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TRACKING OF DISPLACEMENT FIELD USING STEREO-CORRELATION IMAGES

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ABSTRACT

This work aims to realize a method for the tracking of the field of displacements using a stereo correlation procedure. A program has been designed for this, the latter gives to the user the opportunity to choose the tracking mode either of the characteristic points or a random speckle placed on the object to be studied. A well-explained approach has been developed to arrive at precise metric results, starting with the calibration step, and then selecting the follow-up algorithm according to the procedure, arriving at this stage with the calibration results and the 2D correlation for each series of images, one will have the 3D displacement of each point. The program was validated with different test directions (tensile, flexural and deep drawing), while determining the characteristics of the material used and the significant quantities for each test, as it was used for the validation of robots of different architectures (Parallel, serial, delta).

Keywords: Stereo-correlation, stamping, deformation field.

INTRODUCTION

The application of heterogeneous materials or the complex stressing of materials reveal fields of displacement whose multi-scale analysis is indispensable in relation to their microstructure. This is why researchers develop reliable techniques for measuring fields of displacement and deformation which is paramount if one wishes to characterize the (heterogeneous) mechanical effects on a fine scale. The development of a technique allowing the measurement of the kinematic field helps in the modeling of heterogeneous materials and the complex structures that play a primordial role. Everything starting with the problem of measuring displacements or deformations in several fields concerning the behavior of materials using contact sensors such as strain gauges which provide one-way and point measurements, in addition to other disadvantages such as Sensitivity of the gauges to the parasitic forces resulting from the connection between the sensor and the sample used, which influence the measurements taken.

The development of computers and photography equipment, new monitoring techniques are developed, it is the image correlation measurement (2D), they have imposed themselves in recent years thanks to their non-intrusive characters, absence of Contact, their large spatial resolutions in addition to the high sensitivity. With technological development and the emergence of new ways of manufacturing increasingly complex parts with three-dimensional, nonplanar shapes, where more advanced techniques of correlation of images had to be found.

Finally, the solution is the Stereo Image Correlation that couples image correlation with stereovision, enabling the measurement of 3D shapes, as well as displacement fields.

The applications of this technique have been developed in many fields such as experimental mechanics, materials science, civil engineering, electronics, biomedical ... etc.. But also at several spatial scales ranging from electron microscopy to the scanning of large pieces. Make universal?

A number of examples illustrate the use of this technique in the mechanics of solid materials and structures. The following conclusions were obtained, the resolution of the image correlation technique is sufficient to allow the identification of the elastic properties, Plastics and to observe the signs before fracture.

The stereo image correlation technique is becoming more and more famous due to its application in different domains, but it is still sought to universalize this technique for all applications, because each research axis finds that a correlation process is better than the other, in addition it is a technique with several variables (luminosity, angle between the cameras, follow-up of characteristic points, follow-up of flechetisetc ...). In order to solve the problem raised previously, a program was created that unifies the process of stereo correlation for the different applications.

This program allows the user to choose between automatic search (speckle) or manual (characteristic points). The automatic search is applied to the random speckle, but since the operating conditions are not always favorable, our program gives the choice between two correlation processes:

- KLT (Lucas, Kanad, Thomasi);
- SURF (Speeded Up Robust Futures).

The difference between these two processes lies in the sensitivity and the calculation time of each one, for the same image treated the number of correspondence will be different depending on the operating conditions (luminosity, nature of the speckle, quality of the images).

With regard to manual tracking, it can be used for robot validation, metrology where we have a limited number of points to follow.

I. EXPERIMENTAL PROCEDURE

I.1 *Calibration of Cameras*

An important task in 3D computer vision is the calibration of the camera, especially when metric information is required for applications involving accurate dimensional measurements.

We take different photos of the patterns by changing the depth and the rotation, while guaranteeing the appearance of the complete test pattern, then using MATLAB we can calibrate and determine the intrinsic and extrinsic parameters of each camera, Figure 1.

