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THE OPTICAL SYSTEM FOR ELONGATION MEASUREMENT OF HIGHLY DEFORMABLE MATERIALS

Key words

Experimental methods, machine vision, displacements measurement, high elongation measurement, highly deformable materials.

Summary

Displacement measurement in systems exploring the mechanical properties of materials may relate to different physical quantities. It is often related to the measurement of the displacement of working elements executing the load or the measurement of the elongation of the tested measurement area. From the technical point of view, the most complicated aspect to measure is the elongation of the tested measurement area, particularly for objects that have a structure that makes it difficult to mount external sensors, such as inductive, piezoelectric or laser extensometers. The “whole measurement procedure” is based on the detection of the marker’s location. Displacements of markers between adjacent frames exceeding a fixed value are treated as a rupture in the tested object. The disappearance of one of the markers from the camera’s view is treated also as the object rupture. Very good results of marker detection on transparent materials were obtained by the using a fluorescent marker and lighting it with ultraviolet light.

Introduction

The rapid development of optoelectronics contributes to the growing use of optical measurement methods and the rapid development of machine vision [1]. Optical methods can be successfully used to measure displacements, which are very important in the study of mechanical properties of materials and structures. A typical test system used in this type of study consists of a loading and measurement system comprised mostly of force and displacement sensors. Measurement of force and displacement during the loading of samples allows the determination of typical characteristics that define the mechanical and rheological properties of the sample. Displacement measurement in systems exploring mechanical properties may relate to different physical quantities. It is often related to the measurement of the displacement of working elements under load or the measurement of the elongation of the tested measurement area.

From the technical point of view, the most complicated aspect to measure is the elongation of the tested measurement area, particularly for objects that have a structure that makes it difficult to mount external sensors that can provide electronic communication of measurements, such as inductive, piezoelectric, or laser extensometers [5].

Elongation measurement allows the determination of strain, defined as the relative elongation of the base part of the sample, according to the following formula:

$$\varepsilon = \frac{\Delta l}{l} \quad (1)$$

where:

l – base length,

Δl – base length elongation.

The contactless nature of the measurement carried out with the use of optical techniques opens new opportunities for research, e.g. when determining the mechanical properties of tapes, foils and films with very small thickness and large deformability. In this case, conventional sensors cannot be used because of their range and attachment method to the test object.

1. Solution analysis

One of the solutions based on the optical measurement techniques that can be used to measure the elongation of the tested measurement area of the loaded samples is direct observation of changes in the position of markers placed or applied onto the surface of the test object.

Solutions found in this area are mostly based on an optoelectronic circuit comprising a high resolution camera equipped with a lens with adjustable magnification (optical extensometers [2, 3]). This solution introduces significant restrictions in the case of measurements of highly deformable materials for which there is the need to maintain continuity and consistency in the measurement of strain up to 1000% or more. This causes the necessity of an observation field of large dimensions in relation to the initial length of the measurement base. As a result, the sensitivity of the configured measurement system is too low to be useful in practical applications.

In the remainder of this article, a method for strain test in samples with high deformability will be presented that are verified experimentally and implemented in practical application. This method enables the analysis of the sample elongation by means of a system of two cameras and the original image analysis procedures.

The solution to achieve the required resolution is shown in Figure 1. In this system, two measuring marks are tracked by cameras from the start of measurement until they leave the frame of measurement or until a sharp increase in repositioning occurs, which may indicate a rupture of the sample.

The usage of more than one camera produces a suitable measurement resolution. This results from the resolution of the CCD camera, the camera optics, and the size of the observed area. The maximum size of the area observed by the camera is connected with the systems working field of view, in this case, equal to 635 mm. The initial distance between the marks is 10 mm to 300 mm.

An overview of currently available cameras leads to the conclusion that it is possible to find a camera with a USB interface and the speed of data transfer of 480Mbit/s, which, with a resolution of 1280 * 768, allows for the acquisition rates of up to 30 frames per second. Alternatively, one can consider the usage of two FULL HD (1980 * 1080) cameras, which will provide a similar measurement resolution with fewer cameras. However, the higher resolution of the camera, the greater amount of information must be processed and the higher requirements for the operating system and CPU are needed.

In the proposed solution, the camera vision areas overlap, as shown in Figure 2. In order to determine the relative position of cameras and its optical parameters, a calibration process is required. The simplest solution of a calibration problem is to place in the camera field of view with a ruler attached to the device’s jaws.

The calibration process allows one to determine the resolution and linearity of the image and the order of the cameras in order to allow the summarization of a few separate images into one of a known resolution and linearity. To maintain correct lighting conditions, the system should also be equipped with illuminators, as shown in Figure 2. In order to provide better image contrast and details, a screen must be placed behind the measured object.

