

Estimating Structural Dynamic Parameters by Using Visual-Based Technology

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ABSTRACT

Nowadays, various researches and studies have been done to obtain dynamic parameters of different types of structures. Thus, the researchers can assess the response of their used methods. Among many types of these techniques, visual-based technology is a new method that has also given rise to significant progress. Moreover, this method tracks the dynamic behaviors of structures directly and also identifies the dynamic parameters including the natural frequency and damping ratio.

Therefore, in this research, by using a conventional smartphone camera which is located at a specific distance from the specimen and the target, the amount of displacement of the target is obtained during the entry of force. The camera records the vibration by using different numbers of frames per second (FPS) under normal and damaged conditions for verification. Then, the raw data is transferred to the computer which is operated through MATLAB software to track the displacement of the structure based on the targeted point on the specimen.

Thus, the main purpose of this research is to discover dynamic parameters of the structure by utilizing the visual-based method in the laboratory. Finally, the outcomes are compared with the results of the accelerometer and other structural analyses which indicate the negligible 0.06% and 0.16% errors for normal and damaged conditions respectively.

Keywords: Image-based technique, dynamic monitoring, vibration measurement, motion correction, digital image processing, displacement measurement

ÖZ

Günümüzde farklı tipteki yapıların inşaat yer değiştirme, hız ve ivmelerini hesaplamak için çeşitli araştırmalar ve çalışmalar yapılmaktadır. Böylece, dış kuvvetlerin uygulanması sırasında araştırmacılar, onların etkinliğini ve davranışlarını izleyebilir ve anlayabilir. Bu yöntemlerin pek çok türü arasında görsel tabanlı teknoloji, fizibilite ve sağlamlık açısından da önemli ilerlemeler kaydeden yeni bir yöntemdir. Ayrıca, bu yöntem, yapıların dinamik davranışını izler ve doğal frekans, sönüm ve mod şekilleri de dahil olmak üzere yapısal parametre parametrelerinin özelliklerini elde eder.

Bu nedenle bu araştırmada, numuneden ve hedeften belirli bir uzaklıkta bulunan normal bir akıllı telefon kamerası kullanılarak, kuvvet girişi sırasında hedefin yer değiştirme miktarı elde edilmiştir. Kamera titreşimi kaydeder, ardından veriler, yapının hedeflenen noktaya göre yer değiştirmesini izlemek için MATLAB yazılımı aracılığıyla kullanılan bilgisayara aktarılır.

Bu nedenle, bu araştırmanın temel amacı, laboratuvarında bir numune üzerinde görüntü işleme yöntemini kullanarak yapının modal parametrelerini bulmaktır. Bu yöntemde, doğrulama için normal ve normal koşullar altında saniyede farklı sayıda kare kullanılır. Son olarak, bulgular ivmeölçer ve diğer FEM yapısal analizlerinin sonuçlarıyla karşılaştırılır.

Anahtar Kelimeler: Görüntü tabanlı teknik, dinamik izleme, titreşim ölçümü, hareket düzeltme, dijital görüntü işleme, yer değiştirme ölçümü

To My Family...

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LIST OF ABBREVIATIONS

ACC	Accelerometer
ASCE	American Society of Civil Engineers
CCD	Charge Coupled Device
CHARPY	A Systematic Increased Strain-Rate Examination
CS	Compressive Sampling
DIC	Digital Image Correlation
ETABS	Extended Three-Dimensional Analysis of Building System
FEA	Finite Element Analysis
FEM	Finite Element Modeling
FFT	Fast Fourier Transform
FNA	Fast Nonlinear Analysis
FPS	Frame Per Second
FREQ	Frequency
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
IMPRO	Image Processing
MATLAB	Matrix Laboratory
PGA	Peak Ground Acceleration

Chapter 1

INTRODUCTION

1.1 General Introduction

Basically, structural damage detection is a costly process and requires specialized people and modern technologies. For instance, using a large number of accelerometer sensors and installation on the pointed targets where are difficult to connect, as well as the processing of all raw data from different sensors can cause a lot of errors and limitations in this area. Today, a lot of researches have been attempted to introduce modern technologies to overcome these issues. In recent years, many researchers have been measured the displacement of structures by using image processing technologies. These methods are used in a computer analysis system that can quickly assess the dynamic parameters of the structure and therefore can be used to increase the reliability of the results with high accuracy. This study combines the image processing, accelerometer, and structural analysis methods to measure dynamic parameters such as frequency and damping ratio which works regardless of the angle between the smartphone camera and the target. After measuring the dynamic parameters of the structure especially finding the frequency by image processing method, simultaneously, the results are presented the advantages and applications of the selected method which are explained in any steps of investigations. Finally, several rules based on "computer vision" are focused on the technical ability and verification of this method.

1.2 Aim of the Study

This research concentrated to apply the image processing method for measuring the dynamic parameters. In addition, as part of the study, experiments were performed to accurately evaluate the behavior of the structure under free vibration. A steel specimen was tested in the laboratory by using structural analysis and image processing to assess its behavior in different conditions. Consequently, the results of this experimental investigation illustrated that the output data from the determined image processing method and accelerometer were significantly comparable to the results of structural analysis with negligible error.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides a summary of previous studies according to the recent image processing techniques and their integration in civil engineering to investigate the dynamic behaviors of structures by various tools and facilities. Essentially, the evaluation of non-contact dynamic behaviors of structures in recent years has been accompanied by increasing number of applications in civil engineering. Basically, the reduction of physical devices such as sensors or any kind of detectors is particularly unique and fascinating, especially for structures that can be difficult to access. Among these non-contact technologies, vision-based assessments are a reasonable solution that civil engineers are attracted to. These examinations can be achieved from simple equipment such as a mobile phone camera. Virtually, most of these reviews have attempted to provide a solution, diminish and eliminate the errors in the output data from the experiments and correlate the results obtained from the image processing strategy with other methods to verify its accuracy and precision. On the other hand, published articles on the aim of advanced and costly cameras with the ability to compute boosted video (high frame rate per second) provide very valuable evidence compared to the results attained from older and conventional cameras. Therefore, the purpose of this chapter is to extract useful and practical advice from the current literature review that can be utilized to create a cost-effective and beneficial method.

2.2 Summary of Vision-Based Monitoring Technology

2.2.1 The Process of Monitoring

In general, systems based on visual surveillance and video and image processing in all careers (here civil engineering) include factors and accessories such as computer-connected cameras, utilizing numerous software that can evaluate the data in real-time. In addition, these systems can be equipped with multiple cameras that record only during monitoring while assessing data at other times. On the other hand, depending on the distance between the cameras and the targets to be evaluated, lenses with appropriate focus should be used to capture images with acceptable resolution and to pursue marks with adequate accuracy (Sutton 2009, Kohut 2013, Feng 2018 and Dong 2020). For instance, (Baqersad 2017) expanded light bulbs when conducting investigations to measure and track targets in low light situations even in darkness.

The framework and basis of vision base monitoring consist of the following main steps: First of all, establishment, initially, the cameras that are equipped with efficient lenses must be mounted on a tripod in the most appropriate places. Furthermore, for the camera, the specified targets that need to be tracked should be adjusted (according to the selected visual monitoring method). Secondly, calibration, in this step the connection between the pixel coordinates and the physical coordinates is defined, which is basically according to the physical dimension of the body surface and the corresponding image dimension in the pixel. Thirdly, video processing, after recording videos, the motion of each target in each frame of the video is attended. As a result, some information such as displacement is stored as output. (Figure 1)

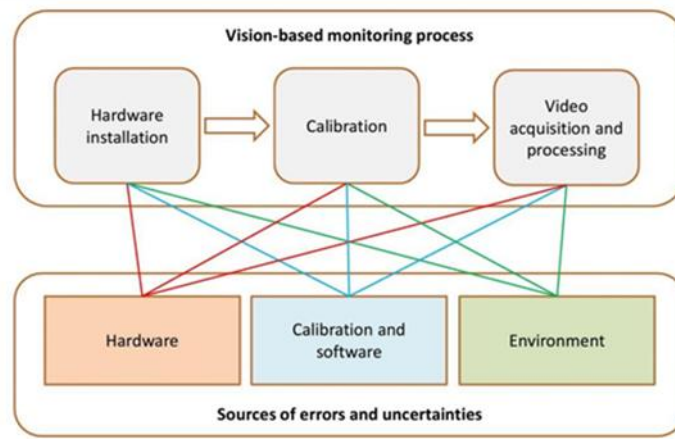


Figure 1: Monitoring framework based on vision and source relationships of errors and uncertainty (Zona, 2020)

2.2.2 Vision-Based Monitoring by Image Processing Technique

In practice, the digital camera captures photos with specified marks, as shown in Figure 2 (X.W.Ye, 2013), using digital image processing and mark fitting algorithms (X.W.Ye et al., 2015, C.Z. Dong et al., 2016, T. H. Yi et al., 2016). Additionally, the marks are followed, and structural removals at those mark locations on the building can be gathered. Without a doubt, using image processing techniques such as image processing correlation transformation following method and similarly transition tagging technique (S.-H. Yen et al., 2015), the vertical and horizontal displacement, also known as two-dimensional 2D displacement (H. W et al., 2002), can be retrieved with any type of digital camera (X.W.Ye and C.Z. Dong, 2016).

