February 2021

OBJECT DETECTION TECHNIQUES USED TO ASSESS DYNAMICS OF VEHICLES; AND OF OTHER MBD SYSTEMS

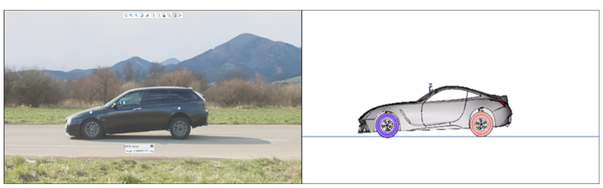
DJH Engineering Technical Newsletter; A. Rajcan, A. Varhanik University of Zilina

Object detection & measurement

Object detection and computer vision can represent a very useful tool applied to assess the dynamic behavior of complex Multi-Body-Dynamic systems in order to better understand the wide variety of parameters and properties that contribute to the resultant motion of such systems in real world scenarios. As a follow up to previous work that focused on the independently suspended axles and vehicle dynamics (Hanko, 2020). DJHEC and students from the University of Zilina, Slovakia are developing a simple and fast measurement procedure based on the computer vision. This technical newsletter shows the initial outcomes of the study performed to measure anti-dive vehicle behavior as well as speed values of a cage in a roller element bearing.

Motivation

DJHEC and University of Zilina recently conducted the R&D effort that concentrated on comparison of MBD simulated results with simple video records to understand whether the values can be comparable when using cost effective measurement techniques. The initial study showed very good correlation between the numerical data and measured samples. Figure 1 shows the anti-dive body inclination during the brake events from the two speed levels of the same tested & simulated vehicle; & compare the MBD results with measured data shown on the graphs (Hanko, 2020).



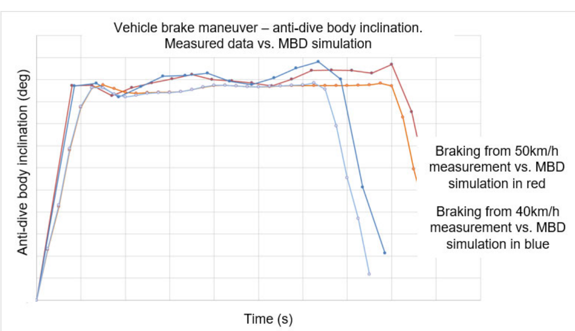


Figure 1. Anti-dive inclination during braking (Hanko, 2020)

To measure the inclination, the video frames were simply post-processed in a CAD program to depict the body angle. This proved to be a time-consuming process which neglected any measurement error. The obtained results have launched the additional study that involves computer vision and object detection techniques described in the next sections to further refine the process.

Object detection & measurement methodology

First, the points of interest are determined by placing the detection targets onto MBD objects. As the measurement is performed intentionally, it is desired the targets can be well recognized either through a specific color or a basic shape. This simplifies segmentation of the pictures taken.

The motion of the measured object is then recorded on a camera. It is important to ensure the video is in focus and the single frames of the video are sharp, which can be achieved through high shutter speed. These parameters, along with video resolution are necessary for high accuracy of measurement. The required video resolution depends on the application. Usually, standard Full HD is sufficient. In general, the higher resolution increases the accuracy on one hand, though affects the processing time on the other hand. Also, the FPS framerate is important, as the framerate determines the sampling frequency of the measurement and the time increment Δt in numerical derivation

Key benefits, approach & software kit:

- Simple and fast measurements
- Wide range of applications
- Measurements of variety of components on complex systems in one measurement
- Measurement process consists of:
  1. Video recording
  2. Image segmentation and calibration
  3. Data analysis
- Software tools used in the analysis:
  1. MATLAB Image processing toolbox,
  2. MATLAB apps – Color tresholder, Image segmenter

done later in the data evaluation phase to calculate velocities and accelerations. The optimal combination of parameters therefore depends on the application. The video is then divided into single images, which are further processed via computer vision to recognize the targets in the images; in other words, to detect the objects.

Image segmentation

Images in numerical codes are represented as sets of arrays. The position of each pixel is defined by its coordinate in the image and the color of each pixel is defined by a set of three numbers. The meaning of each number depends on the used color space. For example, color in RGB cubic color space is defined by the combination of intensity values of 3 basic colors, red, green, and blue. However, it is often more convenient to use different color spaces, like HSL cone (hue, saturation, luminosity), or LAB sphere, where the color is defined by a position on 3 axis scale, being red to green scale, blue to yellow scale and luminosity.