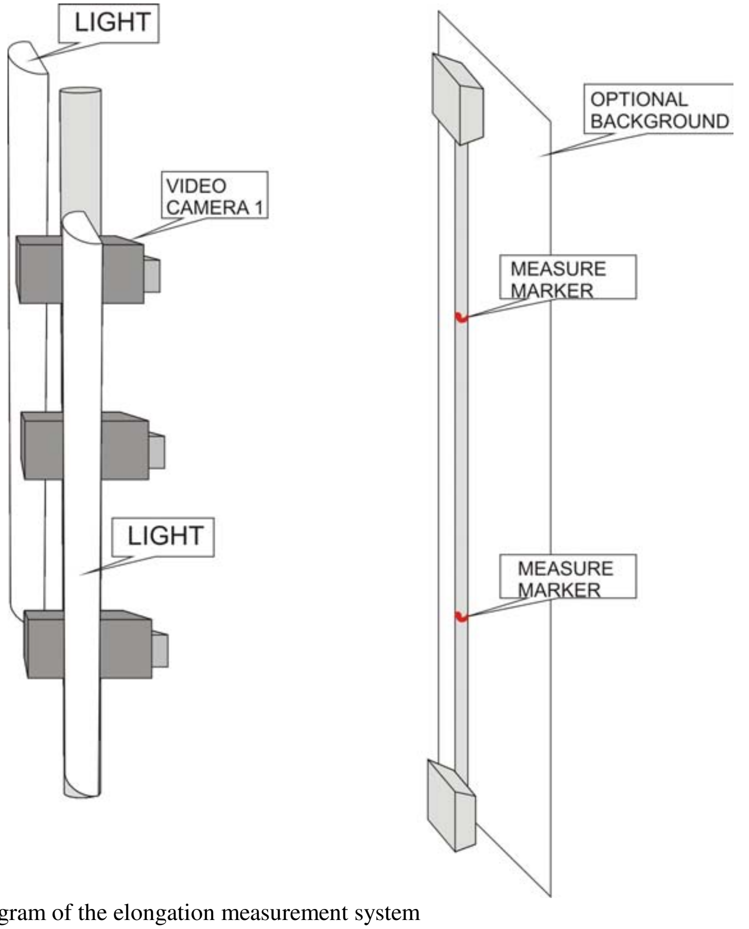

Fig. 1. Diagram of the elongation measurement system

The following three methods of optical tracking of markers have been tested:

- The first assumes the area of tracing selected by the operator. Changes in its position are tracked in each image frame. Image frames are processed by correlation procedures with a fixed maximum displacement.
- The second method assumes tracking of two markers with a fixed size and shape.
- The third method, which is the least resource intensive, is to keep track of a tag with a unique colour applied to the test material.

2. System concept

The developed system uses cameras with FULL-HD resolution. If one image frame is obtained with 1920x1080 pixels resolution and 24 bit colour depth, the amount of information provided by a camera in this frame is equal to 1920 * 1080 * 3 = 6.2 MB (50 Mb). If the frame data is uncompressed, the maximum data transfer speed is about 10 frames per second (according to USB 2.0 bandwidth). Colour depth reduction to 16-bit causes a decrease in frame size to 33 Mb and allows a transmission rate of about 15 fps.

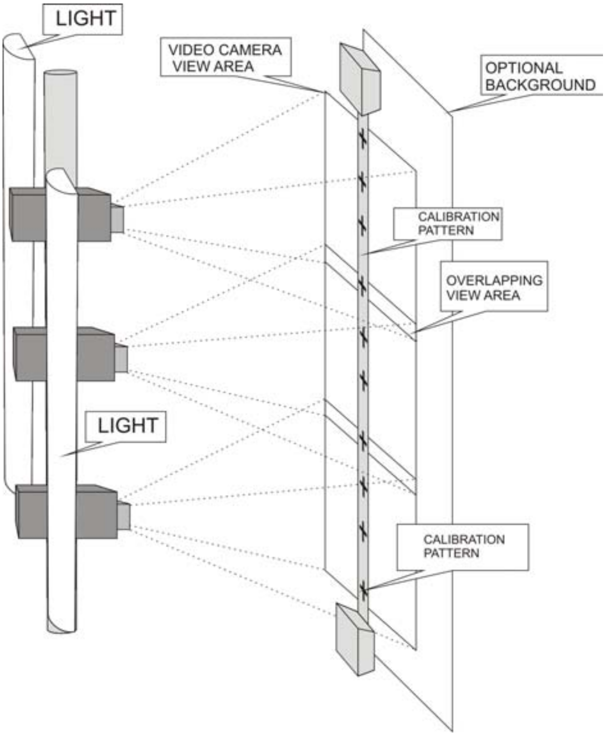

Fig. 2. Diagram of the proposed elongation measurement system

Because of the maximum USB 2.0 bandwidth utilization, the most favourable method of camera connection is to connect each camera to a separate USB host.