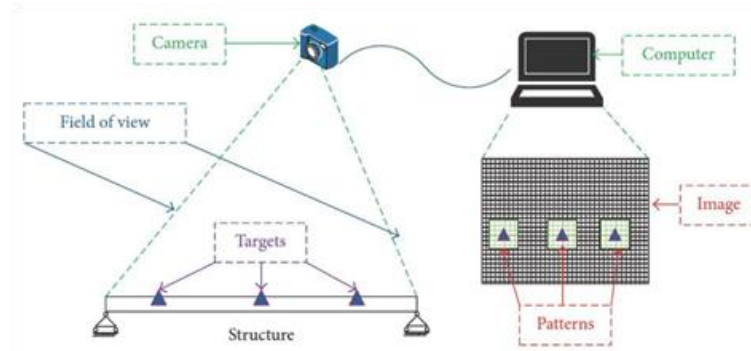


Figure 2: Exhibits the vision-based displacement distribution technique in a two-dimensional field (X.W.Y et al., 2013)

2.2.3 Camera Based on Literature

Nowadays, a modern technique or equipment named motion evolution is organized to realize the shapes of functional variation of a structure. One of the most important tools in the explained area is the collection of digital image correlation (DIC) which is improved the typical frequency to measure the challenge of verifying displacement even under high-frequency conditions (Molina-Viedma et al., 2018). Therefore, to estimate the displacement of any kind of structure, the sub-pixel edge detection method was inaugurated by (Poudel et al., 2005). Furthermore, (Choi et al., 2011) introduced a structural dynamic displacement system which was utilized several ratios by altering camera recorders. Also, (Ho et al., 2012) achieved a simultaneous vision strategy that carried out an image processing technique to evaluate the displacement of many kinds of civil infrastructure. Besides, (Tian and Pan, 2016) proposed the new visual-based displacement strategy by employing LED dots to find the displacement-time diagram on the specific bridge. Likewise, (Yoneyama et al., 2007) assessed the structure deflection distances by adopting the DIC method after applying force analysis to find modal parameters of interpreted structures. In another study, (Busca et al., 2014) was tried to figure out edge detection, a digital image correlation and the invention of a particular vision-based policy to investigate the dynamic behavior of the appointed

structure. Furthermore, (Jeon et al., 2011) introduced a new method for measuring the displacement which was the dual optical method. This technique was attempted to scale the six degrees of freedom of the selected building. Similarly, (Park et al., 2015) assessed the specimen with three-dimensional displacement with diagrams by using a frame tracking process.

Moreover, (Feng et al., 2015) struggled to establish a new vision-based with several detectors to estimate modal parameters of the chosen sample which came out from videos and images without using any target on the sample. This method, included various cameras with particular lenses to evaluate the dispatches in the stable time by the capacity of 150 FPS. Additionally, in another study which was done by (Feng et al., 2015), this study cultivated vision-based detectors and quantity the structural oscillations by observing video frames and also, exploring them by adopting manifestation techniques. A fascinating examination was done by (Yang and Yu, 2016) which analyzed free vibration, velocity and displacement monitoring. In this study, three various techniques were used as confirmation. These methods were included the frame discrepancy tool, percentage image acceleration and visible ebb device. The testing consequences of this survey illustrated that the fluctuation technique was more valid than the image acceleration of the particles because it was employed a special network with some windows on the lens that was being sure of characteristics of the input images highly. Additionally, (Yang and Yu, 2016) and (Yang et al., 2017) also exhibited that high-capacity devices such as FPS were exceptionally meaningful in discovering damages. Also, They reproduced a network that cloud discovered data from a camera with a capacity of 240 FPS that is effortlessly accessible and have a valuable destiny for their use in any kind of structural monitoring techniques. Plus, (Chen et al., 2015) used a digital photogrammetric scenario by

employing a considerable camera for assessing the free vibrations in a bridge. Likewise, (Zhao et al., 2016) prepared a method for sudden assessment of the bridge, that performed a feasibility investigation by struggling with an especial vision-based assessment by capitalizing on a camera of the smartphone. On this occasion, the D-Viewer and iPhone 6 were utilized to figure out the vibration aspects of the cable.



Figure 3: The establishment of smartphones in the laboratory (Zhao et al., 2016)

2.2.4 Omissions and Uncertain Results

On this occasion, in consonance with the last examinations, the analysis of the mistakes in the visual-based technique especially in the civil engineering area can be categorized by previous researchers and early studies such as (Chen, 2019 and Zappa, 2014). Moreover, there are numerous inquiries and investigations which have assessed the significance of crucial aspects of the external factors. As an example, (D’Emilia et al, 2013) demonstrated that revelations between 2 limited classifications of cameras for

operating in the visual-based method can be involved in the amount of precision in the consequences achieved from the image processing method. On the other hand, two cameras had the same detector resolution while they were used two various FPS. In other words, they prepared a comparison between the cheap price camera with about 30 FPS and high quality with about 2000 FPS as a costly camera. They assessed all experiments in an engineering laboratory. Additionally, as confirmation, for proving the validation of results came out from these two different FPS, they tried to measure values by an accelerometer sensor and a laser to evaluate the precision of values among all investigations. As a result, for the low case camera with a capability of lower than 30 FPS with the methods of operated aliasing, the experimental findings illustrated that the fluctuation uncertainty comparing to other implied measurements was below 4% of the vibration domain. In this case, they were assessed the data by qualifying the stable distance of 10 to 80 Hertz. On the other hand, when another camera with a capability of 2000 FPS is employed in the laboratory, the testing outcomes exhibited about 7% comparative uncertainty to the vibration domain between 100 and 400 Hertz of frequencies and also, 12% approximately for values between 500 and 700 Hertz. Normally, the frequency in explained areas and particularly in constructions areas is below 80 Hertz. Therefore, the impact of utilizing unique FPS in this type of analysis to measure free vibration can be indicated. An additional illustration for existed errors in the experiment was considered by (Liu et al., 2016). This study was strived to assess the impact of length between camera and target which monitored the focus of the lens by calibration. Those conclusions suggested that mistakes in the measurements boosted the extent and additionally, it can be diminished by the promotion of focal length or focus by operating an accepted distance. furthermore, the calibration technique can be seriously declined the measurement of uncertainty. Undoubtedly,

these proofs are put out a valuable contribution in elementary options for designing the composition of an image processing system. Moreover, the studies on the examination of errors that illustrated by (Gao et al., 2017, Blaysat, 2016 and Xu, X et al., 2017) explained crucial knowledge on the precision of vision-based networks which could be achieved from the findings of investigations. Necessarily, monitoring of the real buildings is emphasized more inconveniences in the assessment of the errors that are provided to enhance the number of possible explanations in the area when concerned by laboratory investigations.

2.2.5 Current Area Petitions of Vision-Based Vibration Monitoring

There have been a number of widely disseminated struggles demonstrating options for vision-based monitoring in the field of civil engineering, which can be established in the specialized literature. These welfare benefits can be monitored in three areas of the monitoring system: first, distributions of displacements that strain under static loads; second, distributions of displacements that strain under dynamic loads; and third, distributions of displacements that strain under dynamic loads (Park et al., 2018, Alipour et al., 2019, Halding, 2019, Lee, J.,2020, Dong et al., 2020). Second, distributions of displacement-time records in a scaly model in monitored environmental situations, typically in a lab, are studied (Durand-Texte,2019, Civera et al., 2020, Eick et al., 2020, Lai et al., 2020, Ngeljaratan, 2020). Finally, the area distributions of displacement-time records in entire scaled and normal conditions are presented (Dong et al., 2019, Dong, C.Z. and Bas,2020, Fradelos, 2020).

Furthermore, the effect of the detector and sensor advancements in vision-based methods is examined (Luo, 2018, Erdogan, 2020). Subsequently, area distributions of moving elements in turbine patients (Poozesh, 2017, Sarrafi, 2018, Sabato, 2020) acquired vision-based methods and image processing methods should evaluate the

extensions that occur between these monitoring options, which in some cases, there are several journals which confirm initial laboratory confirmations prior to area testing. As a result, the proposed subdivision should indeed be evaluated based on the source of the major donation provided. Table 1 provides some key evidence on the employed application for each reference, which displays the visual progression, templates, element matching, movement development, and loading situation during controlling, as well as parallels with other approaches, alongside the picture and video processing.

Table 1: Significant confirmation on accepted application, image processing technique, loading situations and comparing with further monitoring methods.

References	(FPS)	Technique	Load conditions	Comparing with
Feng et al., 2017	10	Te.matcging	Train movement	GPS, sensors
Chen et al., 2018	30	Visual cycle	traffic jam	Accelerometer
	25	Te.matching	Train movement	Vision-based, sensors
Dong et al., 2020	60	Characteristic matching	People who walking	Accelerometers
Dhanasekar et al., 2019	50	Dantec method	Train movement	Scalar algorithm
Fradelos et al., 2020	30	Visual cycle	People who walking	Accelerometers, GPS
Xu, Y et al., 2018	30	Te.matching	People who walking	Accelerometers

2.2.6 Overall Comparison between Vision-Based Monitoring Techniques

From recent studies, It can be predicted that comparing among all cases was provided reasonable and nice correlations between vision-based and the additional evaluated technical systems. However, the study about a special structure which was a steel bridge that was experimented by (Dong et al., 2020) had some exceptions. There were some variations between the result that came out from accelerometer sensors and the

findings of vision-based which were not insignificant (Figure 4).

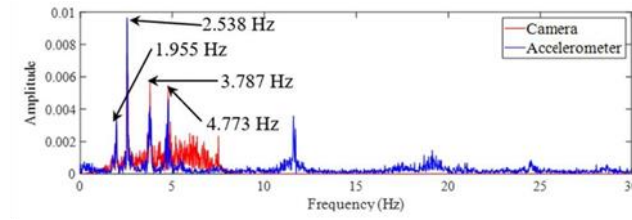


Figure 4: variations results between data obtained from accelerometer sensors and vision-based assessments (Dong et al., 2020)

Additionally, it is essential to remark that, in other representations, there were no especial comparisons among the methods which were employed there according to (Shariati and Schumacher, 2017) explanation. In their examination, they aimed to obtain a Canon camera that employed a universal lens to prepare 60 frames per second video when several apprentices move fluctuation it (Figure 5). Similarly, (Feng and Feng, 2017) described in relation the importance of the distributions to those data received in prior investigations and tried to develop and their comparisons were positive on the same case.

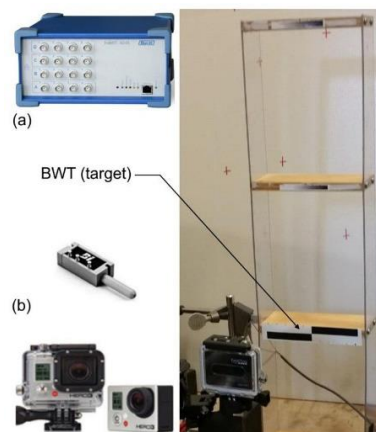


Figure 5: The laboratory-scaled for 3 degree of freedom of structural specimen by (Shariati and Schumacher, 2017)

In (Dhanasekaretal, 2019) the findings of the practical monitoring were acceptable related to the numerical value in duration of the extent of the monitored dynamic parameters. Also, in (Lydonetal, 2019) vision-based monitoring was expended as a combined monitoring network that involved fiber optics with the purpose to fill out the two networks (Figure 6).



