Dynamic Analysis of Mechanical Systems Using Image Processing

Juan D. Pérez, Diego A. Hincapié, Jonathan A. Graciano
Instituto Tecnológico Metropolitano
Calle 73 No.76 A 354 Robledo, 050034
Medellín, Antioquia, Colombia
juanperez238421@correo.itm.edu.co, diegohincapie@itm.edu.co, jonathangraciano@itm.edu.co

Abstract — **Thanks to the fact that nowadays substantial progress has been made in new ways of analyzing our environment using image processing techniques, it is imperative to highlight the importance of applying this methodology to mechanisms, which are our object of study and these elements are present in various sectors, such as industrial, automotive, academic, etc. In the previously mentioned sectors, the mechanisms are a fundamental element for the correct operation of the devices that each sector has. Therefore, knowing the dynamic behavior of the mechanisms is an essential task, since, if any type of failure occurs, it could cause damage to an entire process. The article proposes to develop a methodology that allows the analysis of dynamic variables in different types of mechanisms, through the use of image processing techniques specifically the detection, filtering and tracking of objects, using filters such as the Gaussian filter and background subtraction in order to improve the quality of the information to be analyzed. The results obtained through the application of the proposed methodology were compared with a simulation of a CAD/CAM/CAE software, in this case Siemens NX 12®, these results were satisfactory under certain criteria that will be exposed in the analysis section, thanks to this it can be affirmed that the proposed methodology is acceptable at the time of knowing the dynamic variables in mechanisms.**

Keywords— Dynamic, Mechanism, Image, Tracking.

I. INTRODUCTION

The main subject found in the literature is the tracking of objects through digital images, it should be clarified that according to the articles found it is possible to categorize the techniques or methods used for tracking objects, based on the application that is being performed, for example in the field of fluids when having to analyze a large number of particles the implementation of the PTV method (particle tracking velocimetry) which allows to measure the velocities and trajectories of a moving object [1], or through successive images which can form a video, each separate image is known as a frame (frame) and to identify particular areas of interest [2]. To improve the acquired information (images), usually a series of filters are implemented which have as purpose to use functions by means of algorithms, allowing to alter the images in order to eliminate the noise (random variation of brightness or color in the image) one of the most used filters found in the literature for the solution of this problem is the Gaussian filter that has as purpose to average the information of the image, in order to have a new image with more homogeneous data [3], thus allowing that the non-essential information of the image (elements such as the background or objects different from the target to follow), do not interfere with the analysis. In some cases, averaging the values of an image to focus on an object of study is not enough, because there may be elements of the image such as static objects which can alter the tracking process, therefore, a common practice in the literature is the use of background subtraction techniques [4] in order to obtain a more accurate trajectory.

The objective of this project is the detection, processing and analysis of various dynamic variables for different mechanisms from the implementation of image processing, comparing the information obtained by the proposed methodology with the results provided by the simulation of the different objects of study (mechanisms), in the CAD/CAM/CAE siemens NX 12® software. Using a development environment which incorporates image analysis tools (MATLAB®), it is intended to apply the proposed methodology in order to obtain reliable results that will later be compared. And thus generate an alternative analysis based on the use of image processing for the quantification of dynamic magnitudes of various mechanical systems.

II. METHODOLOGY

A video consists of a sequential series of images, where each image in the sequence is known as a frame, because a large number of these frames are displayed in small time intervals, there is a continuity of motion perceived by the human eye [5], [6]. For the acquisition of this information, first the movement of a mechanism will be simulated using NX 12® software, where a specific point will be selected to find the dynamic variables for that section, the processing and analysis

of the information (images) will be done through MATLAB® [7].

A. Block diagram

Fig. 1. represents the block diagram made up of four sections that represent the methodology of this research. As mentioned above, the initial part of the process to be followed for the detection and analysis of mechanisms is through the simulation of these elements by means of the use of NX 12® software, once this information is acquired, the proposed algorithm is implemented with the objective of tracking the object to be analyzed, and in the same way, its dynamic behavior. It should be clarified that at the time of applying the algorithm a series of filters are implemented with the main objective of reducing and eliminating the background noise of the images (non-essential information), for the methodology the Gaussian filter and background subtraction will be implemented.
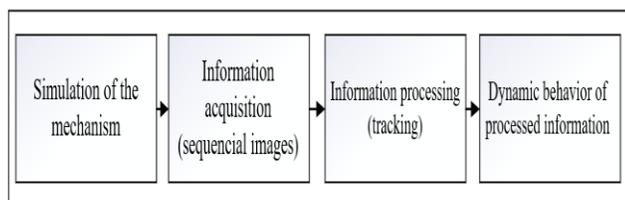
Fig. 1. block diagram for the development of the work methodology