The distance measurement between the two markers is performed in several stages.

1. Before measurements, it is necessary to carry out the system calibration. Calibration is executed with the use of a pattern in which a number of markers are arranged. This allows the system to determine the distance between the camera matrixes and calculate the pixels per 1mm of observed

field ratio. For this process to be successful, it is essential to fulfil the condition of perpendicular placement of the optical axis of the camera to the observed object. The angle between the optical axis of the camera and the object is controlled by software during the calibration phase. Too much image non-linearity will stop the calibration process. After the calibration process, camera positions must remain unchanged.

2. After the test object is mounted in the device handle, it is necessary to define two markers to be observed by the cameras. The markers' positions will be stored at the start of the measurement, and this distance is will be the base value.
3. The movement of the markers is tracked for each frame, which allows a distance calculation between the markers.

Measurement termination is determined by the loss of the visibility of a marker or by exceeding the permissible speed of its movement.

3. Measuring algorithm

At the initial considerations regarding the calculation algorithm, the necessity of homographic transformation on one of the obtained images was taken into account. This transformation would allow merging the images obtained from the left and right camera together. Tests have shown, however, that execution speed of the operation is insufficient. Another necessary condition for the application of such an algorithm was the overlapping of left and right camera images. Through the introduction of an additional step (calibration), it was possible to avoid the images merge operation. This calibration (Figure 3) is performed by using a pattern placed in the jaws of the measuring device. The pattern consists of a series of geometric shapes (squares and circles) detected by the software.

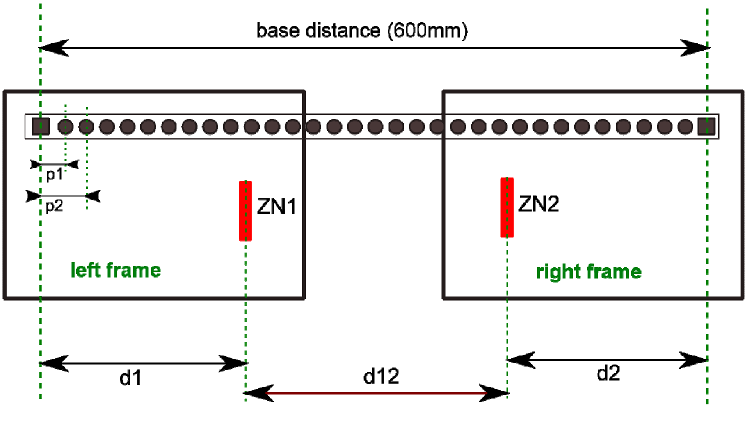

Fig. 3. Calibration step rules

4. The implementation of the measurement process

End tag (squares) detection allows one to specify the location of the base distance in the images from the left and right cameras. Since the distance between the remaining markers (circles) is known, a conversion map of the position expressed in pixels to the position expressed in mm can be calculated with respect to one of the base points – p1, p2 distances on Figure 3. Therefore, knowing the pixel positions of ZN1 and ZN2 markers, it is possible to determine their distance relative to base points (d1, d2) and their mutual distance in mm.

5. Cameras placement – cameras field of view

Cameras can be positioned so that their fields of view are superimposed or completely separated. In the case of cameras with overlapping fields of view, the following cases of marker visibility are possible (see: left marker – ZL, right marker ZP in left – OL and right OP images – Fig. 4):

