

DEVELOPMENT OF AN IMAGE PROCESSING MODEL FOR THE  
MEASUREMENT OF VIBRATIONS IN STRUCTURAL ELEMENTS BY  
MATLAB AND SMARTPHONE DIGITAL CAMERA

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## **DEDICATION**

Dedicated to my beloved Parents and Project Supervisor

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“In The Mighty Name Of Allah, The Most Beneficent, The Most Merciful”

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## **ABSTRACT**

As a practical and competent instrument for quantitative deformation measurement of a structural element, digital image correlation (DIC) is nowadays widely accepted and commonly practiced in the area of structural dynamics, however most of the existing methods rely on expensive devices and require complicated laboratory setup. The aim of this research is to develop a cost-effective model to measure dynamic vibrational displacements of a structure by using digital close-range photogrammetry technique. The main advantage of this model is the simplicity and rapid measurement of vibration using a low-cost smartphone digital camera, and vibrations of non-accessible facilities such as radioactive or high temperature components may be monitored remotely by using this method. The method is based upon obtaining the consecutive stereo images of the vibrating structure with multiple target marks and subsequently developing a programming tool to analyze vibrational displacements of the structure using a simple photogrammetric method with the use of Smartphone Digital Camera technology and MATLAB software. It is found that the proposed model gives good agreement when compared with vibration measurement using expensive High Frame Rate Digital Camera.

## ABSTRAK

Sebagai instrumen yang praktikal dan berkesan untuk mengukur perubahan bentuk kuantitatif elemen struktur, korelasi imej digital (DIC) kini diterima secara meluas dan sering digunakan dalam bidang dinamik struktur, namun kebanyakan kaedah sedia ada bergantung kepada peralatan yang mahal dan memerlukan persiapan makmal yang rumit. Tujuan penyelidikan ini adalah untuk membangunkan model yang efektif dari segi kos untuk mengukur anjakan getaran dinamik struktur dengan menggunakan teknik digital fotogrametri berjarak dekat. Kelebihan utama model ini adalah dari segi kemudahannya dan pengukuran getaran yang lebih pantas menggunakan kamera digital telefon pintar murah, dan getaran yang tidak boleh diakses melalui peralatan makmal seperti komponen radioaktif atau bersuhu tinggi mampu dipantau secara jarak jauh dengan menggunakan kaedah ini. Kaedah ini berasaskan kepada turutan imej stereo daripada struktur yang bergetar yang diperolehi dari pelbagai sasaran, dan seterusnya pengaturcaraan dibangunkan untuk menganalisis anjakan getaran struktur dengan menggunakan kaedah fotogrametri yang mudah dengan penggunaan teknologi Kamera Digital Pintar dan perisian MATLAB. Didapati bahawa model yang dicadangkan menunjukkan keputusan yang setara berbanding dengan pengukuran getaran menggunakan Kamera Digital Berkelajuan Tinggi yang lebih mahal.

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## LIST OF ABBREVIATIONS

|             |   |                               |
|-------------|---|-------------------------------|
| <b>IP</b>   | – | Image Processing              |
| <b>DIC</b>  | – | digital image correlation     |
| <b>NCC</b>  | – | normalized cross-correlation  |
| <b>HFRC</b> | – | High Frame Rate Camera        |
| <b>SDC</b>  | – | Smartphone Digital Camera     |
| <b>KLT</b>  | – | Kanade-Lucas-Tomasi           |
| <b>CHT</b>  | – | Circular Hough Transform      |
| <b>FEM</b>  | – | Finite Element Model          |
| <b>SHM</b>  | – | Structural Health Monitoring  |
| <b>GUI</b>  | – | Graphical User Interface      |
| <b>EVA</b>  | – | Ethylene-vinyl acetate        |
| <b>U-Mo</b> | – | uranium molybdenum            |
| <b>SQL</b>  | – | Structured Query Language     |
| <b>2D</b>   | – | two dimensional               |
| <b>3D</b>   | – | three dimensional             |
| <b>EUS</b>  | – | endoscopic ultrasound         |
| <b>UAV</b>  | – | Unmanned Aerial Vehicle       |
| <b>UTM</b>  | – | Universiti Teknologi Malaysia |
|             | – |                               |

## LIST OF SYMBOLS

|              |   |                                      |
|--------------|---|--------------------------------------|
| $\zeta$      | – | Damping Ratio                        |
| $\omega_n$   | – | Frequency of the structure           |
| $T_n$        | – | Natural time period of the structure |
| $c$          | – | Damping coefficient                  |
| $\delta$     | – | Logarithmic Decrement                |
| $I$          | – | Moment of Inertia                    |
| $r$          | – | Radius                               |
| $u$          | – | Displacement                         |
| $K$          | – | structural stiffness                 |
| $\mathbf{f}$ | – | force                                |
|              | – |                                      |

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# CHAPTER 1

## INTRODUCTION

### 1.1 Problem Background

The evolution of mathematics as a study of logic did not exist before about 1000 B.C. The Greek philosopher Aristotle (350 B.C.) mentioned to the development of optical projection of pictures. Leonardo DA Vinci discovered the fields of mechanics, geometry and optics. During the year of 1492 he proved the ideologies of optical perspective (MacLeish, 1977), that supplies the basis of Photogrammetry even today (Ghosh, 1992).

