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High speed image techniques for construction safety net monitoring in outdoor conditions

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ABSTRACT

The behaviour of a construction safety net and its supporting structure was monitored with a high speed camera and image processing techniques. A 75 kg cylinder was used to simulate a falling human body from a higher location in a sloped surface of a building under construction. The cylinder rolled down over a ramp until it reaches the net. The behaviour of the net and its supporting structure was analysed through the movement of the cylinder once it reaches the net. The impact was captured from a lateral side with a high speed camera working at 512 frames per second. In order to obtain the cylinder position each frame of the sequence was binarized. Through morphological image processing the contour of the cylinder was isolated from the background and with a Hough transform the presence of the circle was detected. With this, forces and accelerations applying on the net and the supporting structure have been described, together with the trajectory of the cylinder. All the experiment has been done in a real structure in outdoors location. Difficulties found in the preparation on the experiment and in extracting the final cylinder contour are described and some recommendations are giving for future implementations.

Keywords: Construction safety net, high speed camera, image processing techniques

1. INTRODUCTION

Temporary edge protections in building construction are regulated in Europe by EN-13374[1]. During the construction phase of sloped surfaces protective systems should be installed to protect workers against falls to the void. When trapping a falling body, these systems should absorb a considerable kinetic energy and should be supple enough to avoid serious injuries to falling people due to deceleration. Because of that, the norm EN 13374 imposes a minimum deflection in the protection system of 200 mm. It also establishes a safety-testing procedure consisting of a ballast falling from 4.33 m height on a 60° sloped surface against the protection system.

Some previous numerical studies suggested that current requirements could be inadequate. Our calculations show that deflections of 200 mm impose strong decelerations, even greater that those advisable for the human being (8-10g) and may cause serious injures. These undesirable effects motivated us to further analyze the dynamic retaining process of the protective system and compare our results with those regulated by the norm.

Deflection of the protection system is defined as the maximum displacement from its original position. The measurement of this parameter is a complex task due to its particular characteristics. This system consists of a surface made by some elastic-plastic material and a supporting structure. Usually the surface is made by a thread net tied to some parts of the supporting structure. The structure is a proposal from some of the authors and is composed of steel curved tubes joined by straight tubes in their ends (figure 1). The instant deflection of the net due to a falling body is indirectly determined by tracking the position of the ballast, a 75 kg cylinder hollow cylinder made with steel and covered with rubber. According to our predictions, the system with a thread net will suffer much greater deflections than 200 mm. These low deflections are only compatible with a more rigid material, like a wire mesh. Since we are interested in knowing how much acceleration is linked with this low deflection both materials will be considered here.

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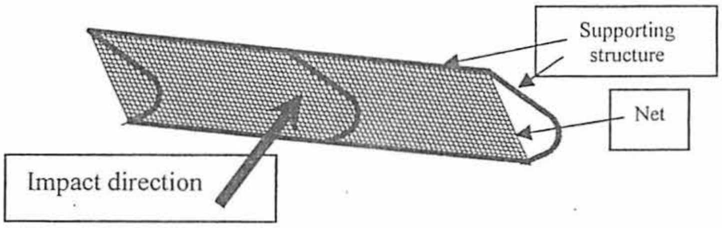

Figure 1. Diagram of the protection system showing its parts and configuration.

In both cases (thread or wire) the material of the net is elastic and maximum deflection and recovery happen in a very short period of time (milliseconds). The speed of the process makes necessary to use systems with high acquiring frequencies. Additionally the total deflection is usually unknown, since it depends on the net holder, the knots stiffness and the net material itself. This fact makes impossible the use of a contact device to measure the instant deflection. Because of this, a high-speed camera working at 512 frames per second (fps) was used both to visualize and to determine the net deflection.

The final objective of this work is to determine the deceleration suffered by the falling body. This will be accomplished by tracking the instant position of the cylinder and then, taking the second temporal derivative. Additionally the cylinder position provides the deflection of the protective system and permits checking if the minimum deflection of 200 mm required by the norm is compatible with undamaging decelerations.

As will be explained below, the setup was arranged so that the basis of the cylinder faced to the camera. Doing so, one is able to determine the position of the cylinder just by tracking the circular shape of the basis. Tracking simple shapes for determining object movements in complex scenes is a common practice and simplifies very much the image processing algorithms[2,3].