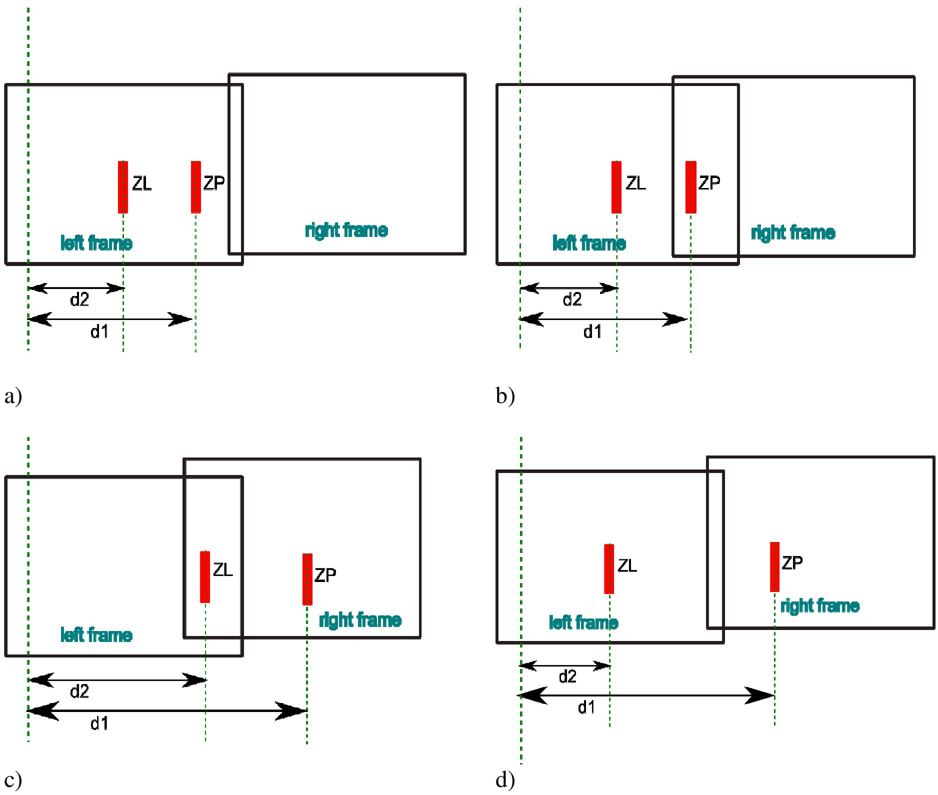

Fig. 4. Combinations of the camera field of view orientation relative to markers

- Both markers are seen by the left camera, none by the right camera, and only the image from left camera is used in the calculation (Fig. 4a).
- Two markers are seen by the left camera, the ZP marker is seen by the right camera, and the OL image is used for the calculation (Fig. 4b).
- One marker is seen in the OL, and the two seen in the OP, the OP image, is used for the calculations (Fig. 4c).
- One marker in OL and one marker in the OP are seen, and both images are used for the calculation (Fig. 4d).

6. Measurement accuracy

Parameters that have an influence on the accuracy of measurement with cameras using static and dynamic methods include the following:

– Static:
  - the camera's resolution and its magnification (the area seen by the camera matrix at a specific resolution),
  - lens errors,
  - errors associated with the detection of elements,
  - errors related to the change in position of the object plane against the plane of the calibration pattern;
– Dynamic, related to measurement of a moving object:
  - dependent on the object's velocity, and
  - the number of frames per second captured by camera.

If we assume that area observed by one camera's matrix is 300 mm wide, than we receive 0.15 mm per one pixel with a resolution of 1920 pixels. The resolution can be increased by decreasing the area observed by the camera.

Measurement errors caused by the dynamics of the system can be defined by the velocity of the object's motion relative to the CCD matrix plane and the acquisition frame rate. When the speed of object is 10cm per second and the acquisition rate is 30 fps, the object moves 3.3 mm between two adjacent frames. Accordingly, the object's speed of 1cm/s results in a 3.3 mm move, which is comparable to resolution. As it is seen from the consideration above, the velocity of the object and the speed of the frame acquisition will have the main impact on the uncertainty of measurement.

7. Image processing procedures

Image processing procedures have been implemented with AForge's library and Microsoft's .NET 4.0 platform. Image acquisition takes place with the DirectX interface. Because the crucial requirement to the proposed processing procedures was the processing speed, it was necessary to carry out preliminary calculations on decimated image frames. After preliminary marker detection, the full detection is carried out on a pre-selected piece of a full resolution image. After tests, it was decided to convert image colour space to HSL. In this colour space, detection of areas containing detected colour is more certain. In the processing images process, the following stages can be extracted:

- The conversion of colour space from BGR to HSL,
- The image decimation,
- The threshold of the image areas that have a pre-set degree of colour similarity,
- the admeasurements of objects (BLOBs) from the threshold image,
- BLOB objects filtration,
- marking the position (the centre of gravity) of found objects, and
- marking the reciprocal distance between markers on the foreground or background of their position in images.

The whole measurement procedure is based on the detection of the marker's location. Displacements of markers between adjacent image frames exceeding a fixed value are treated as a rupture in the tested object. The disappearance of one of the markers from the camera's view is also treated as a rupture. The exemplary application screen showing the detection of a sample rupture is showed in the Figure 5.

