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Reduction of the trailing observed in the video analysis of a moving object illuminated by stroboscopic light

Redução do rastro observado na videoanálise de um objeto em movimento iluminado por luz estroboscópica

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This work presents a new filming technique for objects captured in motion that minimizes the typical trail (blur) left in the recorded videos, increasing the accuracy of the video analyses. In order to reduce this trailing, we present a new technique called *video analysis by stroboscopic illumination*. The technique consists of filming the object of study illuminated only by short and intense pulses of light, without natural or artificial ambient lighting. An electronic device generates the pulses at a frequency adjustable to the frequency of the frames per second that take part in the video. As a result, we present an example of the proposed technique by filming a rubberized sphere launched from a ramp. This technique makes it possible to film by cell phones with low-resolution cameras and a low acquisition rate, allowing the improvement of the results of motion measurements.
Keywords: Experimentation in Physics Education, Video Analysis, Stroboscopic Illumination, Software Tracker.

Este trabalho apresenta a proposta de uma nova técnica de filmagem para objetos capturados em movimento que minimiza o rastro típico (borrão) deixado nos vídeos registrados, permitindo aumentar a precisão das videoanálises realizadas. Com o objetivo de reduzir este rastro, apresentamos uma nova técnica que chamamos de *videoanálise por iluminação estroboscópica*. A técnica consiste na filmagem do objeto de estudo iluminado apenas por pulsos curtos e intensos de luz, sem iluminação ambiente natural ou artificial. Os pulsos são emitidos por um dispositivo eletrônico numa frequência ajustável à frequência de tomada dos quadros por segundo que compõem o vídeo. Como resultado, apresentamos um exemplo da técnica proposta a partir da filmagem de uma esfera emborrachada lançada de uma rampa. Esta técnica viabiliza filmagens por celulares com câmeras de baixa resolução e baixa taxa de aquisição permitindo aprimorar os resultados das medidas de movimento.
Palavras-chave: Experimentação no Ensino de Física, Videoanálise, Iluminação Estroboscópica, Software Tracker.

1. Introduction

When there is a need to study rapid movements so that we cannot measure them by direct observation, it is necessary to adopt techniques that allow analyzing each movement stage in detail. One of these techniques is video analysis, in which the movement of an object is recorded on video and later analyzed frame by frame [1, 2]. However, when this analysis is performed, a phenomenon commonly called trail (blur) is observed, in which a video frame does not register a static image of the object. This effect is repeated in the other frames, and a video with the observed blurred ends up being composed. The blur is more evident when the object's speed is high, or the ambient lighting is poor. The latter, due to the automatic adjustment that the camera makes to capture more light, increases the exposure aperture time (shutter), causing the overlapping of multiple images.

In order to reduce this trail, we present a new technique called strobe illumination by video analysis. The technique consists of leaving the environment without natural or artificial light, and the object of study is illuminated only by strobe light during the video recording. The strobe effect consists of observing a fast phenomenon illuminated by short pulses of light emitted with a constant frequency and compatible with the measured event; that is, the frequency of short pulses of light must be exactly the same of the frequency of *frame per second* (*fps*) of the video recording device.

The present work used an electronic device to generate short pulses of light with a strobe effect that allows recording the movement of a rubberized sphere launched from a ramp, in which each frame of the recorded video reveals a stage of the movement of the sphere without a trace (static image). Figure 1A illustrates a frame referring to the final part of the movement of a sphere along the ramp, in which the record of a trace (blur) can

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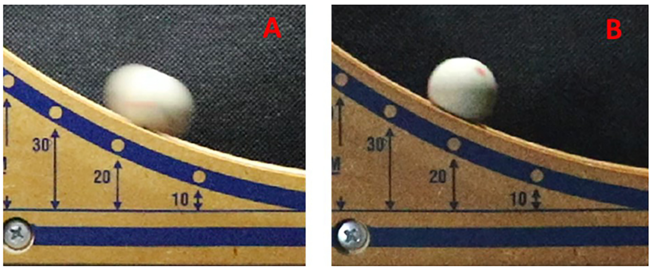

Figure 1: Launching the sphere on a ramp. In (A), a frame of the final part is presented, and we can visualize the trail in the usual filming that does not use the proposed technique. In (B), a frame is shown in the final part with practically no trail, filmed using video analysis technique with strobe lighting. Notice that the red dot marked on the sphere appears only in (B), while in (A), one observes only its long and tortuous trail superimposed on the trail of the sphere itself. Illustration of own authorship.