The manuscript is structured as follows. First, in the Section 2, we will describe the experimental setup and the image processing algorithms for tracking the cylinder position. In Section 3, we will describe the data processing and the main obtained results. Finally, the main conclusions of this work are outlined in Section 4.

2. METHODS

2.1 Experimental setup

All the experimental setup was arranged in a building structure. In order to simulate the falling body, a 75 kg cylinder is dropped from a height of 4.33 m until it reaches the protection system. During all the fall the cylinder rolls over a 60° sloped surface.

Two different protective systems were used here. One of them used a net made of textile thread net while the other is made by a steel wire mesh. The supporting structure of the protection system was common to both nets. This structure was anchored to the ground by two dead weights (see figure 2). For each kind of surface two experiments (falling bodies) were made.

The movement of the cylinder was recorded by a high speed camera located in one side of the experiment with the optical axis passing through the net initial plane (Figure 2). This procedure allows seeing the lateral circumference of the cylinder. Furthermore from this position the net is seen as a straight line and then any deflection of the net due to cylinder impact can be easily detected and measured. The camera used in this experiment was an AOS X-Pri, working at 512 fps with a frame resolution of 800×560 px.

2.2 Image processing algorithm

Detection of the cylinder position consists of two basic steps. In the first step, the scene is binarized and the borders extracted. The image is cleaned in order to remove as much lines as possible. In the second step, the presence of a circular shape is detected by means of the Hough transform[5]. In order to facilitate and accelerate the calculation, the position of the cylinder and its radius is manually estimated in the first frame. For the remaining frames of the sequence, the process is fully automatic.

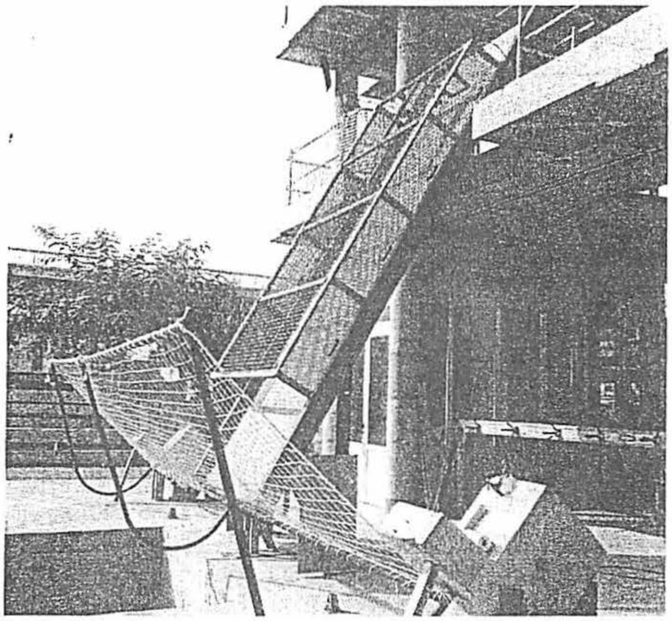

Figure 2. Picture of the experimental setup. Notice the protective system and the slope for the falling ballast.

Let us describe the process point by point. After the video capture, the sequence is moved from the camera to the computer and processed off-line with Matlab4. The first frame of the sequence is presented to the user and three points from the lateral side of the cylinder (a circle) must be selected by hand. From these three points we geometrically estimate the center and the radius of the circle (see figure 3).