Figure 6: Vision-based monitoring network by involving fiber optics (Lydonetal, 2019)

2.3 Using Detectors in Vision-Based

2.3.1 Introduction

The distribution machinery used for observing damage in structures is known as vision-based assessment. The technique patterns are assessed from the detector data in routine monitoring, which influences a large variety of analyses (S. Das et al., 2016). The omission and error references were appraised similarly to the grey degree of interpolation (H.M. Schreier et al., 2000), subtype purpose (G. Crammond et al., 2013), and structural purposes (H.M. Schreier et al., 2000). (L.P. Yu and B. Pan, 2015). With recent advancements, a non-contact vision method for estimating quasi-distributed dynamic parameters and creating motion has been developed. In the case of DIC (Buusca et al., 2014 and X.W. Ye et al., 2013), (D. Ribeiro et al., 2014), were used helpful techniques which were commonly used in vision-based displacement of

detectors. Furthermore, vision-based technology includes the distribution of strain from an image obtained from the camera's acceptable resolution utilizing numerous form algorithms (X.W. Ye et al., 2016, also D. Feng et al., 2017). The pre-produced specimens are compared to the photographs that have been preserved, as well as a score that is calculated based on the number of times the specimens have relayed with the images. Because this number is the highest, it indicates that the target spot is wounded (R.C. Gonzalez and R.E. Woods, 2017 and Salzmann et al. 2003).

2.3.2 Assessing Dynamic Parameters

In this case, the real and huge facilities and civil construction and finally any kind of buildings, primarily combine vertical pressures such as wind and then, during the final steps these data should be evaluated by frequency property for any sort of monitoring such as protection and preparing a safe position against dynamic loading (P. Antunes et al., 2012). On the other hand, due to the monitoring network, the velocity and finally dynamic behavior were examined by the frequencies achieved from the structure. According to obtain the data from these conditions, sensors (detectors) basically, accelerometers have been consumed for fault detection of structures.

2.4 Accelerometer

One of the conventional ways for calculating dynamic parameter values is to use a measuring sensor or accelerometer. Furthermore, this detector is widely utilized for any type of dynamic monitoring. Accelerometers are used to measure velocities in this case, and tripartite sensors are available to measure three upright velocities at the same time. Furthermore, while scanning a structure with outstanding dynamics, the sampling frequency ratio is accessible by relying on significantly standard needs. According to (A. Ariffin et al., 2014), building owners frequently install an accelerometer sensor to analyze dynamic parameters, particularly once conducting a

large analysis for every structure, including bridges, for measuring displacements using a complicated movement transformer without a continuous source level. For instance, in the case of a long-term monitoring building, a common business practice is to activate accelerometers on selected buildings so that detectors were being used to define dynamic behavior natural frequency. The accelerometer are ideal for modal analysis in large networks according to measure rate in three separate axes with low error, noise, and high sensitivity in various circumstances (S. S.Kessler and S. M, 2014). Although this is unsafe to verify a facility's setup based on acceleration measures, many researchers have had the opportunity to combine the use of sensor (accelerometers) as well as other detector techniques such as GPS, (. Z. M. Amin et al., 2003, X.Meng et al., 2011 and F. Moschus and S. Stiros,2011) video and image Processing association (A.Ariffin et al., 2014). These detectors are undeniably the traditional building regions of a structural system. Accelerometers detect structural reactions and process data for structural diagnostics (A.E. Aktan et al., 2003). The velocity detectors generate a significant portion of such data, increasing the system's repository cost. To avoid this conundrum, data compacting techniques, such as compressive sampling(CS), have been enhanced. Several types of equipment have been developed to collect compressed information from the building; Compressive wireless scenting (W.U. Bajwa et al., 2006), CS cameras (D. Takhar et al., 2006), CS analog-to-digital converter (ADC) (S. Kirolos et al., 2006).

2.4.1 GPS Based on Accelerometer

Recently, some researchers have tried to combine new methods including geographic estimation which enhanced for monitoring of buildings. This method was utilized mostly global navigation satellite system which is called GNSS and also global positioning system GPS which was established by (S.B. Im et al., 2013). Moreover,

this theory has computed the functions of assessed targets or specimen in three directions. By utilizing this technique, the modal parameters can be measured the same as visual-based methods. The additional impediment prevented by the GPS detector was the combination of GPS and accelerometer together which was analyzed by (A. Lepadatu et al., 2014). On the other hand, for assessing the modal parameters, frequency established design can be classified to inquire the frequency from GPS and also, the accelerometer with the raw information to define the existing frequency of any kind of buildings easily. Although there was nearly 8% omission among the results of two explained method ratios, the conclusions were satisfactory in the assessment of damage condition. similarly, (Meng et al., 2007) was experimented with the combined devices including GPS and accelerometer on some members of a bridge. The sampling frequency of GPS has arranged 10 Hertz and another side, the accelerator recorded all data by sample frequency of 85 Hertz and these sensors were installed on the same location and worked at the same time.

2.5 Old Generation of Sensors (Accelerometers)

Formal electronic sensors have been used for a long time to observe the dynamic feedback of structure. The accelerometer estimates the three-dimensional velocity of a facility and is both economical and easily launched (M.J. Chae et al., 2012). These detectors are known to spend a lot of power and have a low-resolution capability (G. Kilic and M.S. Unluturk, 2015). The distribution of new production detector technology was validated by using a wireless and wire-based accelerometer network on a highway bridge, for example (D.Zhu et al., 2011) Silicon designs detector and QA classification sensors were the wireless and cable-based sensors tested. Furthermore, the sampling frequency was typically 100Hz or 256Hz. The accelerometers were placed in roughly 20 areas at equal intervals along the route,

which had a total length of 40m (Figure 6). Certainly, the chart demonstrated that the data collection of both accelerometers was entirely parallel, implying that a wireless sensor system could be used for a short-term system.

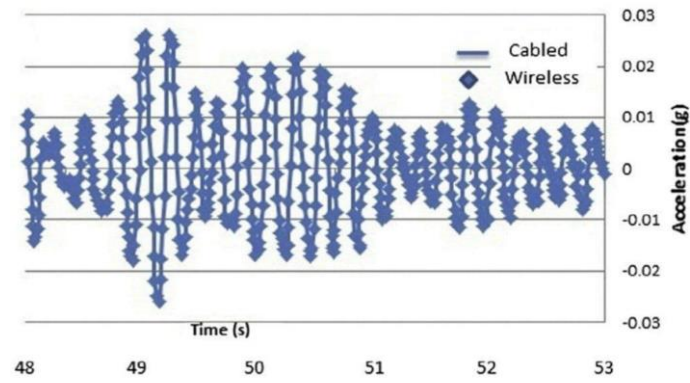


Figure 6: Similarity of data collected from wire-based and wireless sensors (D.Zhu et al., 2011)

Chapter 3

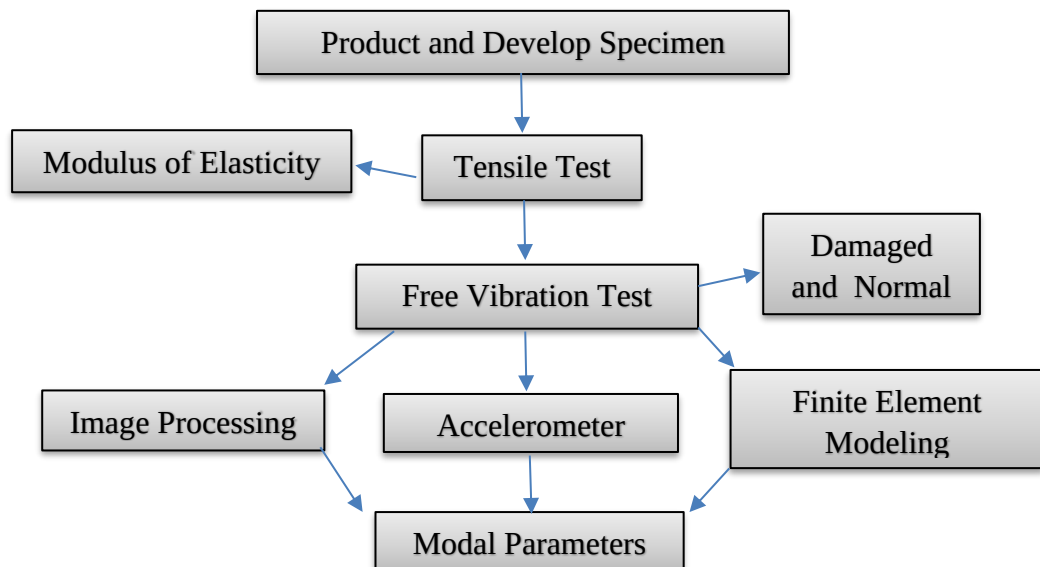
RESEARCH METHODOLOGY

3.1 Introduction

This chapter illustrates the program and test method of researching to detect the dynamic behavior of the structure and the modal parameters. In part of this chapter, the characteristics of the model used in the laboratory will be described, then the test method on this model and the verification modes, including the investigation in the case that the structure is damaged, will be described.

