

# A novel feature-based incremental digital image correlation method to measure large deformations of soft materials

Sneha Prasad<sup>1</sup>, David Kumar<sup>2a</sup>, Sumit Kalra<sup>3</sup>, Arpit Khandelwal<sup>4</sup>

<sup>1</sup> Interdisciplinary Research Division of IoT and Applications, Indian Institute of Technology Jodhpur, Jodhpur 342037, India,

<sup>2</sup> Department of Aerospace Engineering, Indian Institute of Technology Madras, Chennai 600036, India

<sup>3</sup> Department of Computer Science and Engineering, Indian Institute of Technology Jodhpur, Jodhpur 342037, India

<sup>4</sup> Department of Electrical Engineering, Indian Institute of Technology Jodhpur, Jodhpur 342037, India  
<sup>a</sup>david@iitm.ac.in

**Abstract.** Identification of large deformation in soft materials through Digital Image Correlation (DIC) is still a challenging task, due to the non- or -limited invariance to scale and shape of template matching techniques used by correlation coefficient-based criterion. Soft materials under loading encounter large deformation which changes the shape of the materials including the target patterns used for interrogation during displacement and strain computation of the material. A general approach to identify large deformation is to use every preceding image as a reference for the subsequent deformed images, but it suffers from cumulative errors. Thus, this work introduces the concept of feature-based incremental approach with thresholding. It is integrated with DIC to examine large deformations of soft materials. The proposed methodology uses KAZE feature detector and descriptor and defines a threshold value (based on scale and shape of deformed pattern) for selecting reference images instead of using every previous image. The developed methodology reduces cumulative errors and computation time while providing high accuracy large deformations and strains for soft materials.

**Introduction** One of the challenges with the present Digital Image Correlation technique is the identification of large deformation in soft materials under loading conditions, which experiences substantial deformations due to scale and shape changes. This alteration of structure/material tends to decorrelation of the graylevel pixel intensities between the absolute reference image and the deformed image. Since the correlation criteria is a template matching technique that does not consider keypoint features of the images, its performance degrades, and correlation fails if the target image varies in scale and shape. Some studies use an incremental approach to identify such large deformations i.e. they eliminate the concept of absolute reference image and use every preceding image as the reference for the subsequent deformed images. Although this approach is a good approximation for identifying large deformation but it suffers from cumulative errors [1]. Thus, this error dominance can result in an inaccurate deformation parameters. In addition, the current techniques are also limited to small translations and rotations of the target patterns and therefore it becomes necessary to address these challenges. In this work, we propose a feature-based incremental DIC approach to determine the complicated large deformations of soft materials. Our previous studies [2] show that the KAZE algorithm-based feature detection and matching methodology can efficiently provide initialization points for performing optimization operations on images with complex deformations/displacements of the points of interest. We extend this methodology further and integrate it with the incremental referencing approach. Moreover, the designed method defines a threshold value (based on the scale and shape of the deformed patterns) for selecting the reference image instead of considering every preceding image as a reference. In conclusion, the developed technique has the potential to measure large deformations even in the presence of complex scaling, rotations, and shearing of the target patterns. The developed method uses a non-linear optimization algorithm to achieve higher accuracy and is implemented with a parallel computation strategy. Thus, it reduces time complexity and increases efficiency in addition to its robust nature.

## Methodology

In this study, we integrate a KAZE based Strongest Interest Point (SIP) approach as an initial value estimation algorithm. The algorithm provides initial displacement values  $\mathbf{u}$  and  $\mathbf{v}$  to the non-linear correlation function. These displacement values are calculated by the SIP based on the correct correspondences between the thresholded reference image and the deformed image. Among these correct correspondence features, the one with highest metric is selected as the strongest point which is both distinct and has high repeatability. Further, its corresponding homographic location is searched in the deformed image which helps in determining the in-plane displacement of the soft material by subtracting deformed SIP value from the considered reference value SIP. Moreover, elementary analysis shows satisfactory results with respect to the conventional DIC. The present study demonstrates similar correlation coefficients as achieved from the conventional DIC where initial value estimation is given by Phase Correlation Method for each iteration [3]. Hence, the developed method increases robustness and accuracy of the determined displacement values which increase the accuracy of the computed true strain.

