INVESTIGATION OF CONSTRUCTION OBJECT'S DEFORMATION BY LOCAL IMAGE REGISTRATION

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1. ABSTRACT

This paper presents the method of 2D image registration applied to estimation of construction object's deformation. In process of local image registration two similarity measures were used: mutual information and cross-correlation. The presented method is fast and simple technique of monitoring local construction's displacements on basis of reference and control image. Due to availability of high resolution digital cameras it is a cost effective alternative to classical geodetic methods. The accuracy of the proposed solution was verified by precise geodetic measurements.

2. CONSTRACTION OBJECT'S DEFORMATION

Structures and building constructions under load and strain are undergoing stress that is dangerous to their safety. In order to guaranty their stability it is important to run a cyclical surveys of the changes in their geometrical shape. Traditionally geodetic and mechanical methods are used that measure the construction deformation in point wise manner. It is necessary to define the localization of the control points and installation of special measuring equipment before the survey starts. In contrary to them, photogrammetry methods allow to record an image of the controlled object with millions of pixels. The location of control points may be determined and changed at any time, what makes photogrammetry a very flexible method.

Here we present a concept of estimation of object's deformation by a local registration of reference and controlled image.

3. IMAGE REGISTRATION

Image registration is a very important task in analysis of visual data. In the last decades we observe a growing amount of new image registration techniques as well as new ways to use older classical methods. In general the image registration is the process of finding the relation between the images according to a given transformation model. Today both methodology of searching the optimal solution and the models used for registration vary greatly.

In this investigation we applied area based method that used either cross-correlation or mutual information as a similarity measure. We used affine transformation model and calculated optimal solution applying gradient descent method.

4. LOCAL IMAGE REGISTRATION

One of the main problems in image registration is a choice of an appropriate deformation model. When we analyze the deformation of an object on the photography it is very difficult to define any global deformation model that would take into account both unmodified, static, background content and deformed object. In order to solve this problem we decided to use the property that observing an appropriately small region of a deformed image we can see that deformation of the given part is close to affine transformation. This means that instead of performing the global complicated registration we can determine the shifts for a number of points based on their small local content using only affine transformations. As an output we get a set of control points and their shifts, rotations, scaling and sheering. When we are interested in the points shifts only than we can omit the rotation, scale and sheer part leaving only displacements of the points.
In this paper we registered images of the construction object taken at different moments under different loading conditions. The object that we observed was a catwalk of a steel roof in WUT Main Hall. We took one reference image without extra load and a number of images, under different encumbrances. Since all images were deformed by lense distortion we had to calibrate the images first. Later we chose a number of background control points and performed global rigid (only translations and rotations) registration of reference image with deformed images so as to have the same coordinate system for all images. Next we picked regions of interest of the deformed structure for which we performed the local affine registration taking under consideration only their small neighborhood. The achieved shifts were compared with the previous precise measurements of the catwalk.

Fig. 1. Photography of a steel construction of the roof at WUT Main Hall.

4.1 Lense calibration

In our observations of the encumbered catwalk we expected the deformations to be approximately 1mm in central part of the construction, which for a given distance, camera resolution, and view angle of applied lense, 70mm, is equivalent of a sub-pixel shift on a digital image. In order to detect a small shifts of an observed object the algorithm must take into account the lense distortion.

In order to build a correction transformation we took an image of a check-board pattern. The projective transformation was applied to the perfect reference check board pattern so as to align its corners with the image taken. Than a large number of control points were chosen so as to calculate the calibration transformation. We used third order polynomial as a deformation function. It gave satisfactory results removing the deformation in large central part of the field of view, however the distortion in the corners of the image was too high to use those regions for further registration.

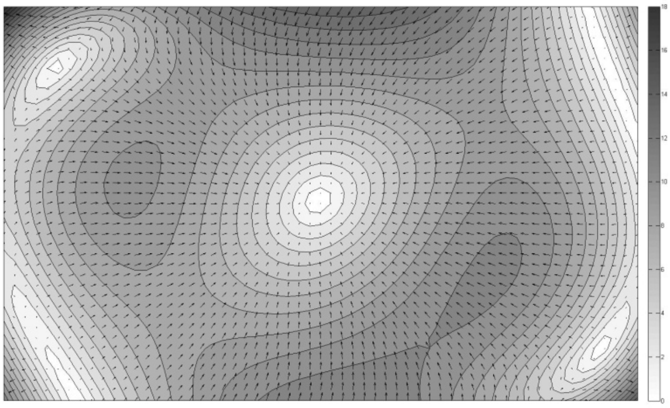

Fig. 2. Calibration function. The arrows define which direction to modify the original photography in order to correct it for a lense distortion. The magnitude of correction was between 0 and 17 pixels.