3.2 Research Schematic

Numerical and Experimental Investigation



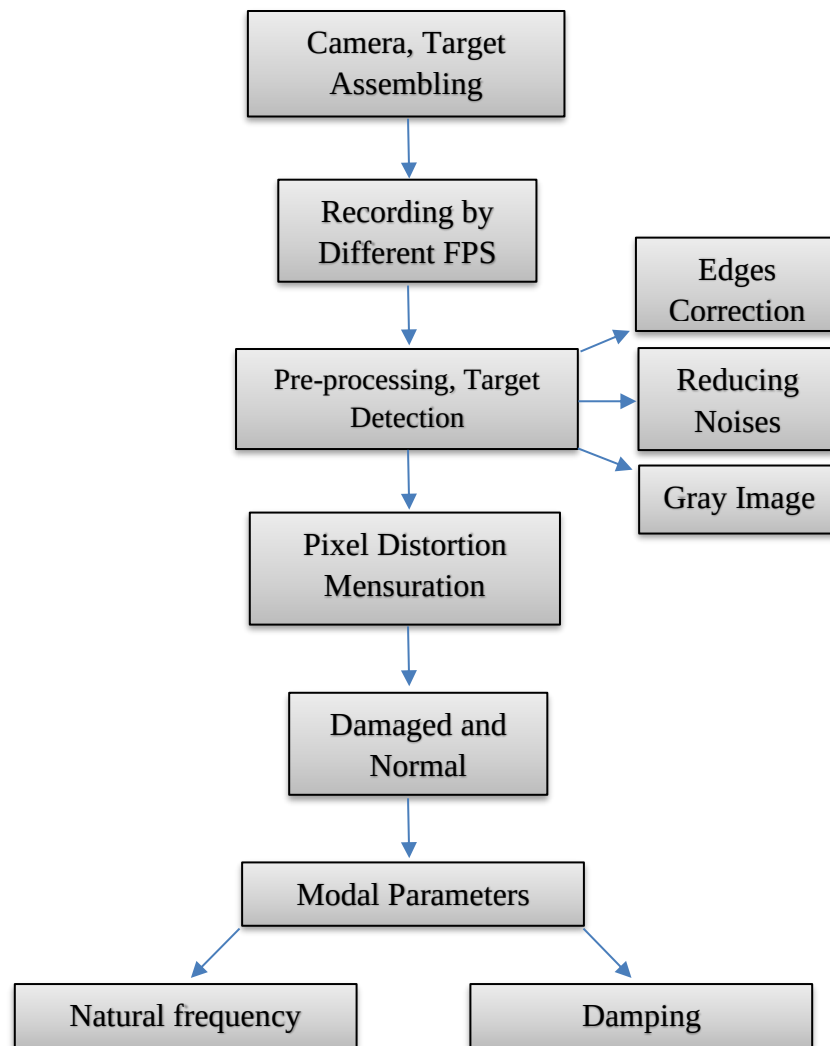


Figure 7: Research procedure

3.3 Experimental Survey

In this section, the aim is to introduce a method to evaluate and detect the dynamic behavior of a structure using a conventional smartphone camera to be used in maintenance and viewing structures. First, a brief description of the properties of the steel specimen to be used in this step is interpreted. Then, the conditions and process of verification and comparison of the results of image and video processing with the reference accelerometer and other tests in the normal and damaged state of the structure will be performed to check the modal parameters.

3.3.1 Frame Property

The steel used in the test is S235JR, which is classified as non-alloy structural steel and is described in EN 10025. As the name implies, it is widely used in the construction industry. This is a vital substance that is used in the construction industry which shows in Table 2, Table 3, Table 4. The S235 grade has outstanding performance and tensile strength and is heated by several operations. (Ovako Manufacturer Official, 2020)

S235JR description

S is the short form of structural steel and 235 refers to the lowest yield strength for the selected steel, the thickness is lower than 16 Millimeter also, JR is specified as the characteristic degree related to CHARPY influence examination power at the temperature 20 degrees of Celsius approximately.

Variants suitability

For heated drop Zinc covering due to the category EN 10025-2:2004: Class one: (Table 1) Si maximum 0.03% and Si +2.5 is maximum 0.09%.

Table 2: Chemical Composition (Ovako Manufacturer Official, 2020)

Variant	Cast	Weldability	C%	Mn%	P%	S%	Cu%	N%
S235JR EN10025-2 (ref)	Std	CEV 0.35	-	-	-	-	-	-
S235JR EN10025-2 (ref)		Pcm 0.25	0.17	1.40	0.035	0.035	0.55	0.0120

Table 3: Mechanical Properties (Ovako Manufacturer Official, 2020)

Variant	Condition	Format	Dimension [mm]	Yield strength min [MPa]	Tensile strength [MPa]	Elongation As [%]
S235JR EN10025-2(ref)	+AR	All formats	< 16	235	360-510	26
			16.1 < 40	225	360-510	26
			40.1 < 63	215	360-510	25
			63.1 < 100	215	360-510	24
			100.1 < 150	195	350-500	22
			150.1 < 200	185	340-490	21

Table 4: Other properties (typical values)

Youngs module (GPa)	Poisson's ratio (-)	Shear module (GPa)	Density (kg/m3)
210	0.3	80	7800

3.3.2 Experimental Test to Determine The Modulus of Elasticity

Due to the sensitivity of the research and the importance of the error rate in correctly diagnosing the results of image and video processing, the test to determine the modulus of elasticity was performed experimentally in the mechanical engineering laboratory. In this experiment, three small samples with approximately equal cross-sections of

steel that were used in the image processing test were examined to determine the modulus of elasticity (Figure 8).



Figure 8: Experimental test to determine the modulus of elasticity

Accordingly, the average of obtained results from the test of all three samples was considered as the modulus of elasticity (Table 5). According to Equations 3.1 and 3.2, to obtain the modulus of elasticity, the area of three specimens was measured first. Then, to calculate the modulus of elasticity accurately, the thickness of each specimen was measured in two steps while the tensile force was increased by the jaws of the traction device (Figure 9). The machine applied a tensile force of 1000 N to the sample in each step until the samples disintegrated and the stress-strain curve was fully formed (Figure 10).

$$\delta = \frac{\rho L}{AE} \quad (3.1)$$

$$E = \frac{\rho L}{A\delta} \quad (3.2)$$

Table 5: Results obtained from the tensile test

Number or samples	Area (MM^2)		Force (N)	$\delta(0)$	$\delta(1)$	δ	Length (MM)	Modulus of elasticity (MPa)
1	17.84085		1000	0.21	0.222	0.012	50	233546.4211
2	18.37585			0.182	0.19	0.008		340120.321
3	18.777719			0.172	0.184	0.012		221804.1857
		Average of total samples(MPa)						265157



Figure 9: Three specimens after tensile tests

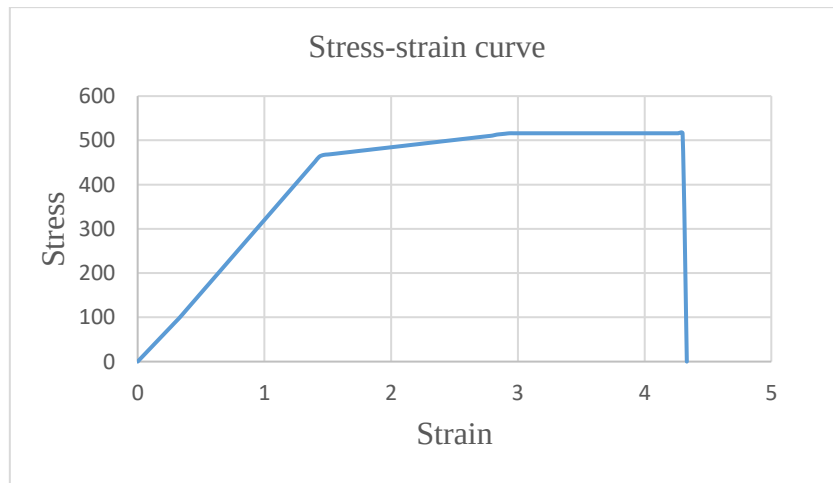


Figure 10: Stress-strain curve of tensile test

3.4 Finite Element Analysis

Due to the importance of fault detection, health monitoring in structures, assessment of modal parameters and dynamic behavior of structures, the first step in using image and

video processing is to prove whether the information recorded from the camera is essentially reliable or not. Is it possible to use smartphone camera to obtain modal parameters and detect the failure in a structure? The only way to prove it, is to utilize different validation methods, and if the answers of these different methods are equal to the answers obtained from the image and video processing methods and the accelerometer, it will be clear that the results are reliable. Therefore, three validation methods were defined in this experiment;

- Using finite element modeling in ETABS software.
- Using theoretical formulas related to calculating the bending modes of the structure
- Using accelerometer (Strukaret al., 2018) to review the capability of available model

3.4.1 Selected Specimen

In this research, the studied model is an integrated single-story structure of S235JR steel type as shown in Figure 11 and Figure 12, which the columns are mounted with fixed supports on a wooden plate by four bolts. To produce this sample, according to the sensitivity of the dynamic response of the structure, a CNC cutting machine was used. The height of the supports is 5 cm from the surface of the wooden plate, which has four holes for connecting the columns to the wooden plate. Therefore, the height of the slab from the surface of the wooden plate with the inclusion of 15 cm columns will be equal to 20 cm, which is considered 15 cm in modeling in ETABS software. Finally, the length, width and elevation are 30 cm, 27.5 cm and 15 cm respectively and this sample was made of steel with a thickness of 1 mm in whole parts (Figure 13 and Figure 14).



Figure 11: The Specimen after installation on a wooden plate



Figure 12: the specimen with checkerboard on the slab for image and video processing tests.

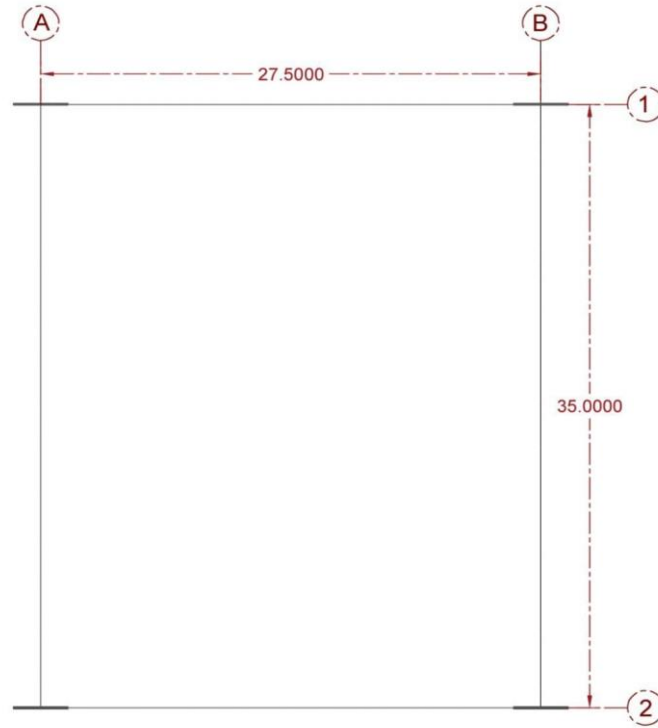


Figure 13: Story plan of the selected specimen (Meter)



Figure 14: Elevation plan of the selected specimen (Meter)

3.4.2 Normal condition

According to the explanations mentioned previously, FEM is performed by using ETABS (Figure 15). For modeling the presented criteria in this study, by assuming that there is no deformation in all stages of the free vibration test, the selected specimen has the same stiffness during the experiment.

Therefore, in this linear analysis, regardless of how much the model deforms, whether the load is applied step by step or suddenly, also, whether there is extremely stress due to the load on the members of the structure, the model will always maintain its initial stiffness during the analysis process.



Figure 15: 3D FEM of the selected specimen by using ETABS

3.4.3 Damaged Condition Analysis

As part of the research, to evaluate the performance of the image and video processing method, a similar analysis is performed by separating one of the columns of the structure as a damaged condition (Figure 16). Therefore, the parameters obtained from the FEM analysis from ETABS, similar to the previous test method (normal condition), were compared with the results obtained from the image processing method and the accelerometer sensor. One of the aims of this analysis is to determine whether using the image and video processing method in a situation where the structure has a different dynamic behavior (here frequency reduction) will give similar results.