## Preliminary Results

This section displays few of the many results for using the KAZE algorithm in comparison to other feature detection and descriptor algorithms as shown in Fig 1 which illustrates the consistency of KAZE in identifying correct number of matched points from 0<sup>th</sup> to 100<sup>th</sup> and 100<sup>th</sup> to 200<sup>th</sup> image. The efficiency of any feature detector and descriptor algorithm is defined by its repeatability and distinctiveness, which is the measure of its feature matching capability. Here, the preliminary results are demonstrated on a soft material. We considered four parameters - correspondence points, computation time, coefficient of variance and feature identification efficacy relative to KAZE algorithm. From Table 1 it can be concluded that KAZE beats all other algorithms by detecting highest number of correct feature points (~8342) with less (Coefficient of Variance) CoV (which indicates that identified features have high accuracy). The feature identification efficacy parameter basically defines the efficiency of the algorithms in identifying correct number of correspondence points between the reference and the deformed image, relative to the points identified by KAZE. The efficacy parameter keeps KAZE points(~8342) as reference and calculates relative feature identification efficacy of other algorithms. Such as efficacy of BRISK(with ~1557 correspondence points) and SURF( with ~1094 correspondence points) are 18.67% and 13.11% respectively. Likewise efficacy of SIFT (with ~5327 correspondence points) is 63.86%.

Performance Parameter	Correspondence points	Computation time [s]	Coefficient of Variance (CoV) [%]	Feature Identification Efficacy w.r.t KAZE [%]
BRISK	1557.7	0.044	61.80	18.67
SIFT	5327.2	0.0062	17.87	63.85
SURF	1094.1	0.0051	60.87	13.11
KAZE	8342.3	0.0126	10.22	-

Table 1. Comparative analysis of BRISK, KAZE, SIFT and SURF algorithms.

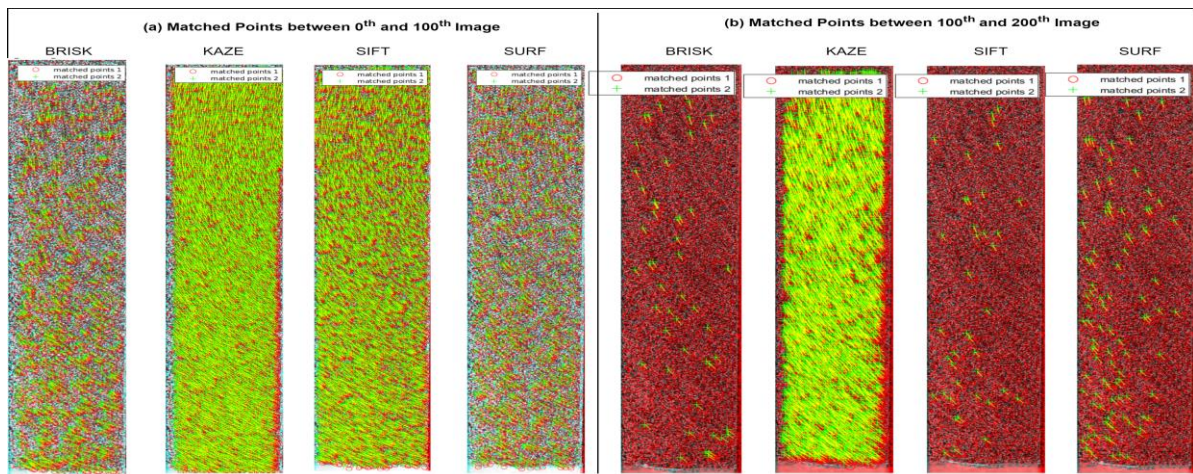


Fig 1. Displays the matched points detected by BRISK, KAZE, SIFT and SURF algorithms, (a) matched points between 0<sup>th</sup> and 100<sup>th</sup> image, (b) matched points between 100<sup>th</sup> and 200<sup>th</sup> image.

## Conclusion

The present study demonstrates a feature-based incremental approach which updates reference images based on shape and scale of deformed images and identifies large deformations of soft materials using KAZE feature detection and descriptor algorithm. The KAZE algorithm provides the strongest interest points (SIP) for feature matching between the thresholded reference and deformed images. Further the detected SIP is given as an initial value of displacement to the non-linear optimization algorithm for strain computation.

## References

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