Figure 2: In (A), the sphere's movement recorded with a trail (blur) is presented. In (B), the sphere's movement is shown, recorded practically without a trail, and filmed using the video analysis technique by strobe illumination. Notice that the three dots marked on the sphere only appear clearly in (B), while in (A), only in the first few frames is it possible to notice that there is some unsharp marking, then it is no longer possible even to see that the dots are there. Illustration of own authorship.

be seen. In Figure 1B, an analogous frame filmed using the strobe illumination video analysis technique shows a record without a trace (static image). Before the ball was launched, three dots of different colors were marked. In Figure 1A, it is impossible to identify the red dot clearly, but only its long and tortuous trail is superimposed on the sphere's trail. However, in Figure 1B, it is possible to clearly identify the red dot and the sphere without a trail.

Using the strobe illumination video analysis technique improves the image quality, i.e., it increases the sharpness of the frames relative to the object's movement. This fact can be evidenced in Figure 2, which illustrates the complete movement of the sphere thrown from a ramp. Figure 2A illustrates the movement along the ramp with a trail, and Figure 2B shows the movement with virtually no trail. Notice that the three points marked on the surface of the sphere only appear clearly in Figure 2B, while in Figure 2A, only in the first frames is it possible to notice that there is some unclear marking, then it is no longer possible even to see that the points are there.

2. Dynamics of the Trail Phenomenon in the Image

The success in photographing a moving object can be impacted by influencing factors such as the ISO (International Organization for Standardization) number, the aperture of the diaphragm, and the time the shutter remains open [3]. The shutter is the part of the camera that opens and closes at a predetermined time interval by controlling the exposure of the image sensor (or film, in the case of analog cameras). For moving objects, the shutter can have two behaviors: stay open for a very short time, register a still image of a portion of the movement, or stay open for a longer time, creating a trail in the image [3]. Figure 3 illustrates the positioning of these components on the camera.

In the camera used in this work, when we make a video in automatic mode, the internal software takes control of the shutter [3], and the movement of the object is recorded frame by frame until the end of the recording. Because the shutter is always open, it is impossible to guarantee that each motion step will be constrained to a single frame (still image), causing the image to trail when a video is analyzed frame by frame. The shutter is a mechanism that protects the camera's image sensor by opening only when the shutter release is triggered to capture light. Figure 4 illustrates the shutter (on the left) and opens it with an exposure image sensor (on the right) on some still cameras [3].

Figure 3: Illustration of the arrangement of the diaphragm, lenses, shutter, and image sensor. Illustration of own authorship.

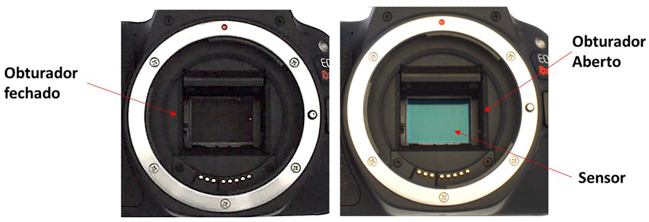

Figure 4: Photos of the shutter closed (left) and open (right). Illustration of own authorship.

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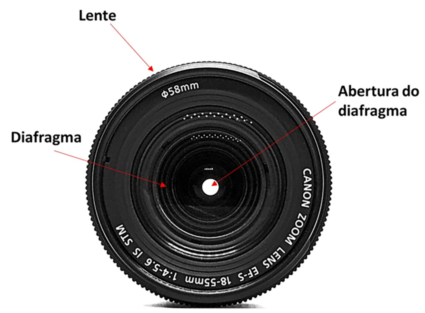

Figure 5: The aperture size of the diaphragm can be fixed or variable, depending on the camera model and lens. Illustration of own authorship.

The diaphragm's aperture allows the amount of light needed for the image sensor to pass through and can be adjustable or fixed (see Figure 5).

3. The Strobe Effect on the Reduction of the Trail in the Image

Trailing is related to the interval of time the shutter remains open while recording motion. When applying a short pulse of strobe light, the duration of the pulse overlaps with the time the shutter stays open, allowing the estimation of the trail under the strobe effect (reduced trail). Figure 6 illustrates the model for estimating the reduced trail.