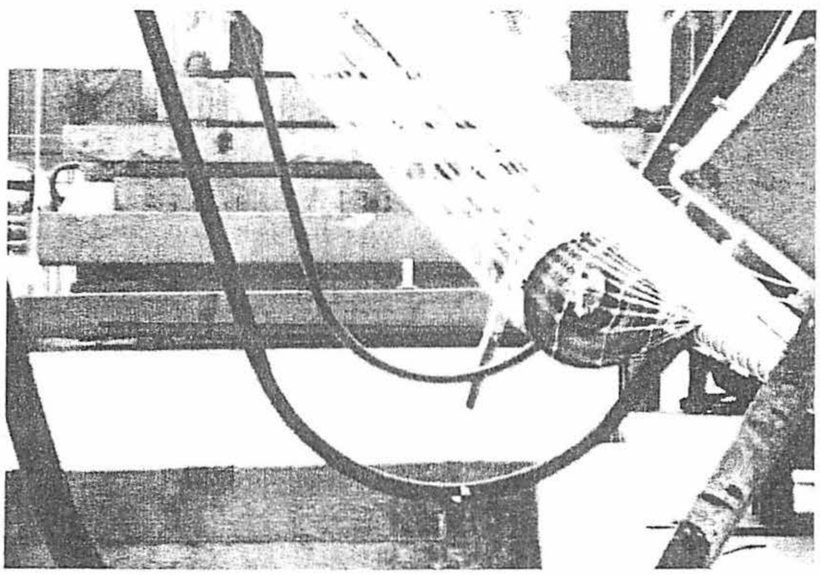

Figure 3. Frame from the captured sequence. The three blue dots permit determination of the centre and the radius of the circle.

Notice that the scene is relatively complex with many objects brighter than the cylinder itself. Thus, segmentation of the target will require accurate hard-clipping of the luminance curves. Alternatively, notice that major part of the scene will remain static along the whole sequence so does not add any important information. Therefore, we can take the absolute difference of two consecutive frames and then multiply this difference by the original image, so only those parts belonging to it will be enhanced while the others will be strongly attenuated.

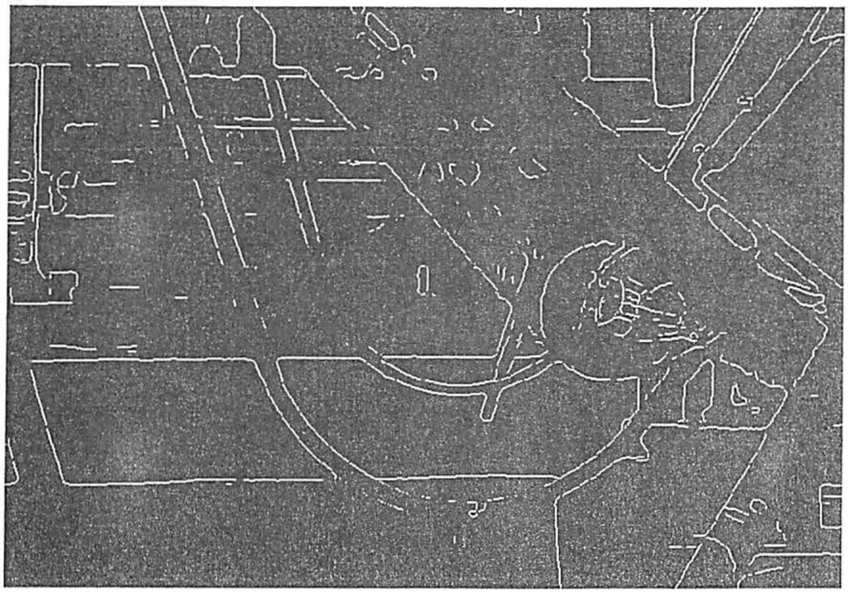

Figure 4. Resulting image after cleaning and applying a Sobel filter.

The image is then cleaned through a median filtering and black holes larger than 3×3 px are eliminated through a morphological closing operation. A Sobel filter will finally extract the borders of the image, as can be seen in figure 4.

Figure 5 Final result of the Hough transform. The red dot marks the centre of the circle.

The Hough transform is a technique that is used to detect features of a particular shape in one binary image. In our case, the radius of a circumference is given as an entrance parameter and the Hough transform will search for the exact position of the circumference centre. . The centre estimated from the first frame will be used to define a region of so the transform will be only applied on a local area of the image. In brief, the algorithm traces circumferences of the desired radius that pass through a particular white pixel of the binary image, and counts how many of the pixels in the image are likely to belong to any of these circumferences. Results of the pixel count are accumulated in one matrix and the exact position of the target is established by the maximum of the accumulator matrix. The process is repeated for all white pixels in the scene. Since the radius may not be clearly established, the algorithm is applied for an interval of radius and the absolute maximum of all the accumulator matrixes is taken as the cylinder position. In figure 5 we present the result of the accumulator for the scene in 4

After circle detection, the center and radius obtained are used as estimators for the following frame. Thus, from the first image, the algorithm runs automatically and detects the position of the cylinder at each frame. In figure 6 we show a montage with different frames of the video. The detected center of the cylinder is marked in each frame. After doing this process in all frames, the complete trajectory is obtained (Figure 7).