4.2 Background registration

Second step of the method is to perform rigid registration of the reference and deformed image so as to align the backgrounds of the photographs. The registration was done using a number of control points located in characteristic regions of the backgrounds. The locations of the points were refined using local affine image registration. Global rigid transformation was estimated by minimizing the mean square error. After this procedure the remaining differences between the images can be associated with the objects deformations.

4.3 Deformation estimation

When both images were aligned in respect to static objects, background, we could estimate the deformation of the observed structure. In this process we select a number of points on the controlled object that we want to calculate shifts for. Than we decide what is the relevant neighborhood for each of them. We need to remember that it is best if this region does not contain any elements from background since it will have an impact on registration process, however the smaller the registration region the less stable algorithm may be. Than by maximizing the similarity measure by gradient descent we looked for best solution. As a similarity measure we used cross-correlation and mutual information.

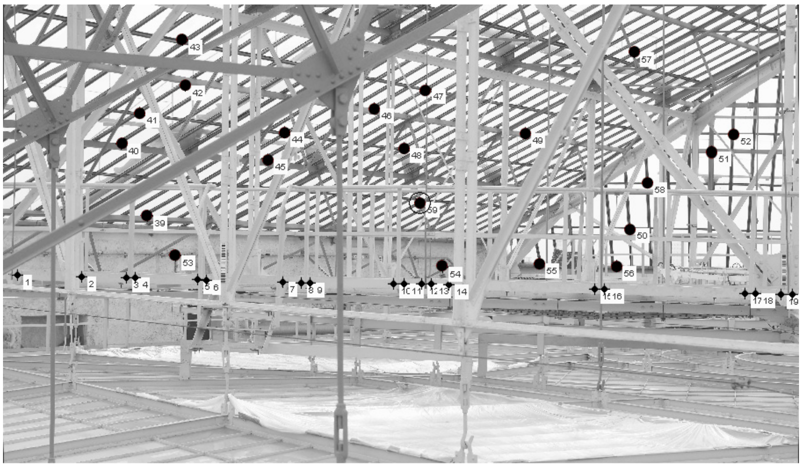

Fig. 3. Control points; black dots – background registration control points; black cross – local points of interest used in deformation estimation.

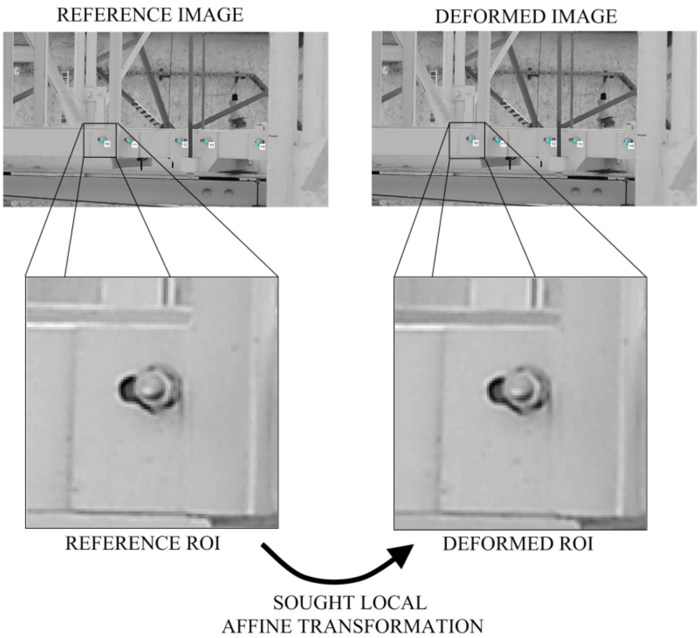

Fig. 4. Calculation of the shift for given points is performed by affine registration of reference ROI and deformed ROI.