Given that the object has a velocity v, we can estimate the size of the trail $\delta s_{(t)}$ from the time interval $\delta t_{(s)}$ where the shutter is open:

$$\delta s_{(t)} = v\delta t_{(s)}. \tag{1}$$

Similarly, we can estimate the size of the reduced trail $\delta s_{(st)}$ from the time interval $\delta t_{(p)} < \delta t_{(s)}$ which corresponds to the duration of the intense pulse of light:

$$\delta s_{(st)} = v\delta t_{(p)}. \tag{2}$$

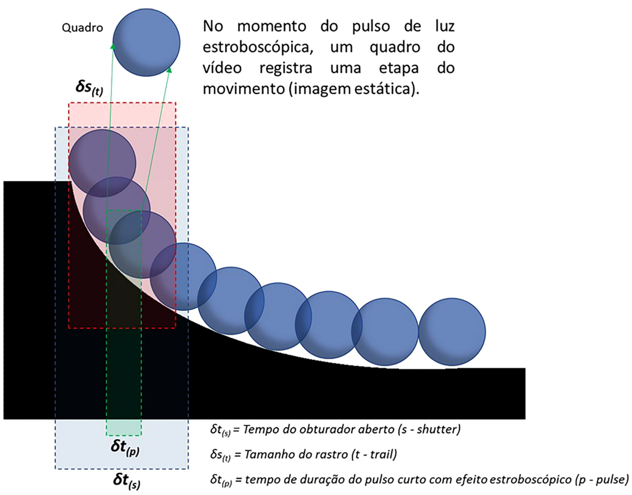

Figure 6: Illustration of trail formation (shutter open) and reduced trail formation (using strobe illumination video analysis technique). Illustration of own authorship.

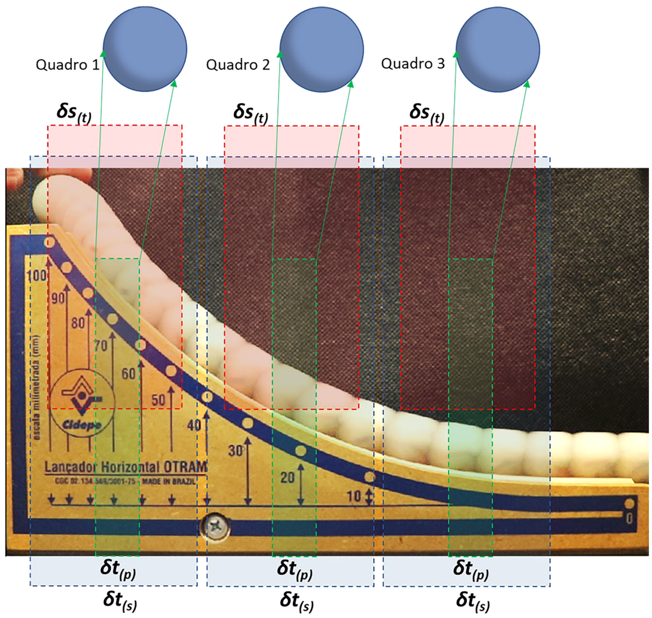

Figure 7: Illustration of the action of short pulses of light with a strobe effect during the video's making and recording of a stage of the movement. Illustration of own authorship.

Figure 7 illustrates the action of short pulses of light with a strobe effect during the video's production and recording of a stage of the movement (static image).

4. Light Pulse Generator with Strobe Effect

The light pulse generator device used in the present work is based on a free-running multivibrator based on the IC555 integrated circuit, consisting of a general-purpose timer that can operate in astable and monostable configurations [4]. Figure 8 illustrates the IC555 integrated circuit.

The operating range as astable goes from a fraction of a hertz to close to 500 kHz. In this configuration,

Figure 8: Integrated circuit IC555. Illustration of own authorship.

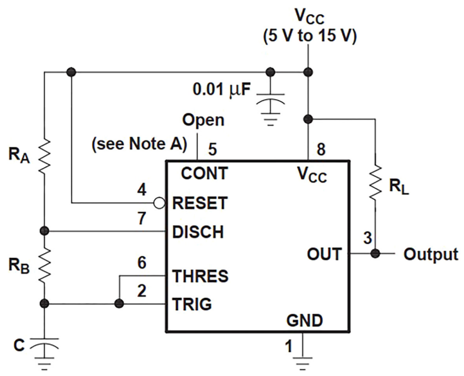

Figure 9: Reference circuit used in the design of a light pulse-generating device. Source: Ref. [5].