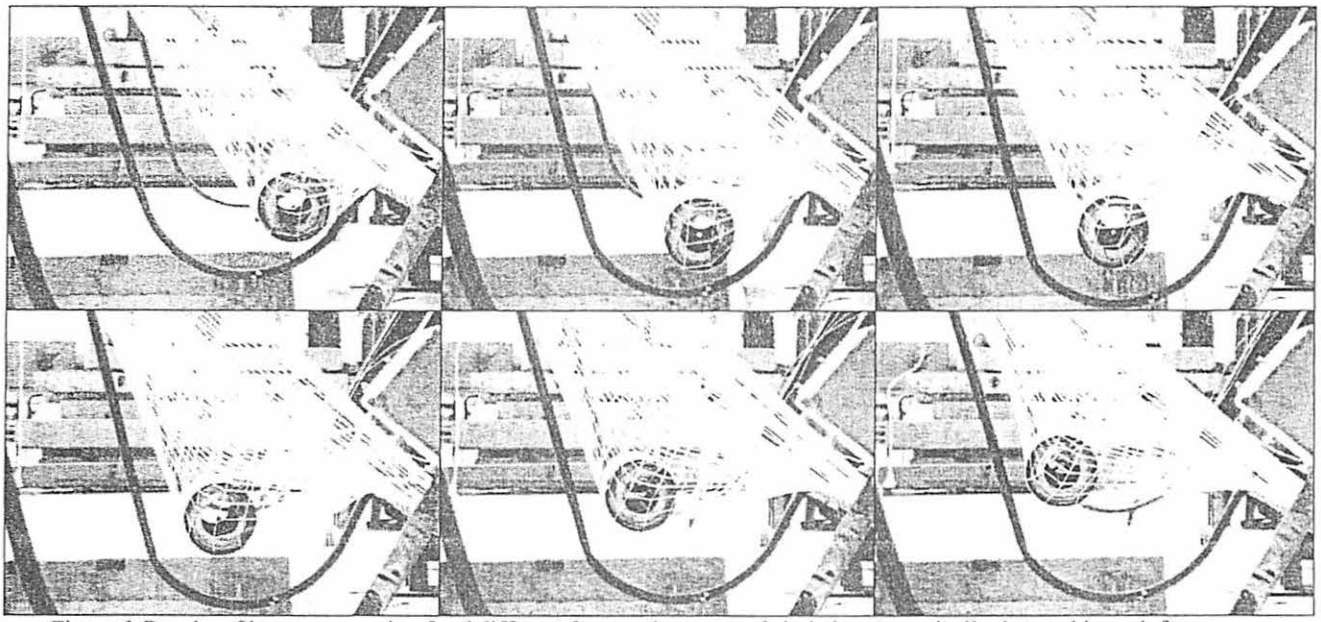

Figure 6. Results of image processing for 6 different frames; the centre of circle is automatically detected in each frame.

3. RESULTS

As we pointed before, the main results of this work are the maximum deflection of the net and the maximum deceleration suffered by the cylinder. All these results can be obtained from the cylinder trajectory in figure 7. Since the cylinder diameter is known, we can calculate the px to mm conversion factor and thus obtain the real movement of the cylinder. Notice that the movement of the circle describes the movement of the cylinder center of gravity only while both of them is parallel to the camera axis. Once the cylinder rebounds in the net, this alignment is lost and the obtained trajectory does not have complete physical correspondence with the body movement.

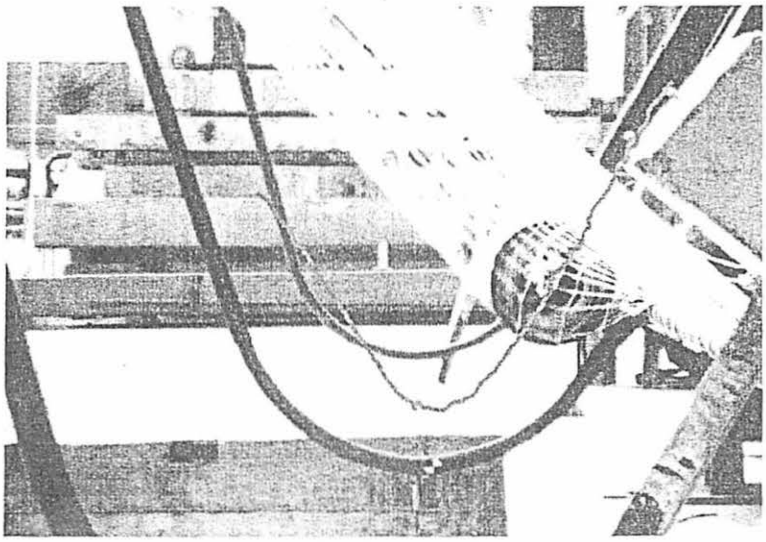

Figure 7. Trajectory of circle centre during the body falling.