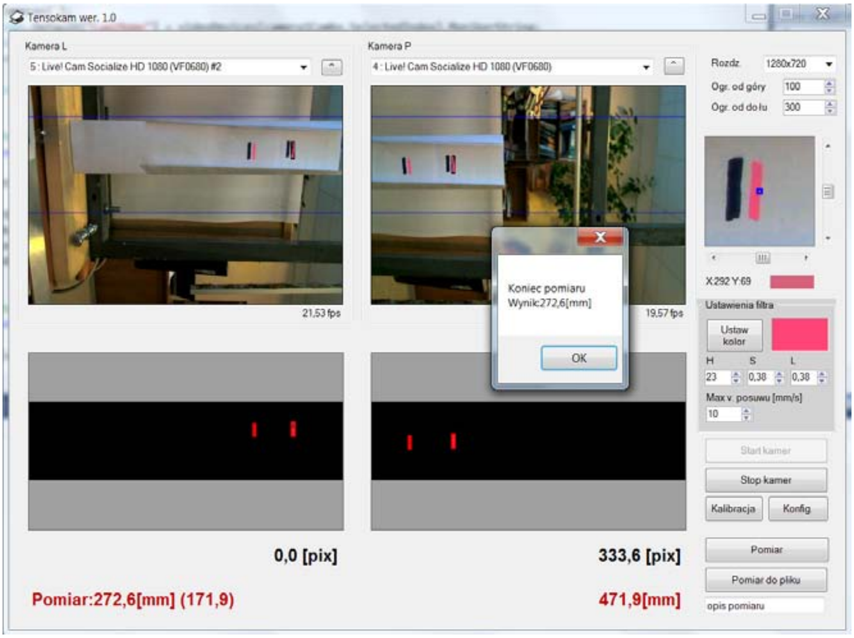

Fig. 5. The exemplary application screen

Conclusion

During the work, a few methods of marker detection and its frame-to-frame shift calculation were tested. The use of correlation methods for finding similar areas were also tested. Satisfying results of the determination of the position of markers and their movement were obtained with the use of correlation methods; however, this was only in the case when a change between adjacent frames was calculated. In the case of analysis realised in relation to the initial frame, results were unsatisfactory. Using a marker with enough of a diversified structure turned out to be the necessary condition for an effective work of the developed algorithm. This method was found to be the very time-consuming, because even in the case of a small marker size, it required many calculations. Taking into account the influence of the velocity of processed frames on the measurement accuracy, correlation methods was qualified as unsuitable and were rejected. It turned out to be necessary to find a time efficient method that would allow the detection of the marker, for example, with the use of a unique colour. In order to obtain low sensitivity for light intensity changes, it turned out to be necessary to change the space of colour to the HSL model. This treatment enables qualifying shades of the same colour as one area.

Although the choice of a much less time-consuming method in comparison to the correlation methods in order to assure effective work with high image resolution (FULL HD) was needed, it was necessary to execute a rough marker search in the decimated picture.

Very good results of marker detection on transparent materials were obtained by the using a fluorescent marker and lighting it with ultraviolet light.

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Eksperymentalny system do pomiaru wydłużeń materiałów o wysokiej odkształcalności

Słowa kluczowe

Metody eksperymentalne, maszynowe widzenie, pomiar przemieszczeń, pomiar dużych odkształceń, wysoko odkształcalne materiały.

Streszczenie

Pomiar przemieszczenia w systemach do badań własności mechanicznych może dotyczyć różnych wielkości fizycznych. Najczęściej związany jest z pomiarem przemieszczenia elementów roboczych realizujący obciążenie, pomiarem odległości pomiędzy uchwytami, w których mocowane są obiekty badań lub pomiarem wydłużenia ich części pomiarowej. Najbardziej skomplikowany z technicznego punktu widzenia jest pomiar wydłużenia części pomiarowej obiektów badań, w szczególności w przypadku obiektów, których budowa utrudnia mocowanie zewnętrznych czujników, takich jak np. czujniki tensometryczne, indukcyjne, laserowe lub piezoelektryczne. Proponowana metoda pomiaru opiera się na detekcji położenia znaczników. Przemieszczenia znaczników pomiędzy sąsiednimi ramkami obrazu przekraczające założoną wartość traktowane są jako zerwanie obiektu. Jako zerwanie obiektu traktowane jest również zniknięcie z pola widzenia kamery jednego ze znaczników. Bardzo dobre wyniki detekcji znacznika na materiałach transparentnych uzyskano, używając fluorescencyjnego znacznika i oświetlając go światłem ultrafioletowym.