Figure 2. Pixel color cloud in HSV color space

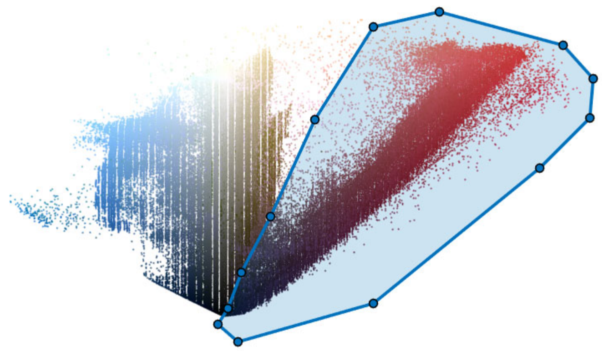


Figure 3. Pixels of interest selected based on the color

The color arrays of an image can be displayed as geometrical points in color space, which allows creating a pixel cloud that places each pixel on its representing coordinate in the 3D color space. This gives an option to rotate such a 3D color space in order to select easily only those pixels that are required for the color segmentation of the targets. Figures 2 & 3 show useful Matlab apps' outputs that simplify color segmentation of an image. For loop of pictures, the code can be derived when writing mathematical algorithms that process the color segmentation of the whole video sequence.

An additional method to detect the object derives from shape segmentation. As an example, the Hough circular transform is a mathematical algorithm that can be applied to detect circular objects of a given radius in an image through their shape and size (Mathworks.com/help, 2012), (Pedersen, 2007). The circular Hough transform also allows to pick the predefined n-strongest circles or setting a detection sensitivity by setting the threshold gradient magnitude; or by including weak and partially obscured circles. The circular Hough transform is however not the only method to detect objects. Other popular methods include the Region properties method (Image Analyst, Retrieved October 24, 2020) or chessboard detection methods (Mathworks, Mathworks.com/help, n.d.).

Image of a vehicle & segmentation

In this example, the vehicle body is firstly segmented based on its color by selecting the red region of the scatter plot in HSL color space (as shown in Figure 3) in a way that resulted in the red pixel separation of the car body (Figure 4).

Next, the image is converted into a binary image, where each pixel is defined only by 0 or 1, and filling algorithms can be used (Figure. 5). This created a mask in the shape of the car, where the car pixels are labeled by value 1 and the rest by value 0 (Figure 6).

By multiplying this mask with the original image, an image where the car is separated from the background enables to easily separate the yellow or blue targets attached to the vehicle (Figure 7).