Maximum deflection can be obtained from simple comparison between two frames: one of them showing the moment when the cylinder contacts the net (figure 8 left) and the second one when maximum deflection is observed on the trajectory (figure 8 centre). The superposition of these two frames is shown in figure 8 right, together with the measured maximum distance. In table I we present the maximum deflections for all cases here considered.

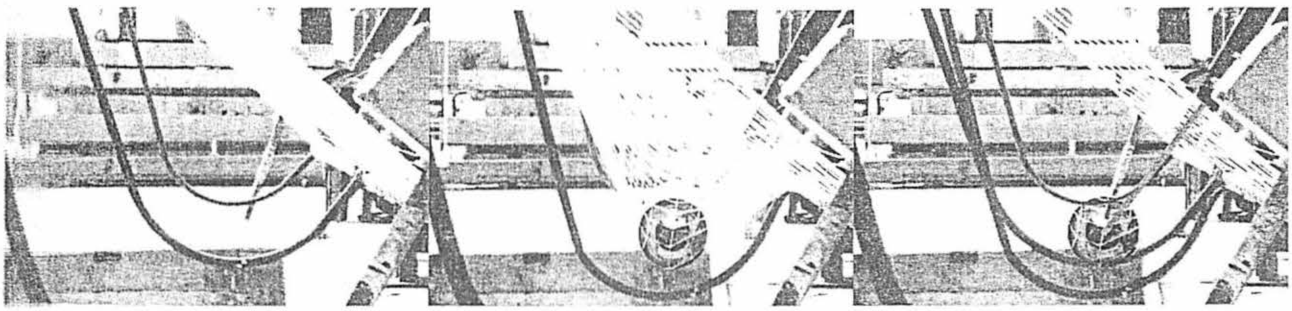

Figure 8. Initial configuration of the protection system (left), moment of maximum deflection of the protection system (centre), superposition of frames and determination of maximum deflection. Displacement of circle centre (red line) (right).

To calculate the maximum deceleration suffered by the cylinder we use the complete trajectory obtained from the image processing algorithm. The acceleration is calculated through 2nd temporal derivative of trajectory. Notice that the cylinder is first trapped by the net and then thrown up again. Since we are only interested in the deceleration process we will only focus in the time period going from the moment the cylinder is thrown (free fall) until it is completely stopped.

It is important to underline here that outdoors experiments cannot be as accurately prepared as lab experiences. A high speed camera requires an important amount of light, since exposition time is very low. Thus, sunny days are preferred for the experiment. Notice also that the cylinder and the net were not prepared for the experiment, so the position and aperture of the camera should maximize the contrast in order to guarantee visibility and object detection.

Although it is difficult to appreciate in figure 7 obtained trajectory is very noisy and this impedes direct numerical derivative. Therefore, a least-squares fitting of the trajectory to a polynomial equation was done. Different degrees of the polynomial equation were used to asses the stability of the result. Once obtained the polynomial adjustment, second derivative of the fitting expression gives the cylinder acceleration. As an example of the results in figure 9 the obtained acceleration for five different polynomial orders is shown for the first experiment against the textile thread net. It is clear that maximum value of acceleration does not depend on the degree of the polynomial equation used in the adjustment.

Then, for the case shown in figure 9, the maximum value for acceleration was 9.4 g. For all studied cases, the results of maximum deflection and maximum deceleration are shown in table 1.

