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# Targetless image-based method for measuring displacements and strains on concrete surfaces with a consumer camera

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## HIGHLIGHTS

- Strain in concrete is usually measured with resistive gauges.
- A non-contact image-based method is presented.
- The method is implemented on a standard digital photographic camera.
- Accuracy of the method is around 8 μm for displacements and 40 με for strain.
- Results are comparable to alternative commercial devices.

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## ABSTRACT

Measurement of concrete strain through non-invasive methods is of great importance in civil engineering and structural analysis. Traditional methods use laser speckle and high quality cameras that may result too expensive for many applications. Here we present a method for measuring concrete deformations with a standard reflex camera and image processing for tracking objects in the concretes surface. Two different approaches are presented here. In the first one, on-purpose objects are drawn on the surface, while on the second one we track small defects on the surface due to air bubbles in the hardening process. The method has been tested on a concrete sample under several loading/unloading cycles. A stop-motion sequence of the process has been captured and analyzed. Results have been successfully compared with the values given by a strain gauge. Accuracy of our methods in tracking objects is below 8 μm, in the order of more expensive commercial devices.



## 1. Introduction

Measurement of concrete strain is a most important subject in civil structures. It can be used as an indirect measure of the concrete stresses, thus giving important information about the condition of the structure. Additionally, it can be also used to detect movements or vibrations on the structure.

Traditionally, the measurement of concrete strain is done using contact sensors like strain gauges. A strain gauge is a flexible long sheet with a foil pattern printed on the surface. This sheet is glued to the concrete surface using a cyanoacrylate adhesive. When concrete stress changes, the thickness of the foil changes and it changes its resistance. A Wheatstone bridge can measure this change in resistance, which is related to the strain. Due to its own nature, small changes in temperature affect the measurement, as well as humidity. Therefore, despite their high accuracy, strain gauges are very sensitive to climatic conditions.

Non-invasive procedures are generally preferred because there is no expensive disposable material when the experiment is destructive (concrete samples). Additionally, non-contact procedures do not need physical access to the target point so their use does not interfere with the normal use of the structure. Moreover, they are independent on the external conditions like temperature or humidity. These characteristics make non-contact procedures safer and more convenient than the rest of procedures.

Non-contact procedures are mainly based on vision systems. These systems are being fast developed in the latest years due to the increasing cameras performances and calculation capacity of the computers. In the literature some new developments based on image techniques can be found. One of the image techniques that have been used to measure concrete strain is based on the sampling Moiré method [1]. It uses a regular repeated pattern

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based on lines with different grey levels as a target on the structure. The relative movement of the lines gives information about the deformations on the sample. Based on this technique, Umemoto et al. [2] have developed a new method to measure strains just using a sticker on the surface to be measured. The big advantage of this method is that the simple visualization of the sticker allows obtaining the measurement, but still it needs a target to be glued on the surface.

Video extensometers are also being used for measuring the strain on different materials (usually metals). These systems use fiducial marks on the material that are tracked with a high-quality camera and software analysis. Usually, Digital Image Correlation (DIC) has been used as a useful tool in the measurement of both displacement and strain [3–5]. In many works, instead of fiducials, speckle pattern generated by a laser beam is used to improve the accuracy of DIC measurements [6]. A simpler alternative, known as pseudo-speckle consists of making a similar pattern by painting a cloud of random spots on the concrete surface under study. In any case, on purpose patterns must be placed or projected on the concrete surface.

Targetless methods have been recently presented in the literature. These methods do not need an object or a special pattern attached to the specimen, but search for illumination changes [7] or defined shapes [8] such as screw heads or holes that are identified and used as targets.

In this work we develop a new procedure to measure concrete strain without the use of any particular target, shape or projected pattern on the concrete surface. Our approach consists of extracting information from the surface texture i.e. the own roughness of the concrete surface. Concrete surface usually shows some superficial irregularities, due to a non-perfect compaction during the placement of concrete into the formwork. The most common superficial irregularities are small holes with irregular shapes and distribution, corresponding to air bubbles that have been trapped during the process. These holes could affect the concrete durability, since they allow air and contaminants to enter into the material but their effect is negligible from the point of view of concrete strength. To avoid these irregularities a very accurate compaction is needed, covering both needle vibrator (with a proper quantity per concrete volume to compact) and vibrating tables to apply vibration to the formwork. This technique, widely used in precast concrete elements, is difficult to apply in big elements that are built on site. Therefore, these superficial irregularities happen very often and they are commonly consented. Anyway, the method presented here could use any superficial irregularities like humidity spots, furrows or even changes of color.