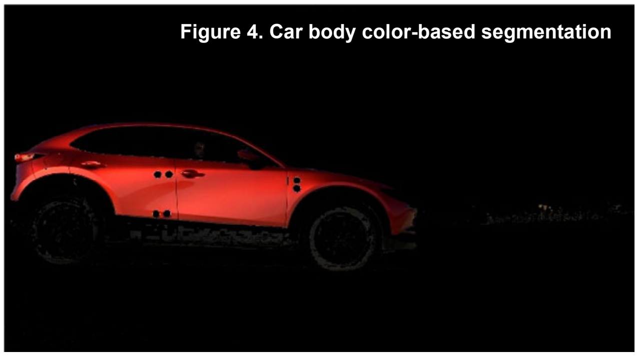


Figure 4. Car body color-based segmentation

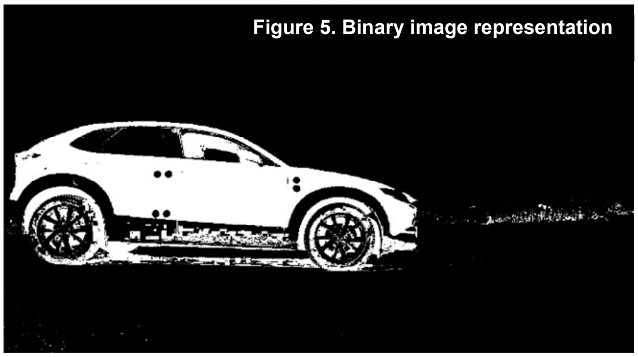


Figure 5. Binary image representation

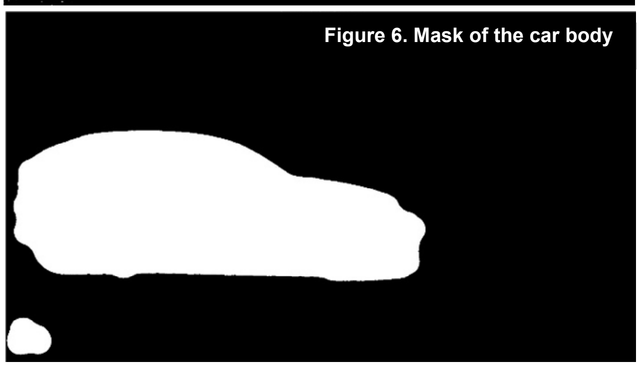


Figure 6. Mask of the car body

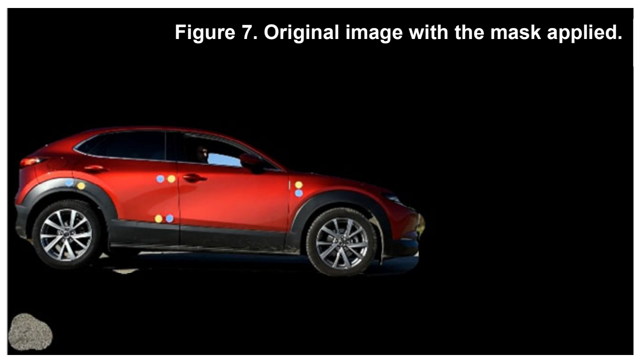


Figure 7. Original image with the mask applied.

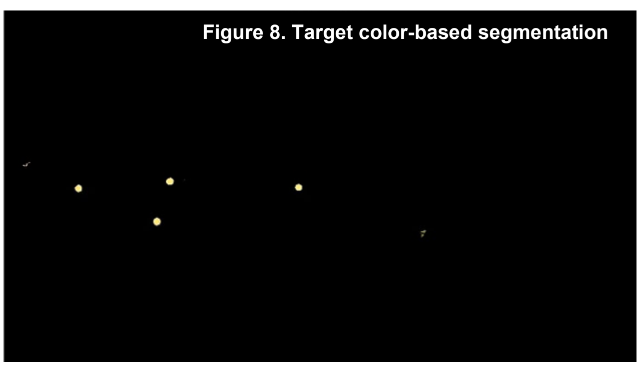


Figure 8. Target color-based segmentation

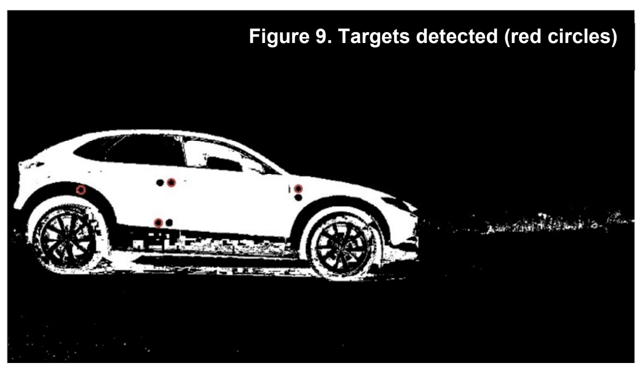


Figure 9. Targets detected (red circles)

Further processing segments the targets and transforms the image into binary showcase. Such an image is prepared for reliable circle detection when using the circular Hough transform (Figure 8).

This results in the detection of circles with known radii and center coordinates that can be plotted back onto any image. Figure 9 displays the detected circles of the yellow targets plotted onto binary image as an example. The center coordinates of each target can be stored in additional arrays and the position of the measured objects can be assessed.

Anti-dive behavior of a braking vehicle

The method described above was used to measure the inclination of a vehicle for the accelerating and braking events. As an example, the distance between a target placed on the rear wheel center and the target placed on the car body right above the wheel center can be determined. The vehicle entered the trap and decelerated in a given zone where the camera was set up. When detecting the positions of the targets, the graphs below were obtained. The positions of the targets are localized in each image as a set of discrete positions on the 1920x1080px grid. As the real initial distance between the 2 targets on a car body is known (later this will be enhanced with a calibration grid), it is possible to determine the accurate dimensions. The frame rate used in this measurement was 60 FPS. The graphs were made smoother through the Savitzky–Golay filter to reduce the noise (Mathworks, Mathworks/help/sgolayfilt, n.d.).

