repeated after some time and the camera was removed in between. As an answer it is important to assess the error. Abstractly the error estimation consists of multiple sources of possible error: lens distortion, chip noise, marker position assessment, marker printing, camera calibration error, paraxiality of the marker position (it is always not preferable to undistort the images as it is another idealization), camera repositioning (distance and angular), roundoffs in the CV algorithms. It is not possible to describe such a complexity here, the error estimation would be valid for the particular case and cannot be simply evaluated here in the extent of this article. That is why an example is shown here, which shows the method when focused on *absolutely stable testing plane*: in such case all movements measured would be made by errors of the measurement itself and not made by the displacements. That is how the reader of the article can have an idea about the error present in the measurement.

2.3 TEST AND ERROR ESTIMATION

The test can be shown in Figure 4, when four markers in the left paper (A4, 297x210 mm) are taken as reference points and four in the right are being evaluated. Marker size was 25 mm, their distance was horizontally 120 mm and vertically 169 mm (center-center), working distance 1.382 m, height of the optical axis (chip axis) was 0.819 m.

The goal of the test was to estimate the error if the camera is moved with precision that one can achieve in-situ if there is a marker on the floor for example. Two linear sliding plates were mounted on each other to be able to simulate the precise displacement simulating errors in repositioning, see Figure 5.

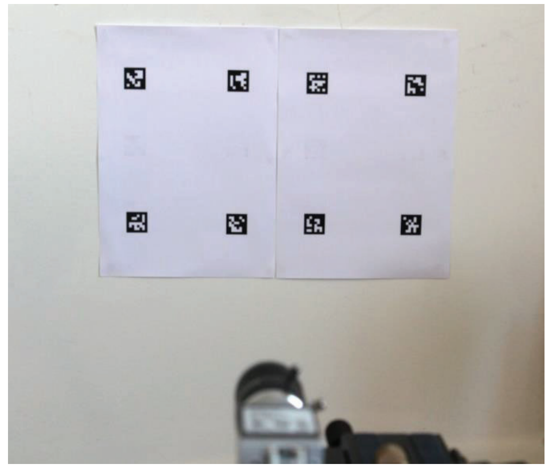

Figure 4: *Testing rig (papers not moved) for the error estimation*

The precise position changed to (points are referred later in results as e.g. 2.3.1 – the first one):

1) -5 cm in X and -5 cm in Z axis (for orientation see Figure 5, going to the left and farther from the object),
2) +5 cm in Z direction (moving closer to the object)
3) yaw - rotate 5 degrees (rotation towards upper left corner in the image)

Output of the analysis is shown in the results section.

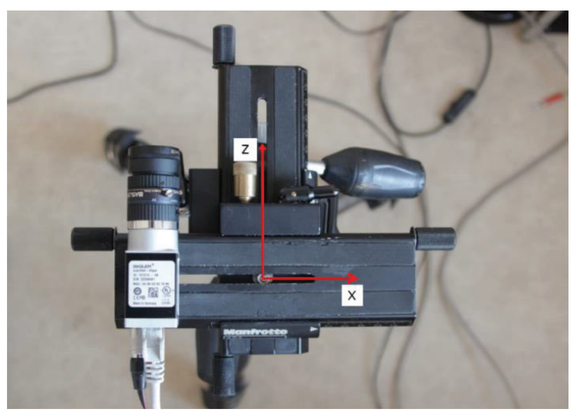

Figure 5: M*ount allows for defined camera (re)positioning in two axes (x and z, bottom)*

2.4 EXAMPLE FROM TIMBER JOINTS MONITORING

To show the measurement system described here more in the context of timber structures, another artificial example of use has been made: lap timber joint with slight rotational move – 5 mm timber peg was placed under the joint (see Figure 5). The movement amplitude is not important here, this case is for illustration of use only. The height of the joint is in reality 60 mm, marker size 8 mm. The same camera was used, lens was 55 mm telecentric (not fully) Computar TEC-M55MPW, same procedure as described above, however, camera was only removed and clicked back to the stand.

Figure 6: Illustration of use in a timber joint, two images are aligned onto each other and the relative move of the markers is computed

3 RESULTS

3.1 TEST AND ERROR ESTIMATION

For the analysis of the camera movement see Figure 6-8. The results are very positive, case -5 cm in both axes is depicted in Figure 6. Maximal error is 0.09 mm, however, remember the whole area is 300 mm by 150 mm.