B. Object detection

Fig. 2. describes the methodology proposed in this study by means of a flow chart. Once the information is obtained (series of sequential images) we proceed to improve the quality of the images, by means of the Gaussian filter that plays a fundamental role in improving the quality of the information to be analyzed [8] this filter aims to highlight the values that represent the point of study, in order to synthesize the non-essential information of the image (elements such as the background or objects other than the target to follow), which do not interfere with the analysis. In some cases, averaging the values of an image to focus on an object of study is not enough, this because there may be elements of the image such as static objects which can alter the tracking process, therefore, a common practice in the literature is the use of background subtraction techniques [9] to obtain a more accurate trajectory.
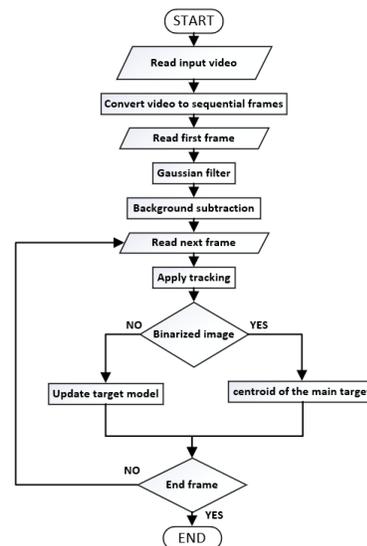
Fig. 2. Flowchart of the proposed method

For the application of the methodology by means of simulation in the CAD/CAM/CAE software, it was chosen to work in a controlled environment, thus eliminating the background elements, leaving in this way the point to be analyzed highlighted, however, when implementing these measures, background noise is still present in the acquired information, therefore, the need to apply the filters mentioned above becomes a necessity, in this way it can be ensured that when analyzing the acquired information the results of the same can be considered as reliable, see Fig.3.
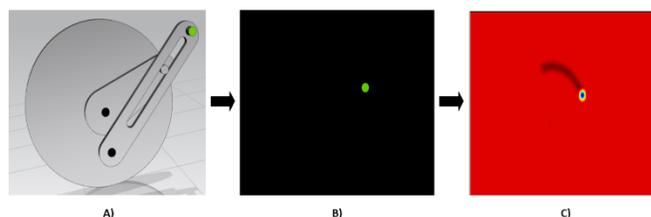
Fig. 3. A) CAD design of the mechanism to be analyzed; B) Elimination of unwanted elements (point to analyze); C) Application of the Gaussian filter

C. Monitoring and position of the object of study

Once the components that generate noise in the series of frames have been eliminated, the image is binarized in order to find the centroid (X and Y position in the image coordinate plane) for each frame that makes up the simulation [10], then each of the dynamic variables of the system is calculated by applying the expressions:

$$x = x_i + v_i + \frac{1}{2}at^2 \tag{1}$$

$$v = \left[\left(\frac{\Delta x}{\Delta t}\right)^2 + \left(\frac{\Delta y}{\Delta t}\right)^2\right]^{\frac{1}{2}} \tag{2}$$

$$a = \left[\left(\frac{\Delta v_x}{\Delta t}\right)^2 + \left(\frac{\Delta v_y}{\Delta t}\right)^2\right]^{\frac{1}{2}} \tag{3}$$

$$\theta = \tan^{-1}\left(\frac{y}{x}\right) \tag{4}$$

$$\omega = \frac{\Delta\theta}{\Delta t} \tag{5}$$

$$\alpha = \frac{\Delta\theta}{\Delta t} \tag{6}$$

Where "x" is the position of the object, "x_i" the initial position, "v_i" initial velocity, "v" is the magnitude of the linear velocity, "a" is the magnitude of the acceleration, "θ" the angular position of the object of study, "ω" is the magnitude of the angular velocity and "α" is the magnitude of the angular acceleration, where the time intervals for the development of the proposed methodology will be given by the amount of 2π programmed in the simulation of the NX 12® software. Knowing the position of the study point for each frame and applying the equations previously described, it is possible to know the dynamic magnitudes experienced by the point of interest for the simulation of the mechanism, it should be clarified that to obtain optimal results it is necessary to know the time intervals of the CAD/CAM/CAE software simulation. Finally, a comparison is made by means of the graphs that describe the dynamic variables of the study point, in this way the results obtained by the simulation in the CAD/CAM/CAE software are compared with the proposed methodology.