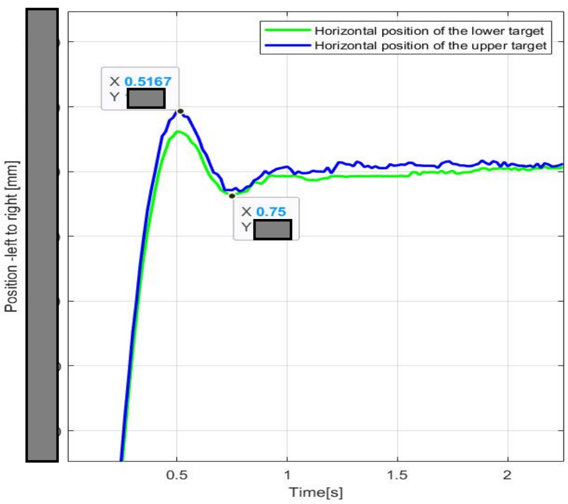


Figure 10. Horizontal position of the rear targets

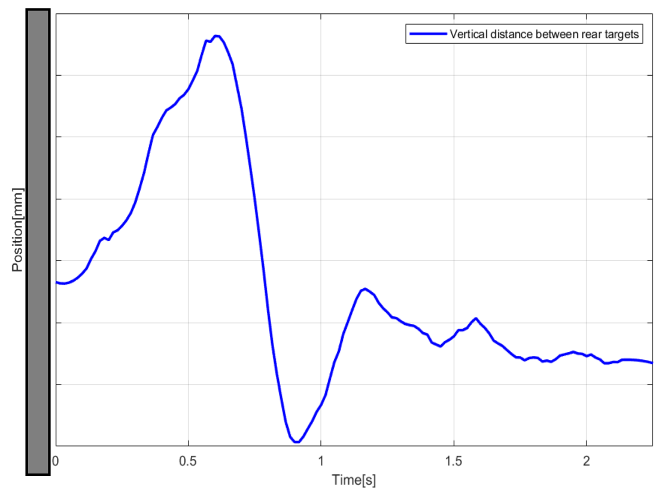


Figure 11. Vertical distance between the rear targets

Figure 10 shows the horizontal position of the rear targets, one placed on the wheel center (the lower target) and one placed on the car body (the upper target). The sequence up to the 0.5 second shows the deceleration. For the next additional 0.25 seconds the measurement shows a subtle backing behavior until the vehicle comes to a standstill state. Figure 11 displays the vertical distance between the rear targets that vary during braking. As the vehicle decelerated, the target distance increased up until the point of full stop, then the car swings back and then stabilizes.

The velocities and deceleration of the targets can be calculated when deriving increments / decrements of the coordinates from any two following frames. Figure 12 shows the vertical velocities of the targets as an example.

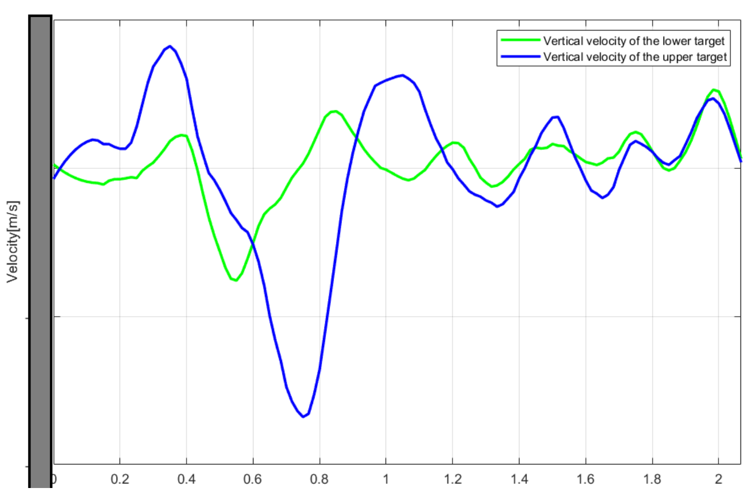


Figure 12. Vertical velocity of the upper and lower rear target

As the R&D program is running, further work in order to improve accuracy through a calibrated camera and a calibration grid is currently ongoing.