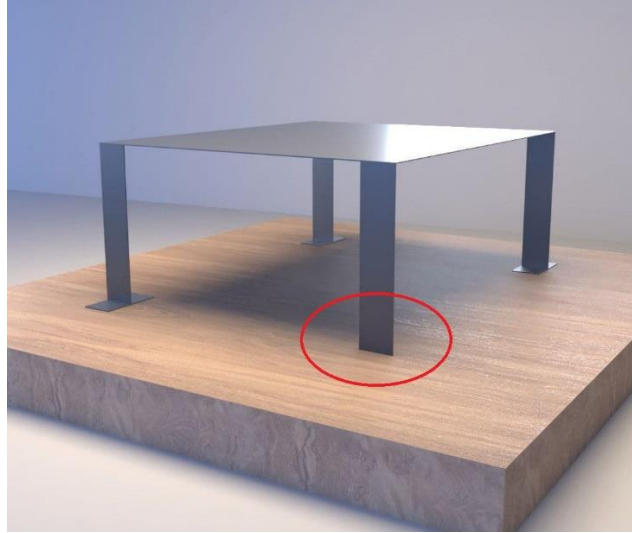


Figure 16: 3D FEM of the selected specimen which damaged in one column by using ETABS

3.4.4 Define Frame Properties in FEA

This section includes the properties of the selected frame, which directly affects the analysis of modal parameters and dynamic behavior, consisting of frequency at the time of force application.

Material Properties

As mentioned in the previous description, it is assumed that all members of the modeled specimen in ETABS software were designed by S235JR and the characteristics are shown in Table 6.

Table 6: Properties of the material used in ETABS

Youngs module (MPa)	Poisson's ratio (-)	Shear module (MPa)	Density (kg/m ³)	Compressive strength (MPa)
265157	0.3	80000	7800	420

Dimension of the constructional system

The structural system of this steel model consisted of columns and one slab, which is

made in the form of a one-story frame with four fixed supports in every column. Moreover, the dimensions of the selected specimen are displayed in Table 7.

Table 7: Dimensions of the specimen

	Width (mm)	Hight (mm)	Thickness(mm)
Column	30	150	1
Slab	-	-	1

3.5 Image Processing Analysis

3.5.1 Introduction

The purpose of this section is to illustrate the method used in this investigation on the selected specimen under two different (normal and damaged) conditions. Due to the displacement of a black dot (black square) which marked on the slab and using several FPS, the edge recognition method was adopted in MATLAB software. In fact, in this method, the videos were defined as input data of MATLAB software, then each frame was examined separately to find the displacement during the free vibration and in the last step, their location was calculated to find modal parameters.

3.5.2 Black Dot (Black Square) Evaluation

As mentioned in the previous section, after sharpening the edges, the shapes in the image must be extracted. This is done with the region props command, which extracts the specifications of all the lines. In fact, all continuous lines in the image are stored as a struct variable in stats. Each object in this section contains features such as size, location, area, and angle (Figure 17).

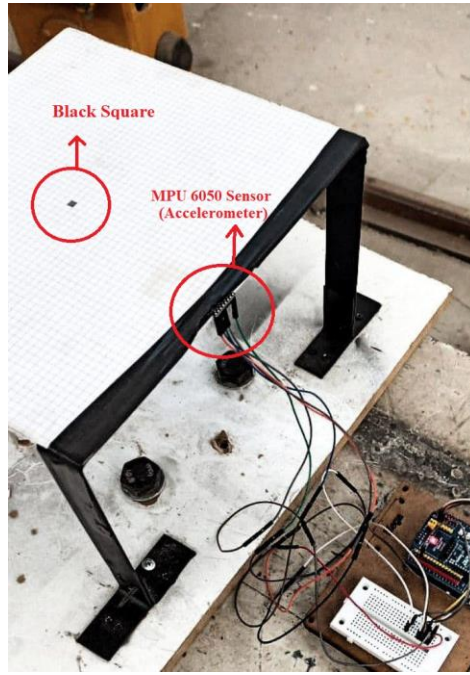


Figure 17: Black square on slab and MPU sensor for free vibration test by accelerometer

3.5.3 Obstructing the Properties of The Black Dot (Black Square)

In this section, to increase the accuracy, a loop is defined among these shapes, which seeks a black square in the center of the image. By using this method, all existing forms were examined and specific conditions were defined. These conditions include dimensions and dimensional ratio, slope, angle and color. If the specified area (along with the frames) has a high percentage of black, the desired shape is selected and x or its location is saved. It should be noted that the said process is checked for all frames. Another condition evaluated is that the corresponding shape (black square) should not be too far from the shape obtained from the previous frame, therefore, this condition was also examined.

3.5.4 Evaluate the Speed of Motion of The Black Dot

After checking the properties and location of all frames in the previous section, location and time are stored in two matrices Xs and Ts. In this section, due to the

vibration entered the sample and because there is no movement at the beginning or possibly at the end of the specimen, all motionless frames were removed. In consequence, places where the speed was zero were removed. Of course, it is worth mentioning that small movements or noise may occur due to noise or error or possible shaking of the camera, therefore, an average of 6 frames was taken and if there is no movement in this interval, this interval will be deleted. However, the point that needs to be mentioned is how to measure speed. The method of measuring the speed of motion is obtained by deriving Xs relative to Ts.

3.5.5 Displacement-Time and Frequency Diagrams

According to the description of the previous section, after scanning all frames of each video, the displacement time values can be available as a matrix. Therefore, in the next step, all modifications in the velocity directions are calculated due to their fractions which are read as positive and negative values. Basically, these are shown the peak of points where the speed is captured as maximum. As a result, by counting these points, the cycling number of the black square can be simply figured. Since power is belonged to a coefficient of velocity in force, accordingly, power can be calculated by using Equation (3.5), assuming force is simplified.

$$P = C * dx \quad (3.5)$$

On this occurrence, due to the displacement which is existed in pixels, therefore, the word C is replaced instead of force in this equation.

Hence, considering the two general aspects of the sample in the mentioned experiment (normal and damaged conditions), the specimen was filmed with four different qualities of 30, 60, 120 and 240 frames per second (FPS). The following diagrams are determined the outputs of the image and video processing investigation is in MATLAB software.

Natural frequency

In addition, by utilizing the results which are came out from MATLAB software, the FFT was adopted to calculate the natural frequency of the steel structure specimen (under both normal and damaged conditions) with four qualities of 30, 60, 120 and 240 FPS.

3.6 Free Vibration Measurement by Accelerometer

3.6.1 Introduction

According to the research that has been done in this field heretofore, the purpose of this experiment is to measure the vibrational properties of a steel sample in the laboratory with the procedure followed by (Wu Li-Jun et al., 2013) with some alterations in the data evaluation method and sampling in order to simplify the analysis step in the image and video processing method. Moreover, to ensure the accuracy of the test, an accelerometer sensor with the test settings was used. As part of the inquiry, the accelerometer is coded to control the modal parameters of the model vibration.

3.6.2 Natural Frequency by Using The Accelerometer

To analyze the data obtained, the accelerometer from Excel 2016 was used to generate Fourier transform (FFT), which changed the data recorded by the accelerometer which was time property to the frequency property and Finally, calculated the natural frequency of every case under both conditions. (Normal state of the specimen and damaged state of the specimen).

3.7 Theoretical Formulas for Evaluating Natural Frequency

Sudden and time-dependent forces (when they have rapid modifications over time) that are applied to structures are called dynamic forces. Earthquake force, wind force, sea wave force on coastal and offshore buildings, moving loads (such as moving a car

over a bridge), the living load of people walking on the floors are instances of dynamic forces. The objective of this section is to discover and verify the consequences of theoretical formulas to describe the natural frequency of the structure with the results of other experiments for two damaged and normal conditions.

3.8 Damping Ratio

This section aims to discover the damping ratio of the structure. For this objective, the Logarithmic Decrement Method was attended by applying a minor amplitude free vibration on the selected specimen for both conditions to take out the intrinsic element damping capability. The analysis of the damping rate was performed by utilizing the attending formula (3.6) (Chopra, 2001).

$$\zeta = \frac{1}{2\pi j} \ln \left(\frac{n_i}{u_{i+j}} \right) \quad (3.6)$$

that j is the amount of cycles and u_i and u_{i+j} include the heights of points of i and $i+j$ terms. Due to the investigation, the amount of obtained cycles were 10, under both conditions for diminishing the fluctuation throughout the result.

Chapter 4

RESULTS AND DISCUSSIONS

4.1 Introduction

As it is illustrated in this chapter, all findings of the equipment and structural experiments will be discussed according to the investigations. Additionally, all observed results are clarified and described regarding to researches which mentioned in the literature review and adapted specimen. Subsequently, the outcomes of the comparative methods including finite element modelling, accelerometer, theoretical formulas and image processing in both damaged and normal circumstances will be justified in a comparable way to promote the influences of utilizing Image Processing on the specimen and any other structures in the civil engineering field.

4.2 Response Measurement by Using Free Vibration Investigation

4.2.1 Introduction

Essentially, a modal investigation is the review of the natural factors and parameters of construction. It can be always obtained to boost constructing fractions for every sort of structure. Perception of both mode shape and natural frequency is valuable for vibration requests and these factors can be figured out from calculated frequency reaction processes by trying shaking tables, hammer and other applications termination. Indeed, there is no variation is required from explained assessments (Rajini N et al, 2012), however, the influence of hammer and tension by hand or rope strategy is adequately in the type of low weight system.

On this occasion, the modal investigation was achieved by taking advantage of an effect of hand tension with 1 cm lateral movement approximately.

4.2.2 Free Vibration Behavior of Specimen (Accelerometer)

As mentioned in Chapter 3, after the beginning of vibration, when a slight vibration was applied as oscillation to the specimen (three times) that it did not enter the nonlinear phase, the motions were recorded at a record rate of 100 Hz. These three vibrations per experiment are prepared as a values validation, thus, due to the similarities among these three values with negligible varieties, from now on, only one of these three results will be written in all tables to avoid duplication. Practically, Figure 18 and Figure 19 illustrate the free vibration behavior of steel specimen for three tensile loads in a row by the accelerometer in the normal and damaged mode respectively.