The aim of this paper is to show that these irregularities can be tracked and, from their position, the concrete strain can be obtained. Additionally we show that the method can be implemented on video sequences obtained form a standard reflex camera working in stop-motion mode. Through image processing algorithms defects of larger size are recognized and segmented from each frame. Then, they are identified as individual blobs and its position is determined. By analyzing the relative distances between them we are able to determine the concrete strain. All image processing is done with Matlab [9] by using the Image and Signal Processing toolboxes, together with our own developed software. Our results are successfully compared with those coming from a strain gauge, thus proving that our method is accurate and reliable.

## 2. Method

A video sequence of a concrete cubic sample subjected to several load–unload cycles is obtained. Two methods will be used here: one consists of using circles drawn on the concrete surface as targets, while the other one uses the small defects on the concrete surface. Picture sequences from a lateral face of the sample have been analyzed and processed as explained below. Additionally, a strain gauge was glued to the sample in order to obtain reference results (see Fig. 1a and b).

Let us consider any of the pictures in Fig. 1. One can see there the circles made with a marker and the small superficial defects that appear as dark objects against a more or less uniform background. This kind of images provides a clear bimodal histogram, as can be seen in Fig. 2a with the main lobes describing the scene background (highest peak) and foreground respectively. Thresholding is automatically done according to Otsu's method, which calculates the optimum threshold level separating the two object classes so that their intra-class variance is minimum [10]. The binary frame so obtained may permits classification and isolation of target objects from the concrete surface as can be seen in Fig. 2b.

Regions are identified, labeled and tracked by algorithmic applications of graph theory [11]. A graph is a representation of a set of objects where some pairs of objects are connected by links. Here primary objects are white pixels and the links between them are established according to connectivity between objects. In this sense, two pixels can be 4-connected or 8-connected depending whether they are orthogonally adjacent or also in diagonal (see Fig. 3). Therefore, all pixels surrounding one target-pixel are 8-connected with it, but not all of them are 4-connected. Therefore, once the complete image is analyzed and the graph is constructed, several groups of connected pixels are detected over the background. On this work each one of these group is called "blob".

In our case, regions or blobs are defined by grouping 8-connected pixels. These regions are individually labeled and their geometrical features are calculated (area, centroid, major and minor axes, eccentricity, etc.). From these features, only the centroid will be relevant for our calculations here.

The procedure just described can provide very noisy results. From all the blobs detected, very small regions can alter its form or even disappear during the process. Therefore, only regions within an area range are selected and tracked along the process.

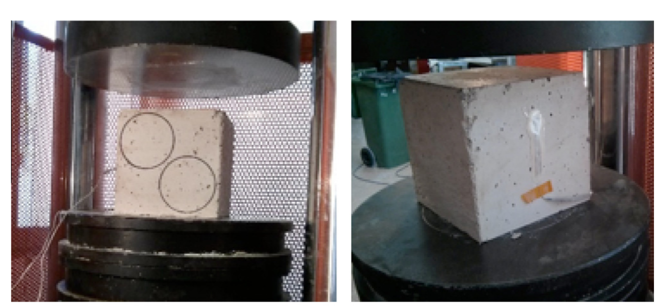
When concrete is subjected to strain, the distance between any centroids in the direction of the strain changes. Once the location of two centroids throughout the time ($t$) is known, the length ($l$) of a line in the direction of the strain can be determined simply by subtracting the locations. The strain is then calculated by dividing the increment of length at a particular time by the initial length, as it is described in Eq. (1).

$$\varepsilon(t) = \frac{l(t) - l(t_0)}{l(t_0)} \tag{1}$$

As we said before, two different approaches have been adopted here. The first approximation imposes two specific regions artificially designed so detection is easier and the procedure is easier checked and followed.

In the first approach, using two circles as objects, the regions are formed by the encircled pixels and the drawn line breaks connectivity with other regions (see Fig. 2b). Notice that aside of the two encircled region, the remaining white pixels also form a region. By filtering all regions whose area is below 20% or above 25% of the total concrete area we select the two regions of interest, as it is represented in Fig. 4. The regions selected have been on purpose-built in an elliptical shape. Small stains inside these regions can be easily erased by using a closing morphological filter [12]. Then, the contour of each region can be extracted and fitted to an ellipse by following the procedure described in [13]. The centroid is then calculated from the obtained ellipse parameters and distance between them in the vertical coordinate is used to obtain the strain as stated in expression (1).

In the second approach, we identify and track the superficial defects in the concrete. Since we have defined the regions as formed by white pixels over a black background, we have inverted all the frames in the sequences, in order to have the object to be tracked in white pixels. Again, blobs can be selected by its size, which in this case ranges from 0.03% to 0.5% of the image size (Fig. 5a) in order to detect the defects in the concrete surface as blobs. Contrary to the previous case, these blobs have not a defined shape. Since these regions are of small size, any pixel variation due to the illumination or small camera movement may affect to the



(a) (b)

**Fig. 1.** Concrete sample used in the test. (a) Frontal view with two targets drawn on it. (b) Rear view with the strain gauge.