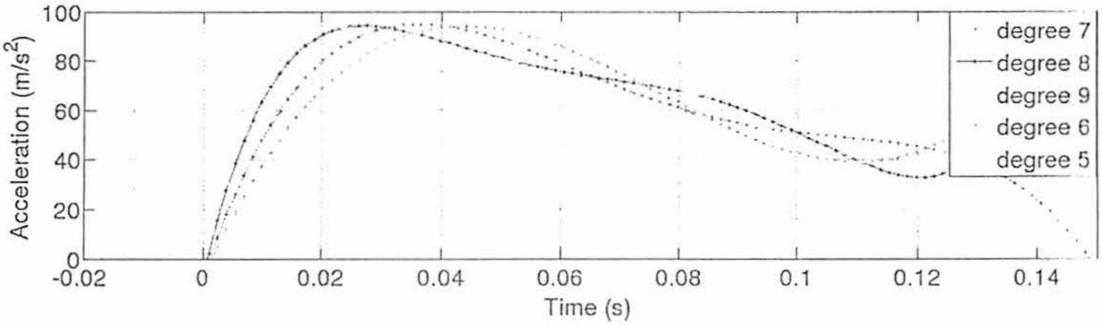

Figure 9. Acceleration for different degrees of polynomial least-squares fitting for first impact against the textile thread net

Table 1. Deflections and accelerations obtained during the experiments in the textile thread net and in the steel wire mesh.

	TEXTILE THREAD NET		STEEL WIRE MESH	
	Test 1	*Test 2*	*Test 1*	*Test 2*
Deflection (mm)	700	500	230	175
Acceleration (g)	9.4	13	29	31

If we compare the obtained values in this work with those recommended by codes, we can see that the steel wire mesh fulfills the recommendation of a minimum deflection of 200 mm but the deceleration suffered by the cylinder is of 30 g, much higher than maximum values that a human body can bear without serious damage[6]. Relatively safe values of acceleration were obtained for the textile thread net, but with deflections between 2.5 and 3.5 times higher than the minimum values required by European Code. Therefore, the results from this work suggest the revision of the minimum deflection criterion of the protection system.

4. CONCLUSIONS

In this work we have revised some recommendations given in the European code EN-13374[1] for safety systems installed in sloped constructions. Safety systems consists of nets and holder and the norm establishes that a maximum deformation of 200 mm is enough to prevent workers injury.

The maximum deformation and deceleration acting on a falling body have been measured experimentally. We installed a security system on a building structure and a 75 kg cylinder was thrown over a 60° sloped surface. With a high speed camera, we tracked the movement of the cylinder while it was trapped and stopped. Detection of the cylinder position was done by using the Hough transform.

Our experiments show that normal textile nets suffer much higher deflections than minimum values required by the European code, but with a deceleration in the limit of human body damage. The minimum values established in the European codes are only achieved by using rigid steel wires meshes but at the cost of transmitting a strong deceleration to the falling bodies. Values found show that values established by the code are not compatible with body safety.

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REFERENCES

[1] EN 13374:2004 "Temporary Edge Protection Systems Product Specification, test methods". CEN (2004)

[2] Mas, D., Espinosa, J., Roig, A. B., Ferrer, B., Perez, J., Illueca, C., "Measurement of wide frecuency range structural micro-vibrations with a pocket digital camera and sub-pixel resolution" Appl. Opt. (in press).

[3] Bruckstein, A. M., O'Gorman, A., "Design of shapes for precise Image registration" IEEE T. Inform. Theory, 44, 3156-3162, (1998).

[4] Matlab Image processing toolbox (Mathworks Inc.) at http://www.mathworks.es/help/toolbox/images/, last seen in 03-16-2012.

[5] Duda, R. O. and P. E. Hart, "Use of the Hough Transformation to Detect Lines and Curves in Pictures," Comm. ACM, Vol. 15, pp. 11–15 (1972).

[6] Voshell, M. "High acceleration and the human body", at http://csel.eng.ohio-state.edu/voshell/gforce.pdf last seen in 03-16-2012

High speed image techni... construction safety ne... in outdoo...

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Abstract

The behaviour of a construction safety net and its supporting structure was monitored with a high speed camera and image processing techniques. A 75 kg cylinder was used to simulate a falling human body from the upstairs floor of a building under construction. The cylinder rolled down over a ramp until it reaches the net. The behaviour of the net and its supporting structure was analysed through the movement of the cylinder once it reaches the net. The impact was captured from a lateral side with a high speed camera working at 512 frames per second. In order to obtain the cylinder position each frame of the sequence was binarized. Through morphological image processing the contour of the cylinder was isolated from the background and with a Hough transform the presence of the circle was detected. With this, forces and accelerations applying on the net and the supporting structure have been described, together with the trajectory of the cylinder. All the experiment has been done in a real structure in outdoors location. Difficulties found in the preparation of the experiment and in extracting the final cylinder contour are described and some recommendations are giving for future implementations.