- Focal length: fc_leftfc_right
- Main point: cc_leftcc_right
- Distortion: kc_leftkc_right

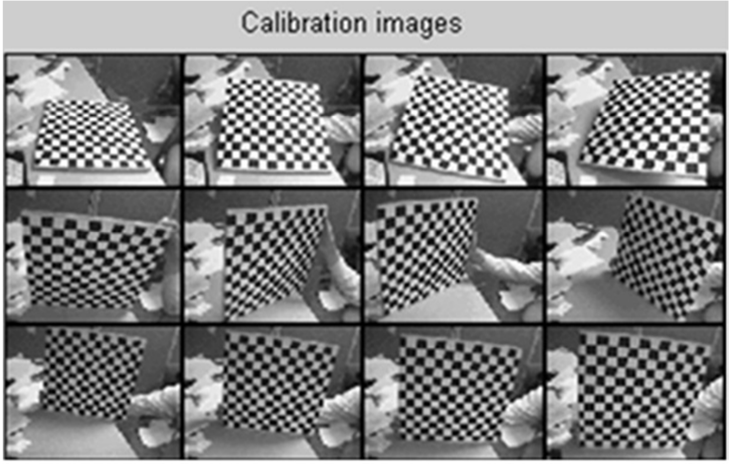

Fig. 1 - Calibration by the test pattern

I.2 *Stereo Calibration*

The calibration of the stereo platform is processed by calibrating each camera independently and then applying the geometrical transformation of the external parameters to determine the geometry of the stereo platform.

The finality of this step will be the extrinsic parameters of the stereo platform defining the relative position of the left camera with respect to the right camera:

- Rotation Vectors: R;
- Translation vector: T.

I.3 *Tracking*

This step is very detailed in Figure 2, it makes it possible to determine for each point in a corresponding sound image in another image, this step can be done either manually or the selection of the points and their corresponding ones is done by the user as the or by tracking processes such as KLT or SURF, such as the tensile or flexure test. The correspondence is done in space (between left and right images) and in time (between image to t and images at t + dt).

I.4 *Triangulation*

Now, we proceed to the triangulation, which is simply the determination of the third dimension for each point while using the coordinates of each point in the left and right image at each instant, the intrinsic and extrinsic parameters, Have the coordinates of each point in space at every moment.

I.5 *Preparation of the Specimens*

A surface speck of natural origin (relief, texture ...) or artificial (spray of black or white paint, etching relief ...) with gradient gray levels is used to ensure the success of the correlation process (see Figure 3).

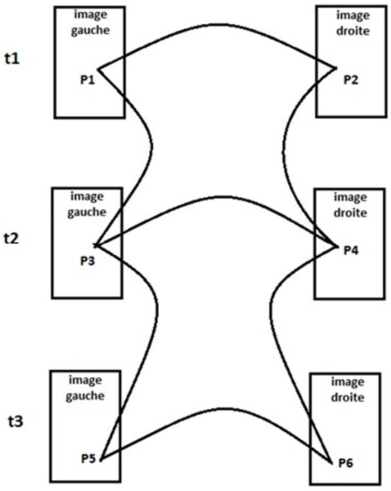

Fig. 2 - Tracking process

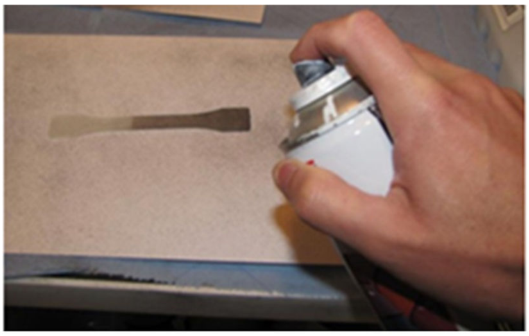

Fig. 3 - Preparation of the specimens

I.6 *Evaluation of Speckle*

The figure below shows the quality of the speckle. The histogram of the gray levels approximates an "ideal" histogram with a distribution over the entire range of values (from 0 to 256). The half-height of the centered and normalized autocorrelation function gives us the radius of autocorrelation (or average size of the spots of the speckle).