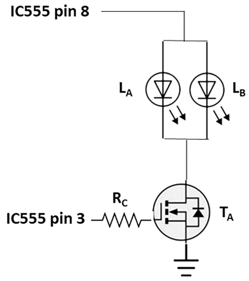

Figure 10: Circuit for connecting the LEDs in the circuit with IC555. Illustration of own authorship.

the operating frequency is given by the R_A, R_B, and C values (see Figure 9). The capacitor (C) is charged through R_A and R_B and discharges via R_A. This cycle of charge and discharge works as an oscillator, generating a rectangular signal that can be used for the operation of a clock or digital circuits [4].

The astable multivibrator has two quasi-unstable states and remains in each for a predetermined time interval as a function of R_A, R_B, and C. Therefore, after a period of time in one of the unstable states, the astable switches to the other quasi-unstable state and remains in it for another period of time. At the end of this period of time, it returns to the previous state, and so on. In this way, the astable multivibrator behaves like an oscillator [4, 5].

The astable mode was adopted because it met the need for a continuous flow of light beams (oscillator), and the frequency of these beams can be selected to meet the required frequency, which can vary from 20 Hz to 1 kHz. In the case of the present work, we set it at 60 Hz (60 blinks per second). The electronic device used was based on the reference circuit available in the technical document of one of the existing manufacturers of the IC555 integrated circuit. In this case, the manufacturer is *Texas Instruments* [5]. Figure 9 illustrates the reference circuit.

In the reference circuit illustrated in Figure 9, the R_L resistor is used to improve the output voltage of pin 3 of the IC555, and its value is equal to 1000 $\Omega(10\%)$ [5]. A driver was developed based on the IFRZ 44N transistor, whose electronic circuit is illustrated in Figure 10, to connect high-luminous-power LEDs in the circuit. This controller is connected in place of the R_L resistor (Figure 9). This circuit can supply up to 20 A of current, depending on the IFRZ 44N transistor.

The circuit components in Figure 10 are T_A = transistor IFRZ 44N; L_A = LED Forest; L_B = LED Lamp; and $R_C = 348\Omega(10\%)$. The R_C resistor keeps the electric current at a value suitable for the transistor's operation. According to the manufacturer, the LED bulbs are connected in parallel and have the following specifications: operating voltage = 12 V; working current = 720 mA; luminance = 800 lumens; power = 9 W; and connector = E27. For the LED bulb to work appropriately, the circuit must be powered by a 12 V source supplying a minimum current of 2.5 A.

The astable mode was adopted to meet the need for a continuous flow of light beams (oscillator) in which the frequency of these beams can be scaled to meet the required frequency, which can vary from 20 Hz to 1 kHz. In the case of the present work, we set it at 60 Hz (60 blinks per second). The electronic device used was based on the reference circuit available in the technical document of one of the existing manufacturers of the IC555 integrated circuit. In this case, the manufacturer is *Texas Instruments* [5]. Figure 9 illustrates the reference circuit.

The light pulse generator used in this work allows the adjustment of the frequency and time width of the active pulse (LED lamp on) and the inactive pulse (LED lamp off).

The frequency can be calculated by:

$$f = \frac{1}{0.8(R_A + R_B)C}, \tag{3}$$

being R_A e R_B are the resistances of the variable resistors (potentiometers) and it is the capacitance of the electrolytic capacitor C, whose value is fixed [6].

The equation for calculating the time in which the pulse is active (T_h) is

$$T_h = 0.8 R_A C \tag{4}$$

and the time the pulse is inactive (T_l) to be calculated by

$$T_l = 0.8 R_B C, \tag{5}$$

according to Ref. [6].

The values of the resistances $R_A = 9940\Omega(10\%)$ e $R_B = 35790\Omega(10\%)$ were obtained by measuring the circuit adjustment potentiometers when synchronized with the camera at 60 *fps*, explicitly. the capacitance value C has a fixed value of 0.459 μF (20%). So, from Equations (3), (4), and (5), we get $f = 59.62$ Hz, $T_h = 3.65$ ms e $T_l = 13.13$ ms, that are compatible with the uncertainties of the electronic components used.

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Knowing the velocity of the object, it is possible to estimate the size of the reduced trail using the technique of *Video Analysis by Strobe Illumination* using Equation (2) and substituting the value of $\delta t_{(p)}$ by T_h.