D. Simulation considerations

Multiple simulations were performed for the mechanism shown in Figure 3-A), varying the simulation parameters such as angular velocity and acceleration for the motion input and the number of steps in the NX 12® software, to subsequently apply the methodology described in the previous sections. The parameters that will be shown in this article correspond to table 1, specifically the comparison between the proposed method and the simulation in the NX 12® software, the parameters selected for this simulation are an angular velocity equal to 6. 25 rad/s, angular acceleration equal to 9 rad/s^2 and an amount of 1000 steps which is equivalent to 1000 frames, with these parameters we are working with a speed of approximately 1769 RPM and considering the fact that we are working with accelerations, as the simulation progresses the amount of information acquired by the proposed method (frames) will be reduced, therefore, the greater the amount of simulation time the differences between the proposed method and the simulation in the CAD/CAM/CAE software will be presented.

III. ANALYSIS

Table 1. Parameters used for the simulation of the mechanism

Angular velocity (rad/s)	2.5	2.5	6.25	15.625	39.0625
Angular acceleration (rad/s^2)	0	3	9	27	81
Steps	500	750	1000	3500	39000

The reason for specifically choosing the parameters described in the simulation considerations section is due to the number of 1000 steps and is due to the fact that when implementing the acceleration variable, the number of frames per second is insufficient to accurately describe the dynamic variables presented by the study point (for the proposed method), therefore, if a lower number of steps is selected for these simulation parameters, the quality of the information (graphs of the dynamic behavior experienced by the mechanism) both for the simulation in the NX 12® software and for the proposed method would be affected. For the opposite case, if the number of steps for the simulation parameters selected in the CAD/CAM/CAE software simulation is increased, the graphs describing the dynamic variables of the study point tend to improve for the simulation in NX 12® and the proposed method, by exceeding a threshold of more than 1200 steps (1200 frames) for the simulation, the results of the proposed methodology are affected due to the time intervals, these generate in the graphs overlapping data thus affecting the expected results, a way to deal with this problem is to implement curve fitting algorithms [11] substantially improving the response obtained by implementing the proposed methodology.