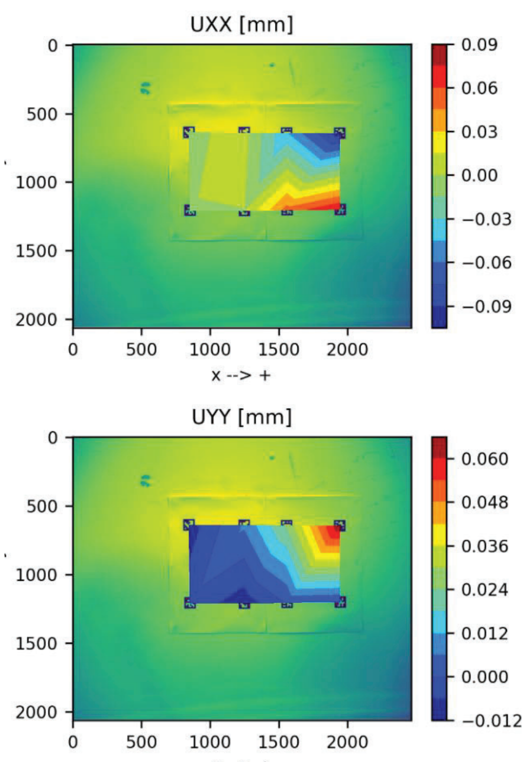

Figure 7: Interpolated displacement field case 2.3.1)

Second configuration, 5 cm movement towards the object provides even better results, maximum is 0.016 mm.

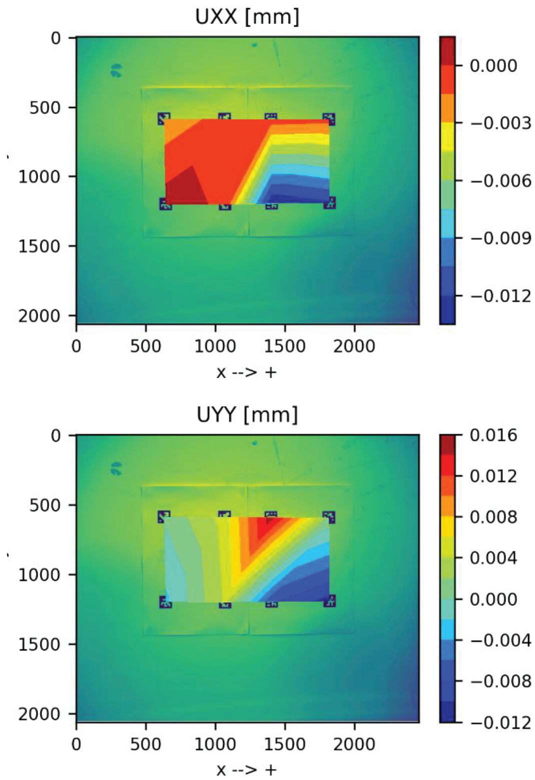

Figure 8: Interpolated displacement field case 2.3.2)

As the worst can be seen the angular rotation 5°, as can be seen in Figure 8. However, the results are still not bad, only 0.12 mm. So, the usability of the method is dependent on the precision in structure displacement one wants to measure and can expect.

If case 2) is compared to 1) and 3) it can be concluded, that biggest errors are present in case there is a big move for from the optical axis outside the paraxial area and the curvature of the lens can produce this amount of distortion (although the image was undistorted). Based on the lens focal length and thus its curvature, this error will be higher in case smaller chip size and shorter focal length is selected.

3.2 EXAMPLE FROM TIMBER JOINTS MONITORING

The results of this analysis from 2.4 can be found in Figure 9. Because not precise prescribed move was made using universal testing machine or similar machine, the results cannot be compared directly to the 5 mm peg size. This example is of course intended to show the potential of the methodology for monitoring of structures in time. Note the fact, that the number of colors in the images is directly specified as the number of contours during plotting of the graphs.

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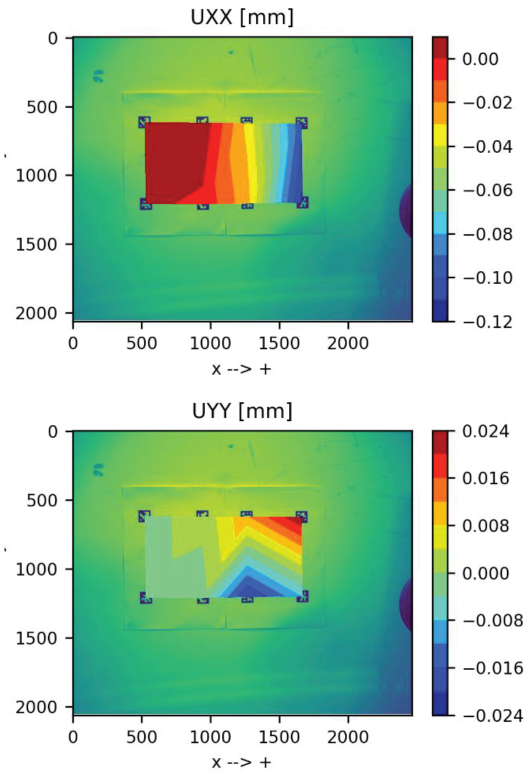