Photogrammetry is the process of obtaining precise measurements about physical objects by means of photography (Lee & Al-Mahaidi, 2008). In this technique the 3D geometry of objects is determined by examining their 2D images. The three dimensional geometry includes shape, size and location. (R. Jiang, Jáuregui, & White, 2008).

The basic principle of Digital Image Correlation method is tracking of the sub images present in reference and deformed images to recover the displacements (Pan & Li, 2011). Other than theoretical analysis, there is also an approach on the experimental analysis of structures. A lot of devices are required during the conventional experimental-based testing, while many drawbacks make this method not so effective and limited. For instance, the strain of a structure can be estimated directly using strain gauges, however it is costly and its usage lifetime is rather limited. A considerable amount of wiring works may require to facilitate a direct connection between the sensors and the data acquisition logger (Kim & Kim, 2013).



## **1.2 Problem Statement**

Development of a MATLAB program for the measurement of vibrations in a structural element by non-contact approach. Image Processing and Object Tracking Toolboxes from MATLAB Software and commonly used smartphone digital camera makes this model simple, easy, user-friendly and cost-effective.

Image Processing method is applied in this study to replace the conventional tools for vibration measurement by normal smartphone camera. Compared to conventional measurement, IP method can be reused to measure deformations of the specimens. By using IP method, we can measure the displacement and strain at any point of the specimen. This method uses low cost and non-contact technique in measuring vibrations in beams, columns and other element of structure.

## **1.3 Research Goal**

Goal of this research is to develop a simple, cost-effective user-friendly MATLAB Programming model for the measurement of vibrations in a structure with the help of digital close-range photogrammetry technique.

### **1.3.1 Research Objectives**

The objectives of the research are:

- (a) to obtain MATLAB codes that can be used in image processing and object tracking
- (b) to modify and rearrange the codes according to the present research aim
- (c) to develop a complete program including object detection, calibration and object tracking in a series of images of a vibration structure

- (d) to obtain the vibration graphs of a vibrating beam recorded by Smart Phone Digital camera, as well as Expensive High Frame Rate Digital camera
- (e) to validate the results based on relative comparison study of both vibration graphs

#### **1.4 Scope of Study**

The investigation applies the idea of low-spending plan photogrammetric procedure where the equipment and the product utilized is financially savvy and easy to use. The fundamental aim of this examination is to decide the most practical approach of the photogrammetric strategy in structural analysis that requires a straightforward testing setup but gives a sensible precision.

The scope of this research is to focus on measurement of dynamic vibrational displacements of a structure using the accessible IP vision framework tool stash in MATLAB programming to get information from captured images and video recordings. This likewise includes the improvement of programming codes with a specific end goal to accomplish the targets of the study.

Any Smartphone Digital camera can be used but in this research Oppo A5 camera is used. Relative validation of proposed method is done by comparing the results obtained by High Frame Rate camera (Sony DSC-RX100M5). A cantilever beam of solid glue made up of Ethylene-vinyl acetate copolymers is used as vibrating structure.

#### **1.5 Significance of Study**

Methods and instrumental setup used in the field of Photogrammetry are complex and much expensive. In this study, it is expected that the method will be simple and the whole setup will be economical by using smartphone camera.



## REFERENCES

1. Andreaus, U., Colloca, M., & Iacoviello, D. (2011). Coupling image processing and stress analysis for damage identification in a human premolar tooth. *Computer Methods and Programs in Biomedicine*, 103(2), 61–73. <https://doi.org/10.1016/j.cmpb.2010.06.009>
2. Başığit, C., Çomak, B., Kiliçarslan, Ş., & Serkan Üncü, I. (2012). Assessment of concrete compressive strength by image processing technique. *Construction and Building Materials*, 37, 526–532. <https://doi.org/10.1016/j.conbuildmat.2012.07.055>
3. Costa, D. D., Júlio, J. V. E., & Araújo, H. (2016). Crack propagation monitoring using an image deformation approach, (September), 1–14. <https://doi.org/10.1002/stc.1973>
4. Ghosh, S. K. (1992). History of Photogrammetry - Analytical Methods and Instruments. In XVIIth ISPRS Congress Technical Commission VI: Economic, Professional and Educational Aspects of Photogrammetry and Remote Sensing (Vol. XXIX, pp. 311–327). <https://doi.org/10.1179/174581607x254776>
5. Jakubas, W., Jaraczewski, M., & Mielnik, R. (2016). SIMULATION STUDY OF A TRACK CIRCUIT TO DETERMINE THE TRAFFIC PARAMETERS OF A RAILWAY VEHICLE DO WYZNACZANIA PARAMETRÓW RUCHU. <https://doi.org/10.4467/2353737XCT.16.255.6054>
6. Jedrusik, P., Walusiak, Ł., Bednarek, I., Koprowski, R., & Wróbel, Z. (2018). Image processing and analysis in lung cancer cells growth. In *Advances in Intelligent Systems and Computing*. [https://doi.org/10.1007/978-3-319-59162-9\\_36](https://doi.org/10.1007/978-3-319-59162-9_36)
7. Jiang, M., Gu, Q., Aoyama, T., Takaki, T., & Ishii, I. (2017). Real-Time Vibration Source Tracking Using High-Speed Vision. *IEEE Sensors Journal*, 17(5), 1513–1527. <https://doi.org/10.1109/JSEN.2016.2647690>
8. Jiang, R., Jáuregui, D. V., & White, K. R. (2008). Close-range photogrammetry applications in bridge measurement: Literature review. *Measurement: Journal of the International Measurement Confederation*.