5. Methodology for Recording the Video

The Tracker software was used to perform the video analysis and images presented in this work [7]. A Canon camera fixed on a tripod recorded video with strobe lighting. The specifications are: model DSLR EOS Rebel SL-2; lens 18 mm – F/5.6; 24-megapixel image sensor.

The environment for making the video must be free of other light sources so that there is no interference with the strobe effect. The recorded video's frame rate was set to 60 frames per second and synchronized with the light pulse generator. The synchronization of the light pulses with the rate of 60 Hz was performed as follows:

1. The camera has been selected in the video recording function.
2. The video was recorded at 60 *fps*.
3. The image from the lens was directed to the camera screen.
4. When turning on the light pulse generator, the external light must be turned off to avoid interfering with the light pulses.
5. In this step, the screen shows dark bands that may be going to the top or bottom of the screen, along with the image, while the frequency is not synchronized.
6. The light pulse generator should be adjusted until the dark band is fixed on the screen without moving up or down. At this point, the synchronization of the frequency of light pulses with the frame rate per second is finished, and it is possible to start recording the video.

Figure 11 illustrates how to view the camera screen when the synchronization between the video's frame rate per second and the strobe light generator has not yet been reached.

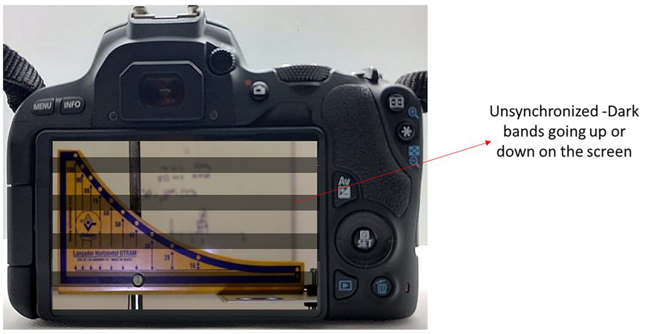

Figure 11: Camera screen when the synchronization between the video frame rate and the short pulse generator of strobe light has not yet been reached. Illustration of own authorship.

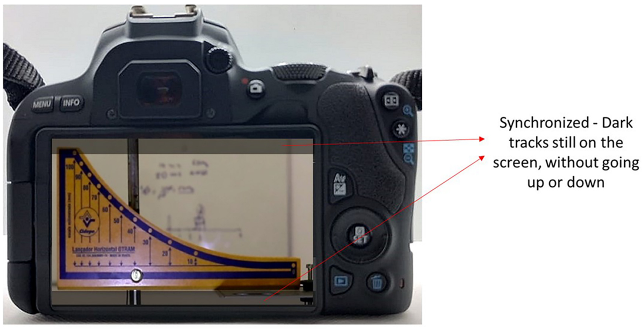

Figure 12: Camera screen when synchronization between the video's frame rate per second and the short strobe light pulse generator was reached. Illustration of own authorship.

Figure 12 illustrates when synchrony is achieved.

The dark bands observed on the camera screen during synchronization with the strobe light pulses are caused by the modulation of light [8].

The term "light modulation" has some variations. The most common are flicker, vibration, and flicker. The Illuminating Engineering Society (IES), the lighting handbook, defines flicker as the most commonly adopted term. Dark bands (flicker) are briefly defined as "luminance variations in time." All artificial light sources modulate light to some degree, usually due to their energy consumption, mainly from main sources (50 Hz or 60 Hz) [8, 9].

Dark bands (flicker) are undesirable information in video recording and photography. Still, in the case of this work, these bands work as a synchronization indicator when the video is taken under the effect of pulses of strobe light. Dark bands appear as a function of the shutter speed and frame rate combination, which can register different fractions of these pulses in each video frame. That is, in a video frame, it is possible that a fraction of this frame is illuminated, and another fraction of this same frame has low or no lighting.

In Figure 13A, each frame registers different fractions of the complete period of the strobe light pulse (unsynchronized), a behavior seen in Figure 11. In Figure 13B,

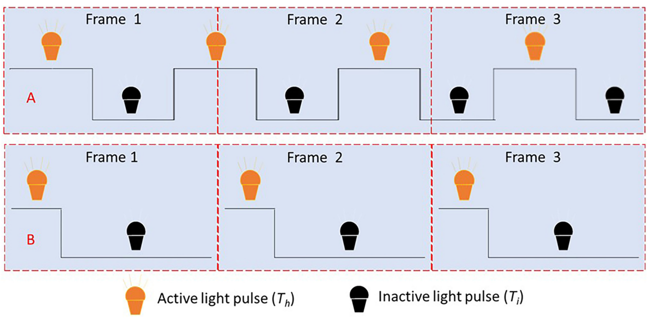

Figure 13: Graphical representation of the dark bands (flicker). Illustration of own authorship.