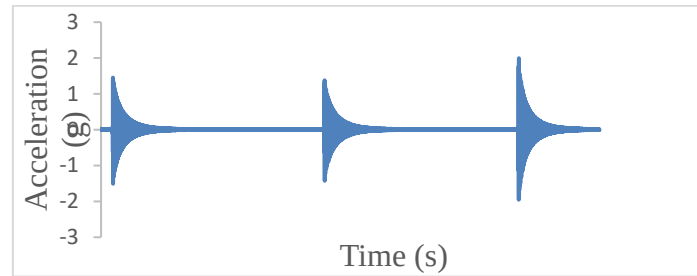


Figure 18: three amplitudes of acceleration of steel specimen under free vibration excitement in normal condition

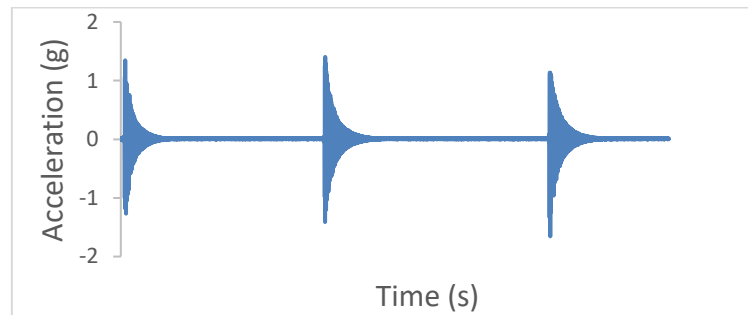


Figure 19: three ranges of acceleration came out from free vibration experiment under damaged condition

4.2.3 Natural Frequency

Accordingly, by correlating the Fast Fourier Transform (FFT) on the signals, a graph of its power density spectrum and frequency was brought out for both normal and damaged states. Figure 20 and Figure 21 displays the consequences of the FFT and the natural frequency of both normal and damaged conditions. As can be found out from diagrams, the frequency of the specimen decreased in damaged condition.

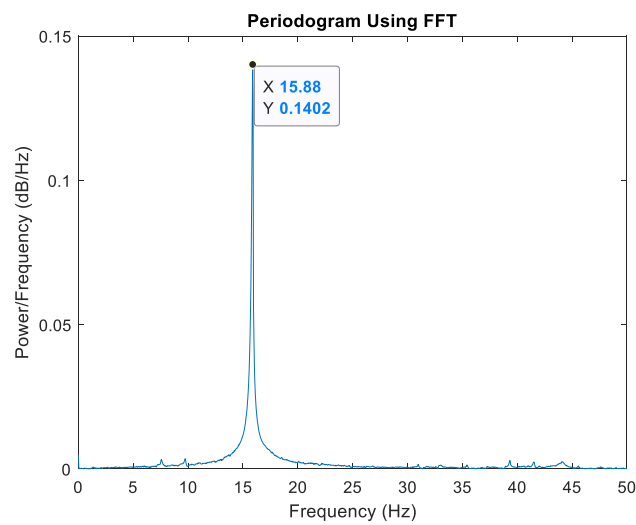


Figure 20: The result of FFT method which illustrates natural frequency of specimen (normal condition)

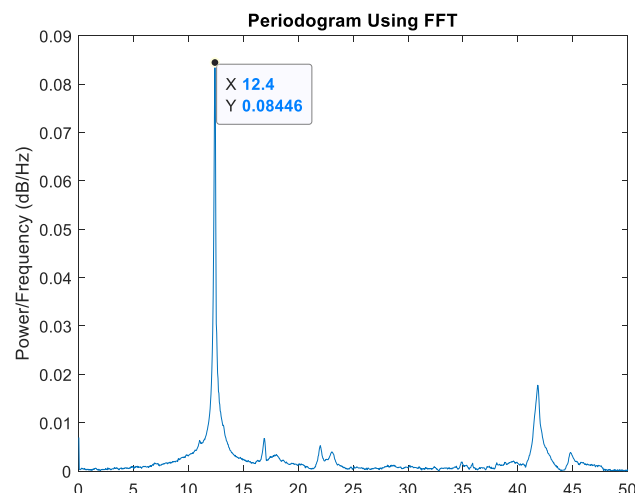


Figure 21: The result of FFT method which illustrates natural frequency of specimen (damaged condition)

4.2.4 Damping Ratio

According to the Figure 25 and Figure 26 which display the free vibration behavior of the specimen under normal and damaged condition for three reiterated shock loading, the damping ratio of the specimen was estimated by performing 10 cycles for both conditions that implied in Figure 22 for the steel specimen. Due to equation 3.6, Table 8 clarifies the results of the damping ratio that came out from free vibration testing of the specimen. Moreover, Table 9 shows the frequencies that are achieved from free vibration investigation

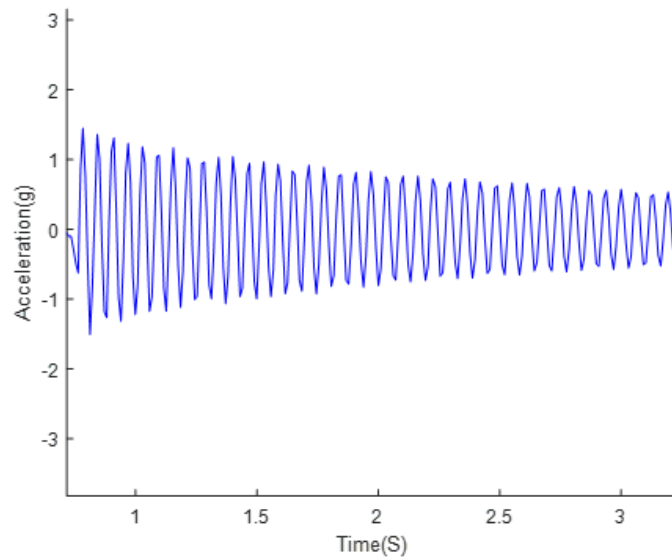


Figure 22: The vibration diagram in time domain of sample under the normal condition at one shock implicated load

Table 8: Damping ratios that are achieved from free vibration investigation (%)

Conditions	1 st test	2 nd test	3 rd test
Normal	0.58	0.51	0.60
Damaged	0.31	0.29	0.33

Table 9: Frequencies which are attained from free vibration test (Hz)

Conditions	1 st test	2 nd test	3 rd test
Normal	15.88	15.87	15.84
Damaged	12.4	12.37	12.42

4.3 Response Measurements Utilizing Image Processing Technique

Normal condition

The proposed strategy employed in this examination is to validate the outcomes of image processing expanding the camera of a smartphone instead of the expensive and inaccessible cameras, particularly in cities and countries with a lack of modern facilities. In the case under consideration, it was aimed to film the selected specimen in the laboratory continuously with unique capacities of frames per second (30,60,120 and 240 FPS) of the smartphone to achieve a time-displacement diagram for each degree in normal mode and the mode which one support is damaged. Figure 23 and figure 24 are represented the displacement-time diagram during the experiment period (0 to 80 seconds approximately) with different capacities of FPS. From there, it can immediately realize that results came out by 30 and 60 FPS is not legible and inaccurate compared to the other diagrams (Figure 24). Therefore, the final results of these investigations that are related to the image processing tests, are based on 240 frames per second. Moreover, Figure 25 shows the displacement curve (pixel unit) in the time area of specimen at one shock pertained load which powered by 240 FPS.

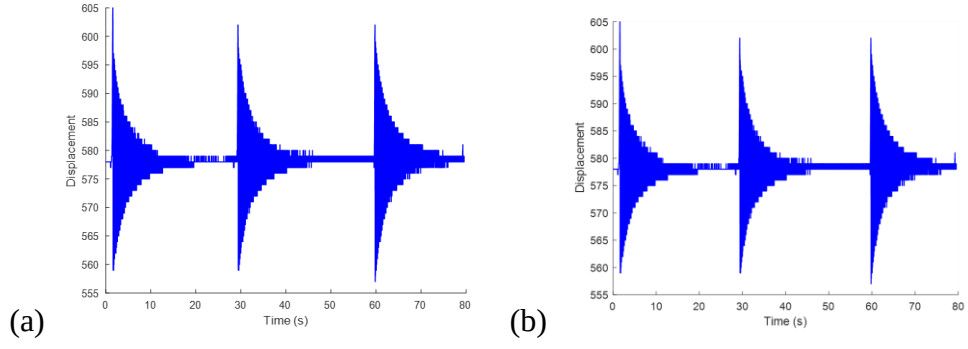


Figure 23: the displacement-time diagram during the experiment (a) using 240 FPS and (b) using 120 FPS

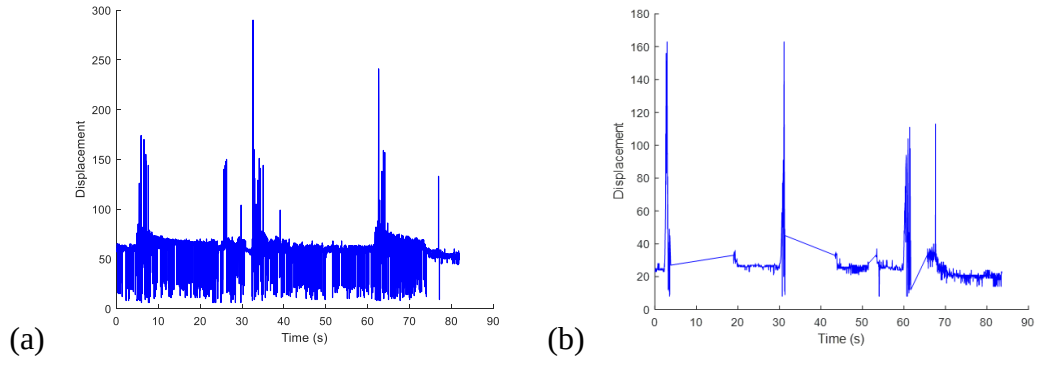


Figure 24: the displacement-time diagram during the experiment (a) using 60 FPS and (b) using 30 FPS

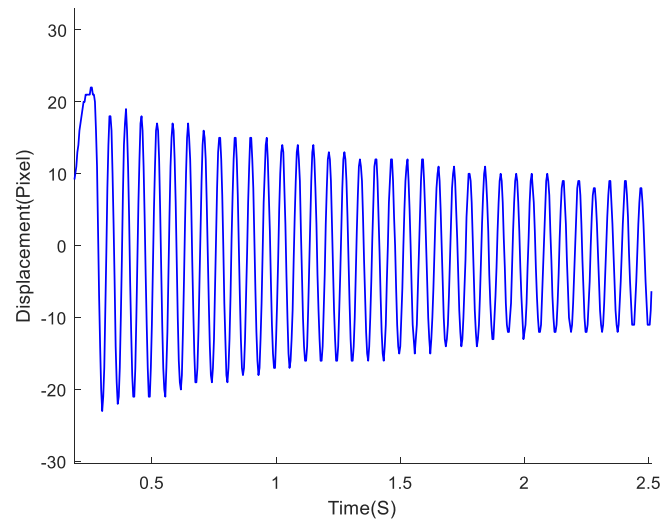


Figure 25: The displacement-time curve of the specimen at one shock pertained load with 240 FPS

Natural Frequency

In the following section, all data were rearranged in a similar process to the accelerometer experiment for preparing the graph of power density spectrum and frequency. The result of which capacities in the normal condition can be recognized in Figure 26. Furthermore, according to the graphs, it can be understood that by altering the frame rate per second (FPS), the value of the frequency will be shifted.