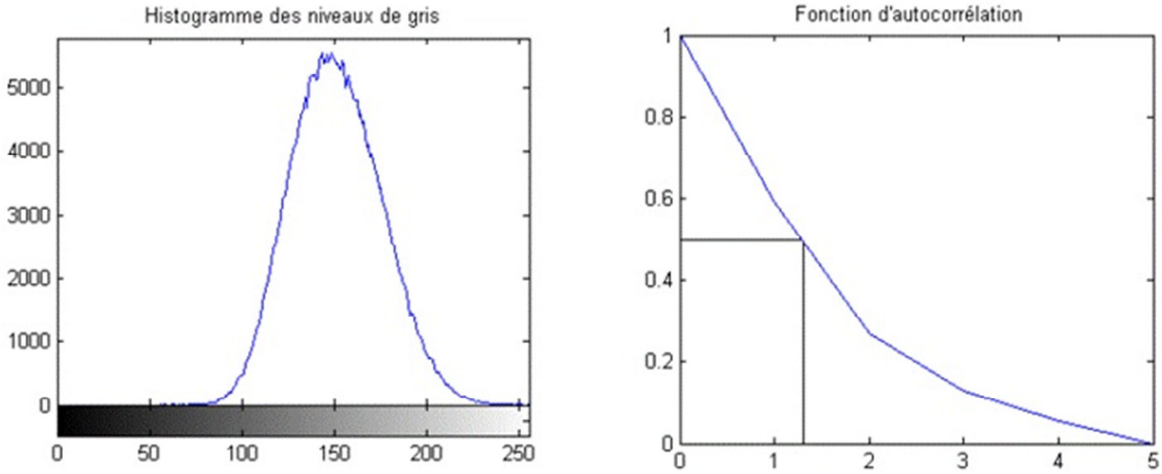

Fig. 4 - Histogram of gray levels

I.7 *Installation of the test bench*

Stereo image correlation is a technique that involves several factors, such as light, image quality, resolution, angle between cameras ... etc.

According to the tests carried out to master this technique, and to be able to pass tests assisted by this technique, one must take into account:

1. The angle between the cameras: the perfect angle range is around 20 °, below this value, the common area between the fields of view of the two cameras decreases, and thus even the number of points of correspondence, On the other hand for angles

greater than 20 °, there will be a deformation of the speckle in both images, which influences the matching process and decreases the number of matches.

2. Auto Focus: Among the intrinsic parameters of the cameras is the focal distance, this feature is influenced by the auto focus, so it must be deactivated to pass the calibration step.
3. Lighting: use a parallel illumination to the front, so avoid flash cameras, because changing the position of the light source affects the detection of points of interest, especially in the Case of cylindrical specimens.

II. RESULTS AND DISCUSS

The results are given in the following tables:

II. 1. Results of the Calibration

Table 1 - Intrinsic parameters of left camera

	Values (pixels)	**Errors**
Focal length(x)	2558.51	20.32702
Focal length (y)	2569.00	40.56778
Main point (x)	1640.51	10.24712
Main point (y)	1162.37	58.69807
	Distortion parameters (radial, then tangential)	
Kc_1	0.068	0.001
Kc_2	-0.196	0.02
Kc_3	-5.500e-5	0.000
Kc_4	-0.002	0.00061

Table 2 - Intrinsic parameters of right camera

	Values (pixels)	**Errors**
Focal length (x)	1535.47677	219.32702
Focal length (y)	1558.71797	226.56778
Main point (x)	845.72417	122.24712
Main point (y)	392.45205	58.69807
	Distortion parameters (radial, then tangential)	
Kc_1	0.0550	0.00188
Kc_2	-0.1534	0.05325
Kc_3	-0.0032	0.00801
Kc_4	0.0052	0.1561

II.2 Stereo Calibration Results

Extrinsic Parameters (after optimization)

Rotation vector: om = [0.00788 0.08773 -0.02057]± [0.00096 0.00827 0.00392]

Translation vector: T = [-17.03075 2.827024.68061]± [7.70866 0.56062 0.85337]

II. 3 Validation of the Program

To prove that the program is efficient, we have to validate it with known dimensions, for this we took a cube whose dimensions are known (45 x 45 x 45 mm3), and we recalculate these dimensions using our program, we obtain the results shown in the table below:

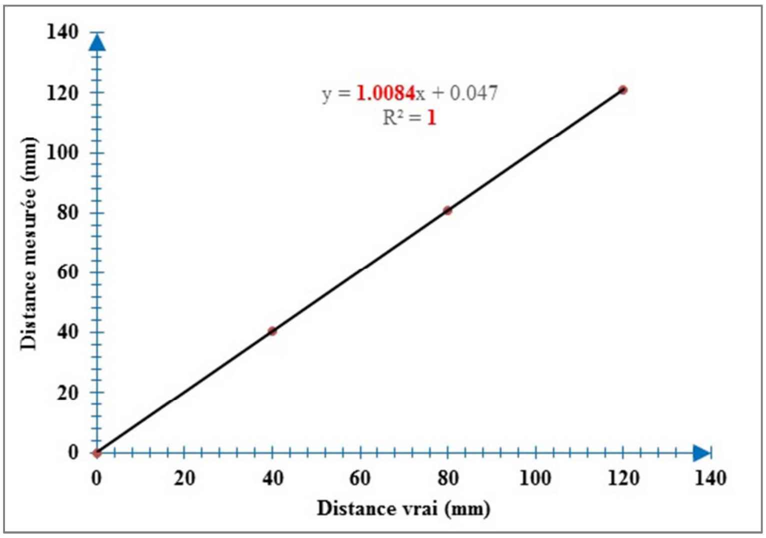

Fig. 5 - Validation curve

The slope of the graph is a = 1.0084, which is practically equal to unity, which shows the strong similarity between the measured distance and the true distance, which allows us to validate our program.

II. 4 Execution of the Tensile Test

This tensile test is applied to a polyamide specimen (YOUNG module: 2.8 GPa, Poisson's ratio: 0.27)

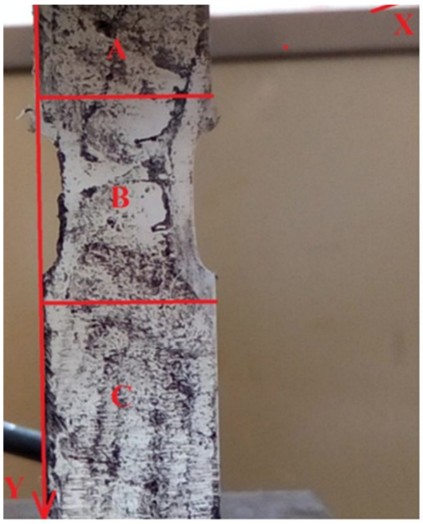

Fig. 6 - The specimen in the initial state.

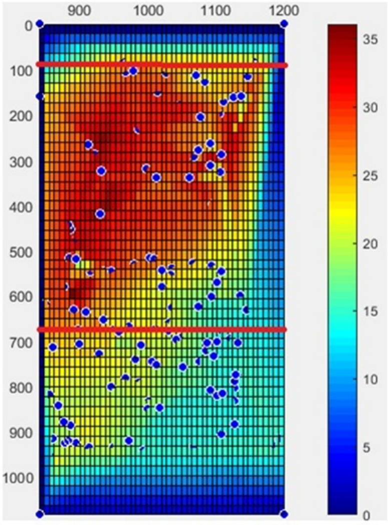

Fig. 7 - Displacement field for the tensile test.

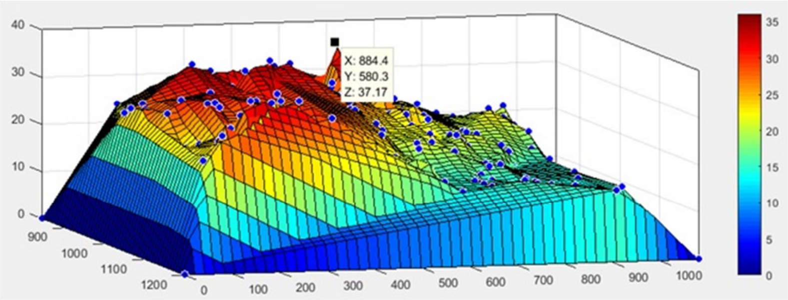

Fig. 8 - 3D displacement field for the tensile test.

After showing the kinematic field, the concentration of stress in the zone of constriction in the middle of the test piece, which appears in the yellow color, is clearly visible, with points near the upper jaw more or less fixed.