<https://doi.org/10.1016/j.measurement.2007.12.005>

9. Jurjo, D. L. B. R., Magluta, C., Roitman, N., & Gonçalves, P. B. (2010). Experimental methodology for the dynamic analysis of slender structures based on digital image processing techniques. *Mechanical Systems and Signal Processing*, 24(5), 1369–1382. <https://doi.org/10.1016/j.ymssp.2009.12.006>
10. Karaşahin, M., Saltan, M., & Çetin, S. (2014). Determination of seal coat deterioration using image processing methods. *Construction and Building Materials*, 53, 273–283. <https://doi.org/10.1016/j.conbuildmat.2013.11.090>
11. Kim, S. W., & Kim, N. S. (2013). Dynamic characteristics of suspension bridge hanger cables using digital image processing. *NDT and E International*, 59, 25–33. <https://doi.org/10.1016/j.ndteint.2013.05.002>
12. Lee, T. K., & Al-Mahaidi, R. (2008). An experimental investigation on shear behaviour of RC T-beams strengthened with CFRP using photogrammetry. *Composite Structures*, 82(2), 185–193. <https://doi.org/10.1016/j.compstruct.2006.12.012>
13. Li, L., Gong, M., Chui, Y. H., & Schneider, M. (2014). A matlab-based image processing algorithm for analyzing cupping profiles of two-layer laminated wood products. *Measurement: Journal of the International Measurement Confederation*, 53, 234–239. <https://doi.org/10.1016/j.measurement.2014.03.035>
14. Liu, C., Tang, C. S., Shi, B., & Suo, W. Bin. (2013). Automatic quantification of crack patterns by image processing. *Computers and Geosciences*, 57, 77–80. <https://doi.org/10.1016/j.cageo.2013.04.008>
15. McAndrew, A. (2005). *An Introduction to Digital Image Processing with Matlab Notes for SCM2511 Image Processing 1. Image Rochester NY (Vol. 1)*. <https://doi.org/10.1109/TBME.2009.2017027>
16. Omid, M., Khojastehnazhand, M., & Tabatabaeefar, A. (2010). Estimating volume and mass of citrus fruits by image processing technique. *Journal of Food Engineering*, 100(2), 315–321. <https://doi.org/10.1016/j.jfoodeng.2010.04.015>
17. Pan, B., & Li, K. (2011). A fast digital image correlation method for deformation measurement. *Optics and Lasers in Engineering*, 49(7), 841–847. <https://doi.org/10.1016/j.optlaseng.2011.02.023>

18. Pereira, F. C., & Pereira, C. E. (2015). Embedded image processing systems for automatic recognition of cracks using UAVs. *IFAC-PapersOnLine*, 28(10), 16–21. <https://doi.org/10.1016/j.ifacol.2015.08.101>
19. Rimkus, A., Podvieszko, A., & Gribniak, V. (2015). Processing Digital Images for Crack Localization in Reinforced Concrete Members. *Procedia Engineering*, 122(Orsdce), 239–243. <https://doi.org/10.1016/j.proeng.2015.10.031>
20. Robert Koprowski, Z. W. (2011). Image Processing in Optical Coherence Tomography. *Assessment*. <https://doi.org/10.1784/insi.45.9.621.52934>
21. Sankarasrinivasan, S., Balasubramanian, E., Karthik, K., Chandrasekar, U., & Gupta, R. (2015). Health Monitoring of Civil Structures with Integrated UAV and Image Processing System. *Procedia Computer Science*, 54, 508–515. <https://doi.org/10.1016/j.procs.2015.06.058>
22. Thomas, H., & Cantré, S. (2009). Applications of low-budget photogrammetry in the geotechnical laboratory. *Photogrammetric Record*, 24(128), 332–350. <https://doi.org/10.1111/j.1477-9730.2009.00551.x>
23. Zhang, M. M., Yang, H., Jin, Z. D., Yu, J. G., Cai, Z. Y., & Li, Z. S. (2010). Differential diagnosis of pancreatic cancer from normal tissue with digital imaging processing and pattern recognition based on a support vector machine of EUS images. *Gastrointestinal Endoscopy*, 72(5), 978–985. <https://doi.org/10.1016/j.gie.2010.06.042>