Other applications

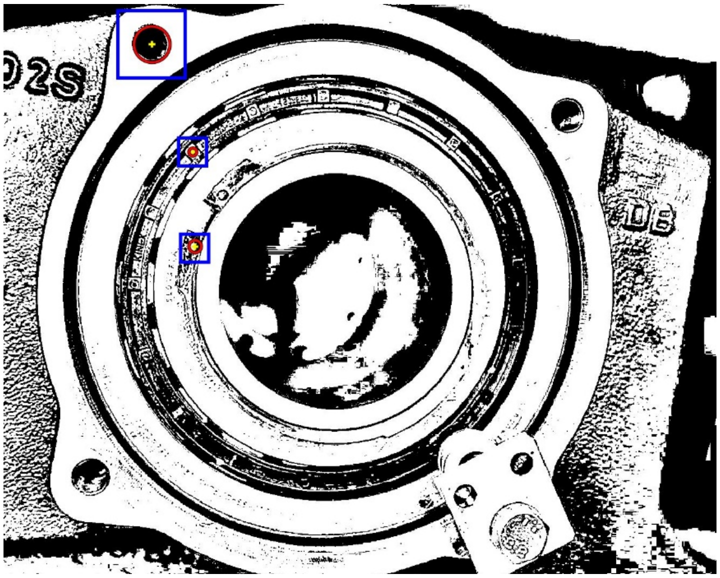


Figure 13. Roller bearing cage velocity measurement.

Another example of this application is illustrated in a task in collaboration with the University of Zilina to measure the velocity difference of the cage and inner race of a roller element bearing from a footage captured with a high-speed camera with over 2,000fps. For this application, a simple tracking algorithm has been developed, which creates a small floating region of interest that follows the detected circles. The key idea is that the circular Hough transform is performed only over this small region, which significantly reduces the investigated area of the image and thus improves the computational time while preventing misdetections. The blue boxes in Figure 13 represent the regions of interest and red circles within are the tracked objects.

In cooperation with a producer of sprayers, there is also a plan to test the object detection measurement techniques to capture dynamic behavior of long sprayer arms when a sprayer passes obstacles. Full publications of the topics are expected to be released in June 2021.

Hardware requirements

Object detection used as a measurement tool offers a very cost-effective way to measure the motion of complex dynamic systems. The only hardware required is the camera to record the video and a computer that can run the code, in this case written in Matlab. Any modern computer has enough computing power to perform the calculations in timespan counted in minutes, as the real time detection is not required for the measurement purpose.

As far as the camera is considered, any modern DSLR camera is capable of capturing the videos in sufficient quality and 60fps is today a standard, which is sufficient for vehicle MBD analysis, or applications alike. Many commercial digital cameras offer even higher frame rates as 120fps, 240fps or even higher. The FPS might be the only limiting parameter, as for some applications higher frame rate might be required. However, even high-speed cameras today become relatively affordable.

In addition, the machine vision techniques can be used with other visual outputs, such as a video from thermal camera, MRI, x-ray, or others. The common applications are now becoming wide spread, such as scanners that check whether a mask is on a face when entering a shopping mall during these times.

Acknowledgement

The students from the University of Zilina would like to express their thanks to Dr. Foltin and his colleagues from Humusoft for their support on the research.

References

Hanko, M. (2020). Kinematic parameters influencing the dynamic response of vehicles assessed through numerical simulations. *University of Žilina, Faculty of Mechanical Engineering, Department of Transport and Handling Machines*.

Image Analyst, I. (Retrieved October 24, 2020). *Image Segmentation Tutorial*. Retrieved from https://www.mathworks.com/matlabcentral/fileexchange/25157-image-segmentation-tutorial, MATLAB Central File Exchange.

Mathworks. (n.d.). *Mathworks.com/help*. Retrieved from https://ch.mathworks.com/help/vision/ref/detectcheckerboardpoints.html

Mathworks. (n.d.). *Mathworks/help/sgolayfilt*. Retrieved from https://ch.mathworks.com/help/signal/ref/sgolayfilt.html?searchHighlight=sgolayfilt&s_tid=srchtitle

Mathworks.com/help. (2012). *Mathworks.com/help/imfindcircles*. Retrieved from https://ch.mathworks.com/help/images/ref/imfindcircles.html

Pedersen, S. J. (2007). Circular Hough Transform. *Aalborg University, Vision, Graphics and Iteractive Systems*