Figure 9: *Interpolated displacement field case 2.3.3)*

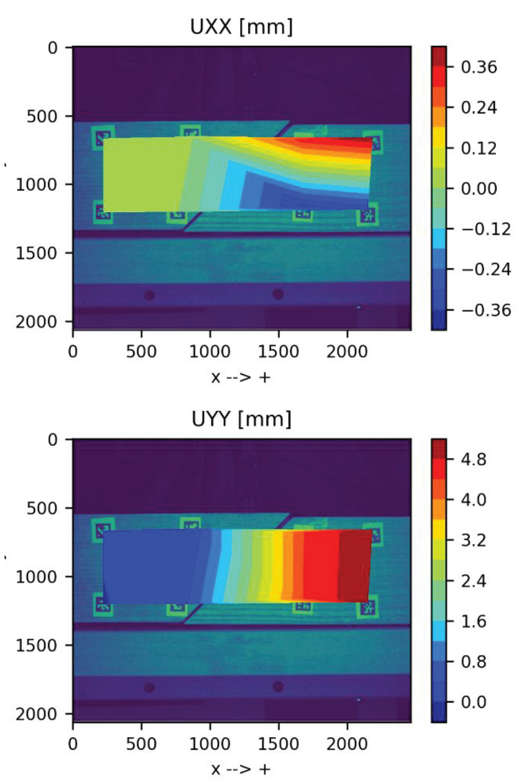

Figure 10: *Interpolated displacement field – half lap joint*

3.3 FINAL REMARKS AND DISCUSSION

The results show according to the author very precise determination of the studied quantities. This enables the method to be used in many applications, where some reference can be found and where only 2D movements take place.

It is good to mention that the displacement field is not continuous enough due to low number of points. That is also the case why one cannot think about strain measurement and stay only in the domain of displacements. Of course, more markers can be glued, the mesh densified and the computed field smoothed using splines; but the quality of strain field will be never the one seen in DIC.

It is a question if one is able to place precisely the camera with say 5 cm error to the place where it was before; from author's experience it definitely is possible, and, actually, it is possible even with higher precision.

The marker-based approach is very convenient because it does not need the same light conditions – markers are recognized even in different light intensity. Such a thing would be never possible when thinking about time-lapse digital image correlation. It should be pointed out that the technique overgoes the problems with shadows in DIC, a problem very often found in rough surfaces and annual rings when the light is repositioned back. The markers can be also removed without any stain remaining on the body.

If swelling or shrinking is present, the inspector can put a reference piece of (metal or glass) ruler. Another option is to use markers made of material that do not swell (e.g. silicone-based).

The algorithm takes images which are saved and which can be also analyzed by somebody else later. This can play a significant role when survey of the joint shape is required. It can be used in relatively short periods to quantify the amount of creep, and the results are so precise, that the trend can be assessed (is the crack active or is it already not moving/opening?). Big magnification can be used as well, in this case the precision of repositioning is a very sensitive parameter.

As the biggest disadvantage thus remains the need of reference points inside the picture. This can be, however, solved using another precise positioning system: a rigid and stable object can be mounted before the 2D object and use the advantage of depth of field to focus properly both objects. ArUco detection of not well focused markers is possible and can be valid.

4 CONCLUSIONS

The paper describes a procedure that is able to monitor very precisely marker displacement in time. The marker position and density as well as the whole procedure is based on experience and precision, and thus depends also on the person who prepares it. Error estimation and a sample of use is described. The marker tracking itself – not along with the projective transformation - can be used for other uses as well – e.g. assessment of stiffness of a testing rig using optical measurement (MMB test). However, the original use could be broad and might be very cheap and fruitful for all interested in long term monitoring of timber structures or in-situ survey. Since it is not based on a commercial code, the method is provided to the scientific community as is. The technique is not a solution for everything and needs proper selection of use. For some types of long-term structure monitoring it is perfectly suitable.

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