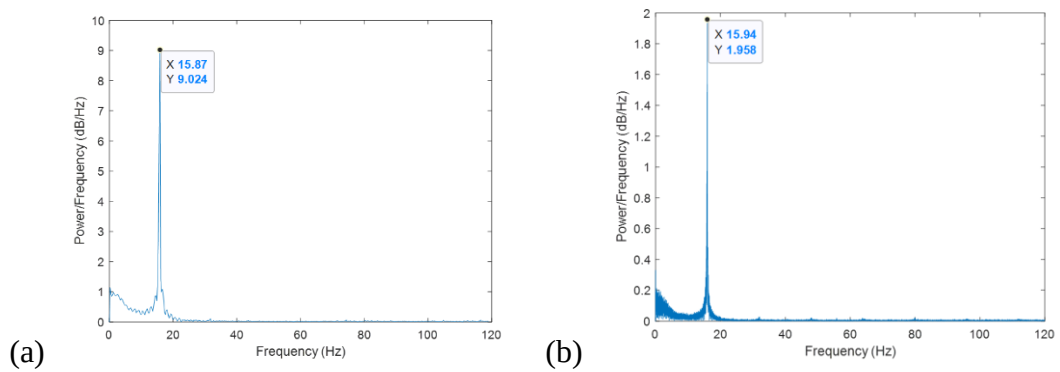


Figure 26 : Natural frequency of specimen by using FFT with different FPS (a) 240FPS, (b) 120 FPS (normal condition)

Damaged condition

Figure 27 is illustrated the frequency of structure under damaged condition investigation by two different capacities.

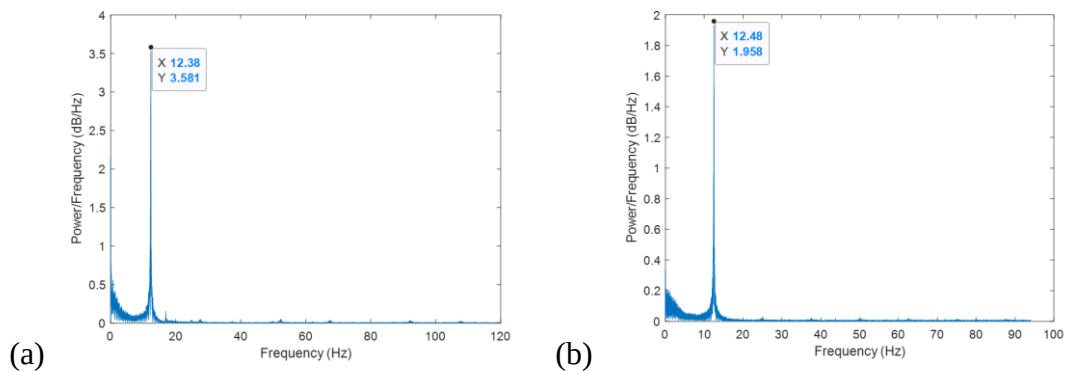


Figure 27: Natural frequency of specimen by using FFT with different FPS. damaged condition (a) 240FPS, (b) 120 FPS

Damping Ratio

According to the Figure 25 which present the displacement-time graph of the black square of the specimen under normal condition by using 240 FPS as one of three repeated impact loading, the damping ratio was calculated (one pixel is equal to 0.264583 millimeters) by operating 10 cycles for both damaged and normal conditions similarly .

4.4 Influence of FPS on The Investigation

The basis of this paragraph is to relate and correlate data reached from image processing operations. According to the information provided previously, four different capacities of the camera (smartphone) were used in this experiment. Table 10 illustrates a comparison of the data collected in the normal and damaged styles. On the other hand, because in each examination three vibrations were involved in the structure, the average frequency attained from all three vibrations is written in each fraction.

Error

The error rate of each video capturing mode (FPS) compared to the frequency achieved from the accelerometer is introduced in Figure 28 which displays the amount of error due to the fluctuation of FPS. Obviously, from the diagram, it can be obtained that by boosting the FPS from 30 to 240 FPS the results will be more accurate. On the other hand, after 120 FPS, there is no significant fluctuation in the result of the image processing experiment for both conditions under investigation.

Table 10: The Frequencies collected in the normal and damaged modes with different FPS

Conditions		30FPS (hz)	60FPS (hz)	120FPS (hz)	240FPS (hz)
test1	Normal	~10	~13	15.94	15.87
	Damaged	~15.5	~13.33	12.48	12.38
test2	Normal	~11.2	~13.7	16	15.79
	Damaged	~16.4	~14.2	12.55	12.40
test3	Normal	~10.8	~12	15.98	15.83
	Damaged	~15.8	~15	12.62	12.33

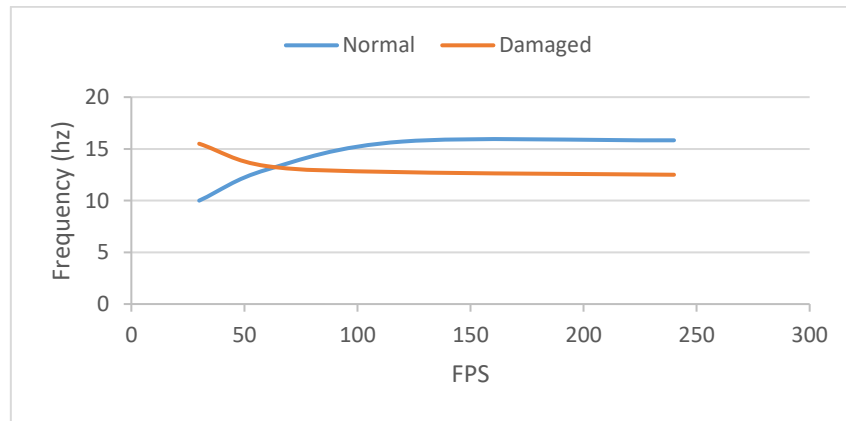


Figure 28: Displays the amount of error due to the fluctuation of FPS

4.5 Response Assessment of Frequency (Other Methods)

4.5.1 Investigating the Dynamic Parameters by FEM

As mentioned in the previous chapter, the Finite Element Modelling and Analysis can be conducted by employing ETABS software. The specimen in this research was performed utilizing the dimensions invested in section 3.4.2. Furthermore, as a component of the analyses, two different criteria were assessed to evaluate the investigations to verify the accuracy of the examinations. Table 11 and Table 12 exhibit the results showed up from FEM for both normal and damaged conditions respectively.

Table 11: Modal Periods and Frequencies Came out From ETABS Under Normal Condition

Case Unitless	Mode Unitless	Period sec	Frequency cyc/sec	CircFreq rad/sec	Eigenvalue rad ² /sec ²
Modal	1	0.064	15.573	97.8501	9574.650

Table 12: Modal Periods and Frequencies Came out From ETABS Under damaged Condition

Case Unitless	Mode Unitless	Period sec	Frequenc y cyc/sec	CircFreq rad/sec	Eigenvalue rad ² /sec ²
Modal	1	0.079	12.672	79.6209	6339.487

3.8.1 Hand Calculation Evaluation of Dynamic Behavior of The Specimen

Due to section 3.8, natural frequency can be assessed by theoretical formal for two under examination conditions to compare with other methods as verification. Furthermore, the stiffness of the columns is extensively higher than the stiffness of the beam against lateral forces. Therefore, with a reasonable approximation, the stiffness of the slab was discarded and the total stiffness of the four columns was taken as the frame stiffness as normal condition (Equation 3.5). Moreover, in the case of damaged mode, 3 columns can be calculated similarly. Due to the resemblance of the columns, the stiffness of all columns are equal to K. (Figure 29)

$$K = 4 \frac{12EI}{L^3} \quad (3.5)$$

Where, I can be calculated by (Equation 3.6) as the Moment of Inertia of the specimen.

$$I = \frac{bh^3}{12} \quad (3.6)$$

Hence, according to the (Equation 3.7 and 3.8), the natural frequency is executed for the structure.

$$w_n = \sqrt{\frac{K}{m}} \quad (3.7)$$

$$f_n = \frac{w_n}{2\pi} \quad (3.8)$$

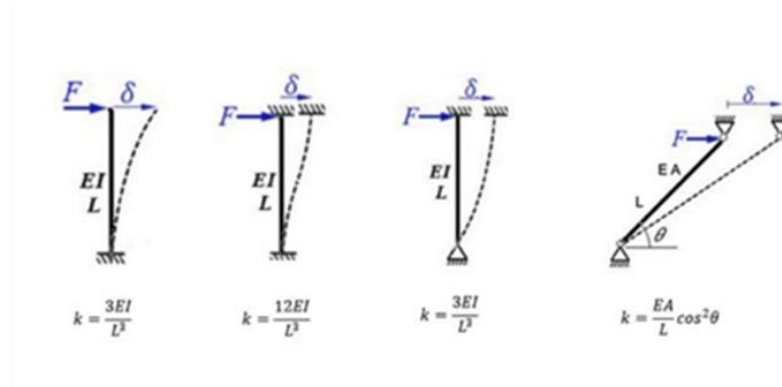


Figure 29: Lateral Stiffness of Several Samples of Columns with Different Support Conditions

Table 13 illustrates the performance review of the methods evaluated in this study including accelerometer, theoretical formulas, finite element modelling and image processing techniques under two different aspects. The frequency of the experimental investigation came out from the image processing method is written as the average of 240 FPS according to the existence of error which explained in section 4.4 and the equality among the results of three applied loads per test with insignificant variations under both conditions. Therefore, in this section, the outcomes of neutral frequencies and damping ratios (Table 14) are organized 240 FPS as the most similar answer to the accelerometer.