As can be seen in Fig 4 and 5, the behavior of the linear velocity and acceleration graphs are similar, both for the velocity and acceleration graphs, as time passes it can be noticed that there are peaks between the simulation in NX 12® and the proposed method, as mentioned above. Parametrically for Fig 6 and 7, which represent the angular velocity and acceleration respectively, there is a similar behavior between the methodology and the simulation in the CAD/CAM/CAE software, considering that as time progresses the differences between the results of the proposed methodology will vary. It should be clarified that for all the graphs that represent the dynamic variables described above, a scaling must be added (factor of 1.29) [12] this adjustment must be made because when implementing the proposed method, variables such as space dimensions or characteristics of the size of the mechanism of the simulation in the NX 12® software are not taken into consideration.
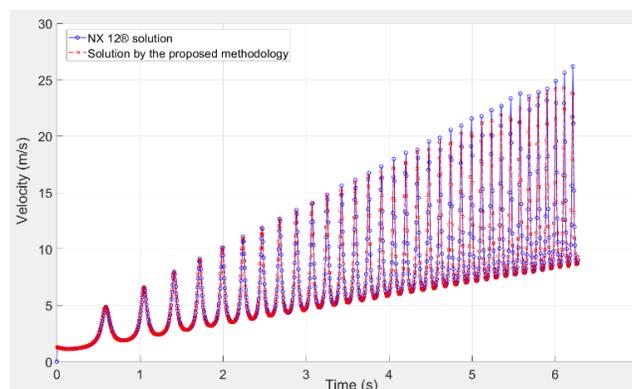
Fig. 4. Absolute linear velocity superimposed on the object of study by means of NX 12® and the proposed methodology
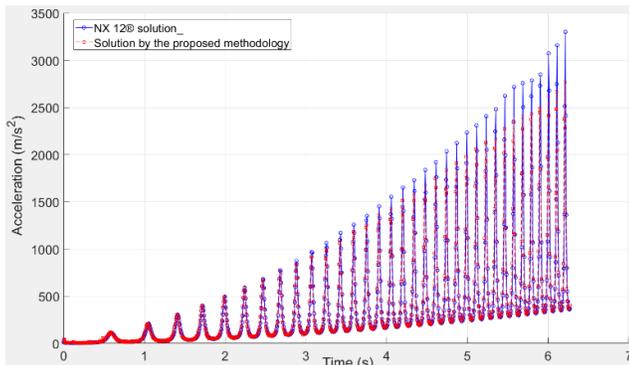
Fig. 5. Superimposed absolute linear acceleration of the object of study using NX 12® and the proposed methodology.
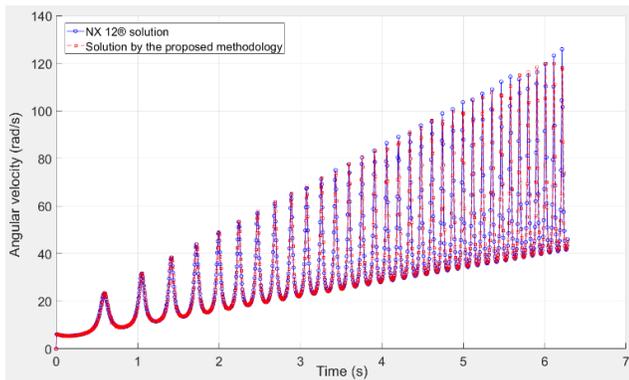
Fig. 6. angular velocity superimposed on the object of study by means of NX 12® and the proposed methodology.
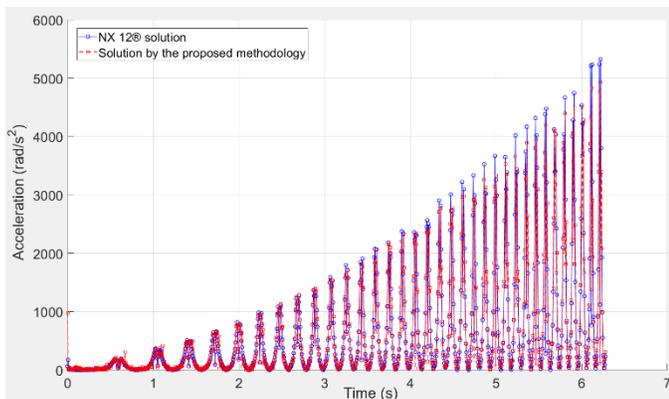
Fig. 7. superimposed angular acceleration of the object of study using NX 12® and the proposed methodology.

IV. CONCLUSION

For this article, a proposal of an algorithm for the detection and
analysis of the dynamic variables presented by a mechanism was presented, selecting a study point that, for the analysis carried out, the selected point has the main characteristic of performing a complex movement. Multiple simulations were performed with different parameters for the mechanism, where the results obtained by means of the proposed methodology were satisfactory in spite of having certain limitations when selecting the number of steps in the NX 12® software.

Since the development of the proposed methodology is based on a dynamic simulation using NX 12®, its results will be affected if the simulation parameters defined are not adequate, therefore, the ideal selection of the number of steps that the simulation should have is a key element to obtain reliable results by means of the CAD/CAM/CAE software and the proposed methodology. For the linear and angular acceleration it can be observed in the behavior of the figures (5,7), the difference that exists between the simulation performed using the NX 12® software and the proposed methodology, this difference becomes much more noticeable as time passes, compared to the figures (4,6), this feature is due to the parameters selected for the simulation (number of steps), Therefore, by not using a greater number of steps for the development of the CAD/CAM/CAE software simulation, the amount of information (frames) obtained by the proposed methodology is insufficient to perform an accurate analysis of the behavior of the dynamic variables (mainly accelerations).

By increasing the number of steps for the simulation, the graphs describing the dynamic variables will be affected due to the above mentioned in the analysis section, having such a minimal time delta for the proposed method generates overlapping information in the graphs, affecting the analysis proposed by the methodology. To solve this type of limitations, curve fitting techniques must be implemented.

Although the results obtained by the proposed methodology are not exact (compared with the NX 12® software), these results are sufficiently congruent to affirm that the proposed method is acceptable. For future work, improvements in the proposed methodology should be implemented, applying state prediction filters such as the Kalman filter could substantially improve the results of the article.

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