4.4 Cross-correlation

In signal processing the cross-correlation is commonly used as a measure of similarity of two signals as function of time lag. In image processing we compare a 2D discrete signals as a function of spatial shift. Since we needed to achieve a sub-pixel precision we calculated normalized cross-correlation of reference image r(x,y) and transformed deformed image d(x,y). The transformation with the highest cross-correlation coefficient was chosen as a solution.

$$Xcorr = \frac{1}{n-1}\sum_{x,y}\frac{(r(x,y)-\bar{r})(d(x,y)-\bar{d})}{\sigma_r\sigma_d}$$

where:

n -	**number of pixels in images r(x,y) and d(x,y)**
r(x,y) –	**region of interest from reference image**
$\bar{r}$ -	**mean value of pixels in r(x,y)**
d(x,y) -	**region of interest from deformed image**
$\bar{d}$ -	**mean value of pixels in d(x,y)**
σ_r -	**standard deviation in r(x,y)**
σ_d -	**standard deviation in d(x,y)**

4.5 Mutual Information

Mutual information is an idea taken from information theory. We say that two images are the same if they contain the same information. To define information in the image we use Shannon's entropy,

$$H = -\sum_i p_i log(p_i)$$

where p_i is probability to find i-th intensity in the given image.

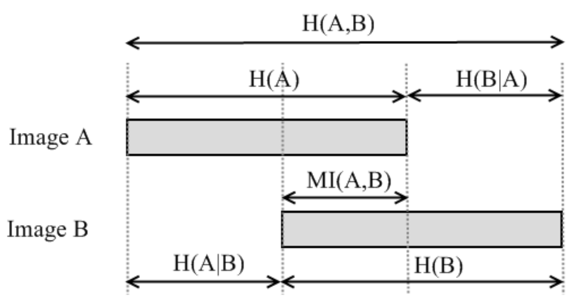

Fig. 5. Relationship between mutual information of images A and B MI(A,B) and entropies of: images H(A) and H(B), conditional entropies H(B|A) and H(A|B) and joined entropy H(A,B).

Mutual information is determined based on information theory in the following way:

$$MI(A,B) = H(A) + H(B) - H(A,B)$$

In order to compute joined entropy, first we build joined histogram of registered images which is a basis for calculation of probabilities of finding each intensities in joined image. The best registration of the images is achieved when mutual information is highest.

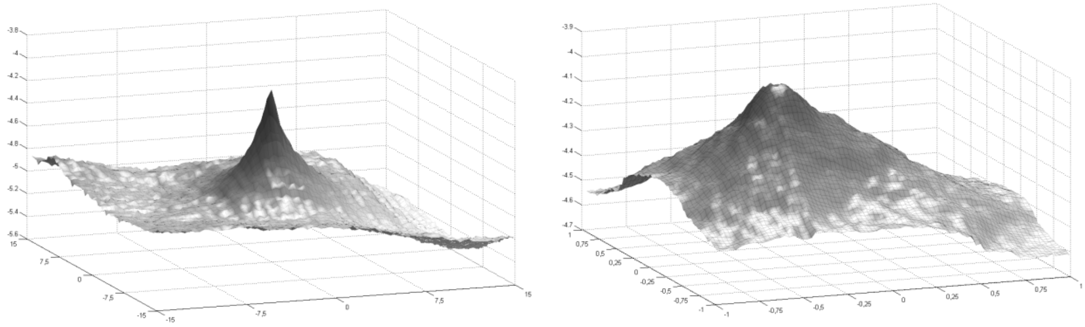

Fig. 6. An example of mutual information similarity measure for two images. X and Y axis correspond to relative shift of the images in each direction. Right graph is a close up of the peak region.

5. RESULTS

The presented method of local image registration was applied to estimation of deformation of steel catwalk under load. The images of the object were taken with Nikon D3x digital camera with 24 M pixels CMOS array and 70 mm lense.

The vertical displacement of the center part of the catwalk estimated with our method is 0.9 mm. This value was confirmed by precise leveling measurements which measured sag of 0.85 mm. The point wise leveling measurements are only possible at spots with bar-code rods. Proposed method gives us far more flexibility of choosing control points in expense of high precision. However for many monitoring tasks precision achieved by us is satisfactory. On figure 3 we can see that estimated displacements for presented control points are coherent. Vertical displacement is smallest at the points of support and rises in the middle of the beam.

Fig. 7. Result of local registration for selected points on the catwalk. The vectors show calculated shift for selected points. The longest vector is 0.72 pixels what corresponds to around 0.9 mm.

6. CONCLUSIONS

The study proved right the possibility to use modern digital cameras to monitor deformation of construction objects.
The estimated deformation was in agreement with earlier measurement performed with leveling instrument.
In the proposed method the operator only picks a set of reference and control points on both images. The precise calculation of displacement is done automatically.
We observed required sub-pixel accuracy of the registration method.
In most cases the proposed method doesn't need installation of special measurement points. The geometrical features of a reference point neighborhood is used instead.
High shutter speed of digital cameras allow to take the snapshots of the objects deformation in time as short as 1/8000 sec. and is an interesting way to monitor dynamic changes of an object's geometry.

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