Subsequently, we will follow the displacement of two points max and min at different times, the following graph shows the displacement as a function of time:

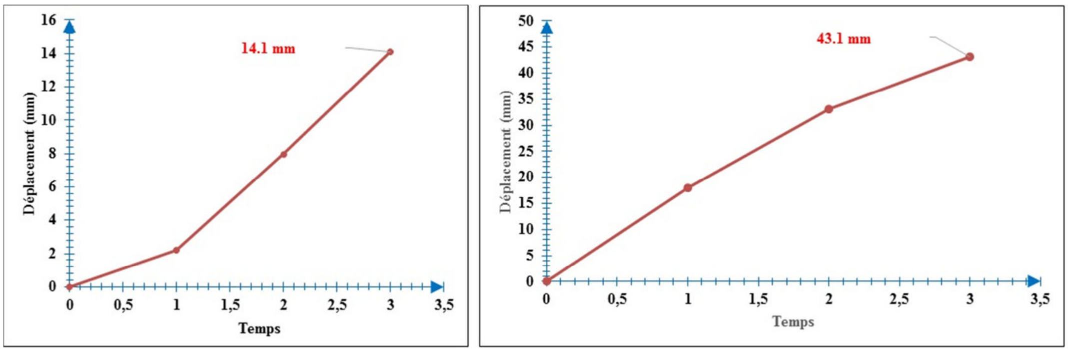

Fig. 9 - Tracking of points at displacement max and min

In order to see closely the interest of this test, we will determine the fish coefficient of this material, knowing that in the literature, the value of this coefficient is 0.27, in order to determine the practical value, traceεz=f(εx), car:$\varepsilon_z = -\upsilon\varepsilon_x$

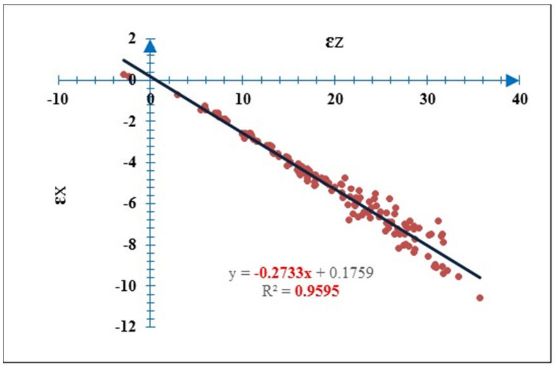

Fig. 10 - Deformation according to z as a function of deformation along x

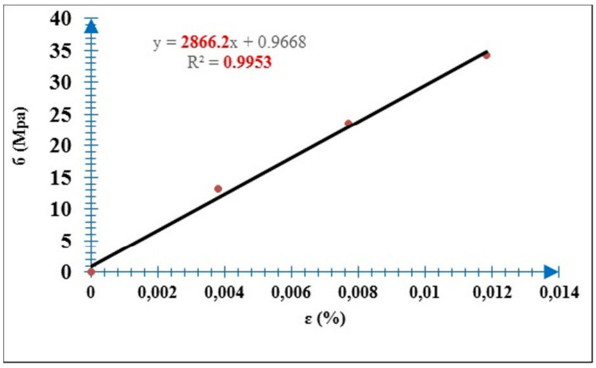

Fig. 11 - Stress as a function of strain

According to the egg-laying of the graph which represents the coefficient of fish, we see that this technique is effective, it presents an error of 1.52%. Then, we will evaluate the YOUNG modulus, by plotting the traction curve. According to Hook's law, the laying of the graph represents the YOUNG modulus.

According to the equation of the trend curve, we can derive the value of the YOUNG module found by our program, which is E = 2.866 GPa, comparing this value with that available in the literature, which is E = 2.800 GPa, there is an error of only 2.36%, which is due to calibration errors or the quality of the images.

I.7.1 Bending Test Results

In the following graph, we represent the points in 3D space, and to simplify the visualization, we put them in coordinates (X, Y, Z) where Z is the module of the displacement vector.