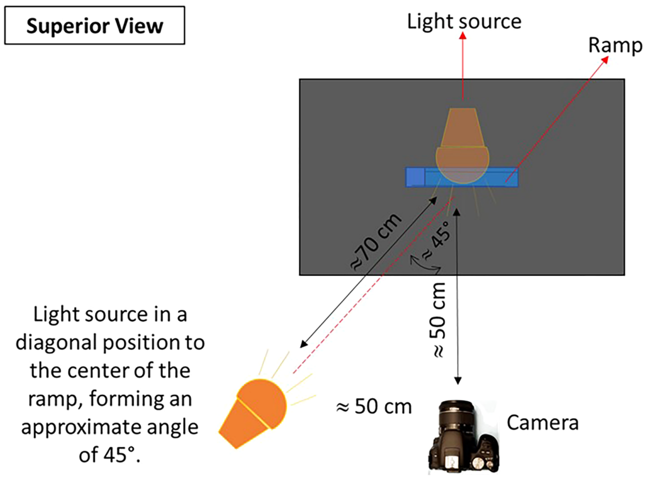

Figure 14: Top view of the light sources' positioning and the camera position used to record the video. Illustration of own authorship.

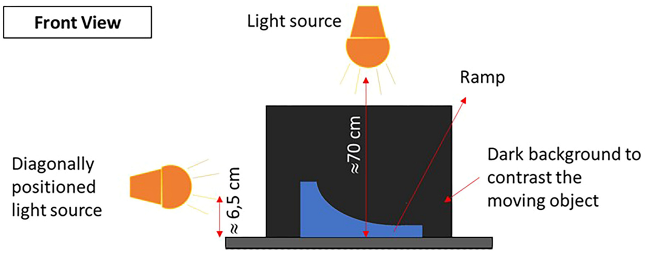

Figure 15: Front view of the positioning of the light sources.

the frames record a complete period of the strobe light pulse (synchronized), and its behavior can be seen in Figure 12.

Dark bands (flicker) move upward on the camera screen when the frequency of the strobe light pulses is greater than the frame rate. When the frequency of the light pulses is lower than the frame rate per second, the dark bands move downwards, and when equalizing the frequency with the frame rate per second, due to the strobe effect, the dark bands under the human gaze appear stationary. Depending on the variation in the value of the resistors R_a and R_b for the frequency adjustment, the sizes of T_h and T_i may vary.

Figure 14 illustrates the top view of the positioning of the light sources synchronized with the short pulse generator and the camera's position used to record the video.

Figure 15 illustrates the front view of the positioning of the synchronized light sources. The distances reported in Figures 14 and 15 are approximate and were defined over several attempts to obtain the best relationship between lighting and sharpness in the recorded video.

Figure 16: Experimental setup. (A) an upper view (Figure 12); (B) a front view (Figure 13). Illustration of own authorship.

In Figure 16, a photograph illustrates the experimental setup described in Figures 12 and 13.

6. Conclusion

The presence of the trail in the image, caused by the shutter action, can interfere with the quality of the data obtained by the video analysis. The time in which the shutter remains open is essential for an excellent photographic record of moving objects, but in the case of a video, the time in which the shutter remains open is more extended concerning the time of recording the frames. The *internal software* of most cameras and smartphones takes control of the shutter time depending on the intensity of the light in the environment, originating the trail in the image. In good natural lighting, the shutter time control is usually reduced. However, the user can control the shutter on some higher-cost professional cameras.

Using the technique of *video analysis by strobe illumination* conceived in this work, it was possible to reduce the trail in the image. The technique adopted a light pulse generator with a strobe effect because the moment a generated light pulse hits the moving object, part of this movement is "frozen" and recorded in a video frame. Therefore, the video analysis technique *by strobe illumination* enables cell phones to film with low-resolution cameras and an acquisition rate of at least 30 *fps*, allowing for improvement of position, velocity, and acceleration measurements.

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