Table 13: Response Evaluation of Mean Frequency

Conditions	Accel. (Hz)	Image Processing (Hz)	Error (%)	FEM (Hz)	Formulas (Hz)
Normal	15.88	15.87	0.06	15.57	15.59
Damaged	12.4	12.38	0.16	12.67	12.32

Table 14: The Results of Mean Damping Ratio (%) of each Method

Conditions	Normal	Damaged
Accel.	0.57	0.33
Image Processing	0.49	0.36

Chapter 5

CONCLUSION

This research has concentrated on the execution of dynamic behavior for structures by operating image processing techniques in comparison to monitor the other methods involving free vibration test by an accelerometer, FEM and theoretical formulas. As part of this analysis, analytical and experimental assessments were performed to exhaustively validate the impact of alteration of FPS and accordingly structural behavior of specimen and finally accuracy of several methods. On the purpose of the above opinions the additional understandings are clarified:

- Any kind of smartphone with the potential to record videos above 120 frames per second can be used as equipment to examine the dynamic behavior of the structure.
- The findings obtained from the image processing investigation by the smartphone with the recording capacity of more than 120 frames per second (here 120 and 240 frames per second) are incredibly accurate and valid compared to other methods with the negligible 0.06% and 0.16% errors comparing to results of the accelerometer for normal and damaged conditions respectively.
- Due to the development of technology in the production of mobile cameras and the existence of intelligent software such as MATLAB, the distance between the camera installation location and the target to be followed in small structures has no impact on calculation and processing.

- The outcomes of the image processing test in both normal and damaged modes with the recording capacity of 30 and 60 frames per second due to the small number of frames have the error of 37% and 25% respectively.
- According to the comparison of the results collected from the smart-phone camera and accelerometer including the discussion about the effect of FPS, it can be explained that by increasing the frame rate per second in both normal and damaged states, the error is reduced conversely.
- Tensile testing to determine the modulus of elasticity has a direct influence on the accuracy of the examination results, especially in FEM.
- A comparison of the conclusions attained from each experiment to determine the natural frequency of the structure confirms the negligible error using the smartphone as a camera for the image processing experiments.
- The conclusions of the image processing experience with a capacity of 120 and more than 120 frames per second are similar and by improving capacity, there is not extensively change in the output results.
- The location of the smartphone camera is particularly important due to its low weight. Therefore, the vibration caused by the camera (human errors and environmental noises) has a direct impact on the processing steps.
- The accuracy and similarity of the examination results correctly indicate that to discover the dynamic parameters of the structure, it is not essential to use expensive

cameras or to use several cameras at the same time.

- In this research, it is conducted to describe in relation to damping ratios by utilizing an accelerometer and a mobile phone camera under normal and damaged conditions. The examinations were operated on a single-story steel specimen and assessed with 30, 60, 120 and 240 FPS. The results achieved from these investigations, exhibit the accuracy of the results obtained from the image processing method.
- According to the findings of the damping ratio from each investigation, the amount of the damping in the damaged condition is less than normal factor which signifies, when the damping rate is higher, the amplitude declines and the system stops sooner.

Eventually, additional study is required in this area to deal with several of the misplaced topics in the literature such as the influence of light and temperature on the output data from any measurement device.

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APPENDICES

Appendix A: Camera

In this investigation, the specimen was filmed by using the Xiaomi Note 8 Pro smartphone camera, the specifications are presented in (Table 8). The rear camera comes with four separate modules (Figure 19). A 64MP primary wide-angle camera is accompanied by an 8MP ultra-wide with a 13mm-equivalent focal length and a 2MP dedicated depth sensor. There is no tele-camera, but the Redmi offers a 2MP dedicated macro camera. (Xiaomi official,2020)

- 64MP AI Quad Camera
- 64MP ultra high-resolution primary camera
- 64MP, 0.8 μ m, 1/1.7"CMOS image sensor, 1.6 μ m 4-in-1 Super Pixel, f/1.89, FOV 79°
- 120° ultra-wide-angle lens
- 8MP, 1.12 μ m, f/2.2, FOV 120°
- 2cm ultra-macro lens
- 2MP, 1.75 μ m
- depth sensor
- 2MP, 1.75 μ m
- Zoom:10x digital zoom
- Focus: Phase detection focus | Contrast detection focus
- Photo resolution: up to 9248 x 6936 pixels
- Video resolution: up to 3840x2160 pixels expression of the natural frequency below

Table 15: Rear camera video features

4K recording	30fps
1080P recording	60fps / 30fps
720P recording	30fps
1080P ultra-wide angle video recording	30fps
720P ultra-wide angle video recording	30fps
1080P slow motion recording	120fps
720P slow motion recording	960fps / 240fps / 120fps



Figure 30: The rear camera with four separate modules (Xiaomi official,2020)

CCD Sensor

CCD sensor or Charge Coupled Device is a type of sensor that many cameras are equipped with this technology. In this sensor which is equipped with a light sensitive chip (Figure 20), the area is divided into a large number of pixels, the images reach the surface of the chips through the lens, and in proportion to the intensity of the light entering each pixel, a certain amount of electrical charge is generated in that pixel. therefore, the optical image becomes an electrical image. In other words, CCD converts incoming light into electrical signals, it is an electric light converter.

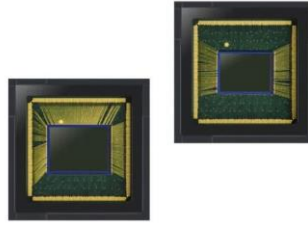


Figure 31: 64-megapixel ISOCELL Bright GW1 and 48-megapixel ISOCELL Bright GM2(Xiaomi official,2020)

Appendix B: Basic Steps of Image Processing

Input Data

Captured videos by smartphone with different FPS.

Pre-processing stage

After obtaining the input information of each video, pre-processing operations are performed to eliminate noise, isolate and improve the differentiation of areas where there is a possibility of verbal and numerical information. The main purpose of this step is the video enhancement and remove unnecessary components (here Checkered sheet on the slab).

Processing

In this step, by using the edge recognition method, each frame of videos are read separately to make a specific matrix and coordinates of the black dot by following the target. Finally, at the end of processing, these coordinates are kept together to prepare the displacement-time diagram during the free vibration test.

Output

The last step is the output, which is a report resulting from the analysis. This step includes the displacement-time diagram and natural frequency by using FFT.

Creating Gray Image (Convert RGB Image to Index)

Initially, changes were made to each frame to increase the resolution of the images. Basically, using this command, the RGB image is converted to an Index image, which requires a map matrix to create this type of image correctly. In fact, the map matrix

produces numbers between 0 and 1 with 4 decimal places.

This matrix is actually a 3-layer matrix of the main colors red, green and blue, which stores a sample of the colors in the image and uses it as a color box. If this matrix is not used, the image will become colorless. Also, the X matrix is actually a 16-bit number that represents a number of the map matrix. The value of n determines the accuracy and number of color samples of the image. The higher this number (up to 65536) determines the quality of this image. As a result, in the first step, the image is converted to a gray image by the `rgb2gray` function in MATLAB. On the other hand, several filters have been applied to the image, including: sharpening filters, graying, binary, and checkerboard noise cancellation. Also, according to the test conditions, the checkered lines of the filmed screen were removed, because in its processing, it creates fewer edges and speeds up the work.

Eliminate checkerboard noise:

```
se = strel('square',10);  
im = imopen(im,se);  
im=medfilt2(im, [15, 15]);
```

Filling the break points as well as increasing and improving the quality:

```
level,EM] = graythresh(im);  
BW = imbinarize(im,level);  
  
im_fill = imfill(BW, 'holes');  
  
im_addad = im_fill - BW;  
se = strel('square', 3);  
im_addad = imopen(im_addad, se);  
im_addad = imclose(im_addad, se);  
im_addad2 = ~im_addad;  
im_fill = im_fill .* im_addad2;
```

Finally, after performing the mentioned processes, the correct edges of the image were extracted. This is done with the edge command.

```
im_fill12=edge(im_fill1);  
stats = regionprops(im_fill12,'all');
```

Appendix C: Accelerometer Evolution

The basis and purpose of configuring this sensor in this experiment is to sample the steel specimen and analyze the results and compare it with the results of the image processing method utilizing the Arduino-based revolution that prepare a valid and economical titration.

According to enhance this expedition, the additional components have been developed.

- MPU-6050 sensor which is used by sampling ratio of 100 Hertz (Figure 21).
- Microcontroller Arduino Uno R3 (Figure 22).
- Connecting wires between the sensor and the microcontroller (Figure 23)



Figure 32: MPU 6050 Sensor



Figure 33: Uno R3 microcontroller 6050

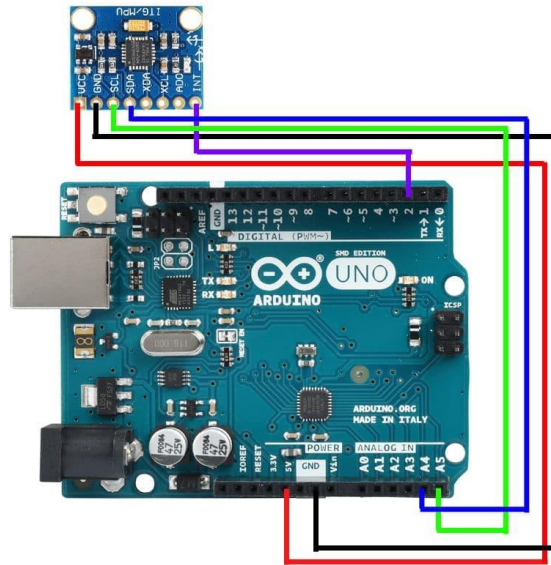


Figure 34: connecting of the Arduino chip to MPU

Moving Average Filter to Reduce Noises

Basically, data recorded in the laboratory and experimental environment must be pre-processed to reduce ambient noise and uncontrollable noise. The method used is called the moving average filter is utilized, which involves taking the average of a set quantity of output data and removing it from the sensor reading. This approach is the most used digital filter because of its simplicity.

Sensor Communicates with The Microcontroller

Arduino IDE (Integrated development environment) was utilized for programming and coding C ++ and pouring it into Arduino. The Arduino application is divided into two parts: the first is concerned with the accelerometer sensor, and the second is concerned with receiving and assessing data.