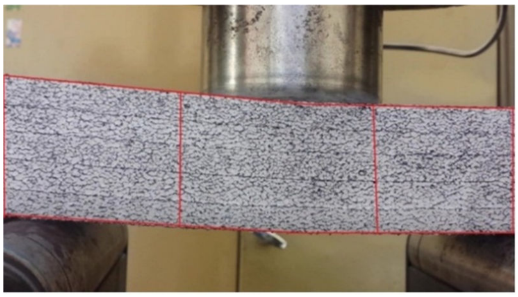

Fig. 12 - The specimen during the loading.

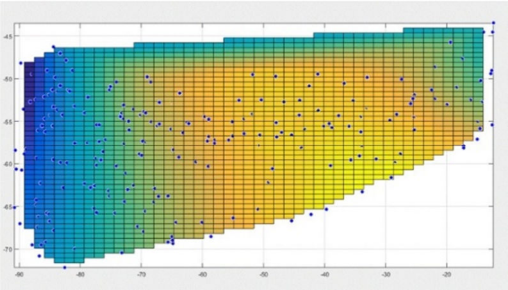

Fig. 13 - Displacement field for bending test

From the results obtained, it is found that there are three zones which are formed:

- At the extremities, the displacements are weak;
- In the center, the displacement is important (arrow max), danger zone.

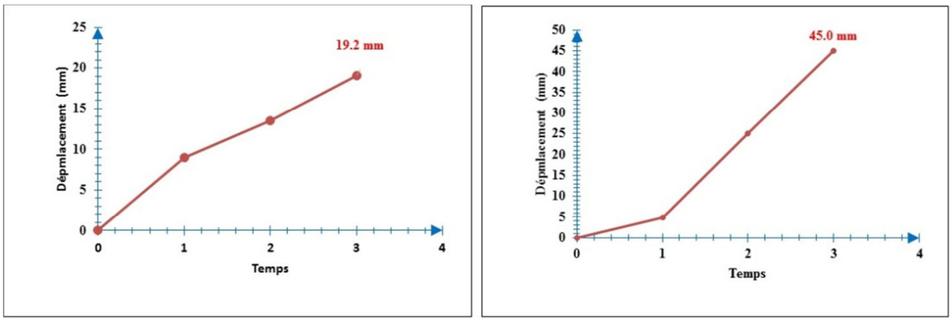

Fig. 14 - Tracking point with max and min displacement.

I.7.2 Results of Stamping Test

In this case we used 5 pairs of images (left and right), and we followed 5 points on the same radius (Figure 15), since the deformation is axisymmetric, for 5 different instants. The following table shows the instantaneous cumulative displacements of each point cited in the previous figure.

Table 3 - Follow-up of stamping points for different instants

	instant 2	**instant 3**	**instant 4**	**instant 5**
point 1	1,70	4,68	5,21	5,40
point 2	1,67	7,89	9,10	11,86
point 3	3,30	8,17	12,37	12,56
point 4	3,11	7,05	9,03	9,99
point 5	2,38	5,10	8,74	9,87

And here is the graphic representation of the different movements in different moments:

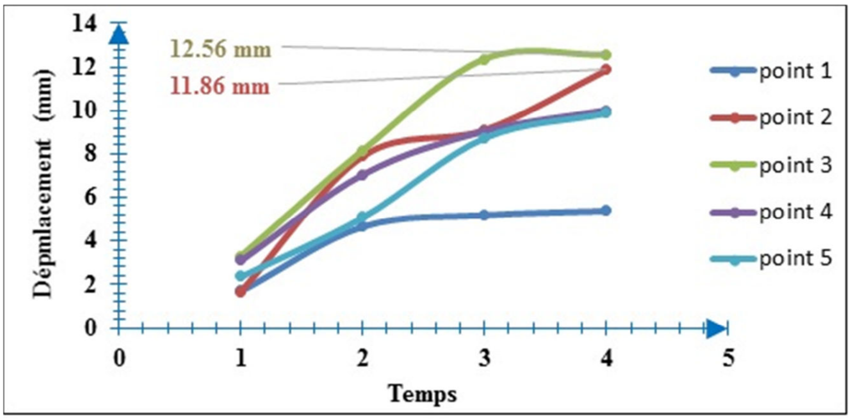

Fig. 15 - Déplacement des points suivis en fonction du temps

It is noted that the displacement is more important for the second and third points. Comparing with other works, it is found that the displacement is greater at the level of the skirt and moreover at this level that it is likely to cause a shearing of the stamping (Figure 17).

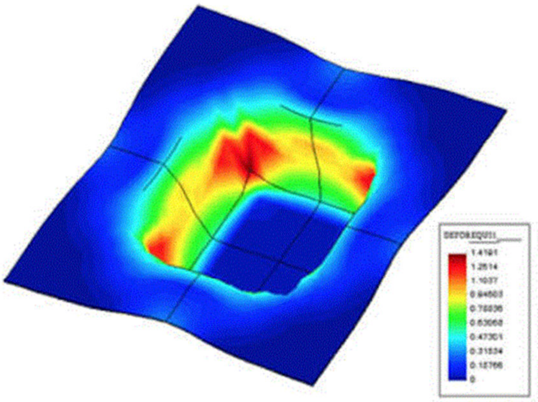

Fig. 16 - LS-DYNA stamping simulation results

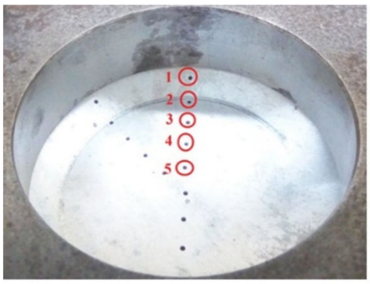

Fig. 17 - Tracked points

CONCLUSION

The digital correlation technique presented here allows the determination of displacement and deformation fields. In its multi-scale version, small deformations as well as very large deformations can be measured between two consecutive images.

An alternative approach to identification has been developed for the determination of elastic properties from measurements of displacement fields on the surface of a sample. It is based on a finite element formulation of the equilibrium deviation for which displacements the elastic properties are unknown. These have been assumed to be constant on each element. The current development and use of reliable, accurate and robust displacement field measurement techniques allows the characterization of fields of mechanical properties. All these developments open the door to the dialogue between experiment and calculation in the modeling of materials and structures in which field measurements and identification are the hyphen.

We presented in this paper the binocular stereo technique based on the correlation which can measure:

- The 3D shape of a static object;
- The deformed object undergoes mechanical stress in 3D.

The main advantages of this technique are:

- No regular grid should be applied to the room; Just mark it with a pattern that can be done in seconds with an aerosol paint, a single pair of stereo images can calculate the 3D shape of the deformed surface.
- We obtain a dense 3D reconstruction composed of more than 1.3 M of data points. The meshes used to calculate the local deformations are generated at the processing level from the dense 3D reconstructions provided by the stereo-correlation algorithm.
- We can generate meshes of all sizes.

For the easy use of this technique using our program, we propose an algorithm to follow, result of our tests and tests.

REFERENCES

[1] F. Hild, (2003). Thèse de l'université de Paris IV, France.

[2] J. E. Dufour, (2015). Thèse de l'Ecole Supérieure de CACHAN, France.

[3] B. Marvalová, T. H. Nam, "Deformation measurement and analysis of inflated air-spring shell using stereo-correlation technique".Support de cours.

[4] T.Mbarek, L.Robert, H. Sammouda, B.Charrier, J-J.Orteu, F. Hugot, (2013). Thèse de l'université PAUL SABATIER - TOULOUSE III. France.

[5] L. Crouzeix, (2008). « Identification de champs de propriétés mécaniques des structures composites à partir de mesures de champs de déplacements » Support de cours.

[6] O.Ait Aider, P. Hoppenot et E.Colle Cemif-LSC, Localisation camera/objet par correspondances point 3d-pixel application à la localisation d'un robot mobile, université d'Evry Val-d'Essonne.

[7] D. Garcia, J.J. Orteu, (2001). Thèse de l'Ecole des Mines d'Albi France.

[8] J. N. Prie, S. Calloch, C. Cluzel, F. Hild, (2002). Thèse de l'université de Paris IV, France.

[9] J.-E. Pierréc. Passieu Xa, J.-N. Périé, F. Bugarina, L. Roberta, (2015).Thèse de l'université PAUL SABATIER - TOULOUSE III. France.

[10] Y. Wang, D. Joannic, A. Lalande, P. Delassus, J-F. Fontaine, (2013).GALWAY. Ireland.