Method

- **Experimental setup**

All the experimental setup was arranged in a building structure. In order to simulate the falling body, a 75 kg cylinder is dropped from a height of 4.33 m over a 60º sloped surface until it reaches the protection system (Fig. 1). Two different protection systems were used here. One of them used a net made of textile thread net while the other is made by a steel wire mesh. The supporting structure of the protection system was common to both nets. This structure was anchored to the ground by two dead weights. For each kind of surface two experiments were made.

The movement of the cylinder was recorded by a high speed camera located in one side of the experiment. The camera used in this experiment was an AOS X-Pri, working at 512 fps with a frame resolution of 800 x 560 px. In this video sequence some simple shapes can be tracked for determinig object movements[1].

Figure 1. Experimental setup

- **Image processing algorithm**

Detection of the cylinder position consists of two basic steps. In the first step, the scene is binarized and the borders extracted. The image is cleaned in order to remove as much noise as possible. In the second step, the presence of a circular shape is detected by means of the Hough transform. In order to facilitate and accelerate the calculation, the position of the cylinder and its radius is manually estimated in the first frame. For the remaining frames of the sequence, the process is fully automatic.

After the video capture, the sequence is moved from the camera to the computer and processed off-line with Matlab. The first frame of the sequence is presented to the user and three points from the lateral side of the cylinder (a circle) must be selected by hand. From these three points we geometrically estimate the center and the radius of the circle.

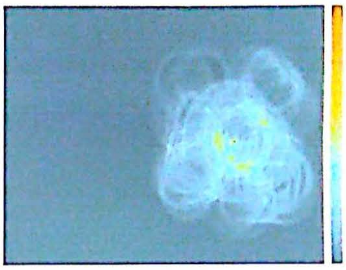

Figure 2. Hough transform

We can take the absolute difference of two consecutive frames and then multiply this difference by the original image, so only those parts belonging to it will be enhanced while the others will be strongly attenuated. The image is then cleaned through a median filtering. A Sobel filter will finally extract the borders of the image. Then, the Hough transform will search for the exact position of the circumference centre (Fig. 2). This algorithm traces circumferences that pass through a particular white pixel of the binary image, and counts how many of the pixels in the image are likely to belong to any of these circumferences.

From the first image, the algorithm runs automatically and detects the position of the cylinder at each frame (Fig. 3). After doing this process in all frames, the complete trajectory is obtained (Fig. 4).

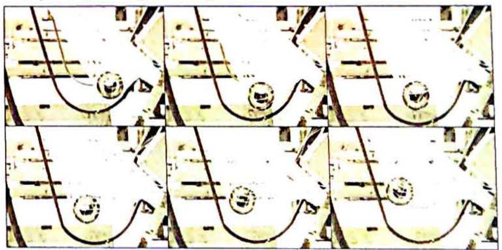

Figure 3. Automatic detection of cilynder

Results

The main results of this work are the maximum deflection of the net and the maximum deceleration suffered by the cylinder. All these results can be obtained from the cylinder trajectory. Since the cylinder diameter is known, we can calculate the px to mm conversion factor and thus obtain the real movement of the cylinder

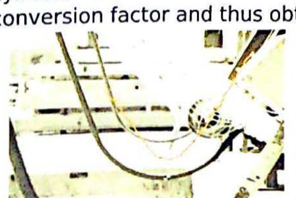

Figure 4. Trajectory

A least-squares fitting of the trajectory to a polynomial equation was done. Different degrees of the polynomial equation were used to asses the stability of the result. Second derivative of the fitting expression gives the cylinder acceleration (Fig. 5).

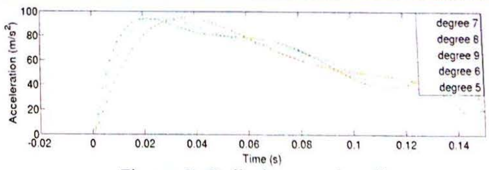

Figure 5. Cylinder acceleration

Finally, it was found that steel wire mesh fulfills the recommendation of a minimum deflection of 200 mm but with a deceleration of 30 g, too much for a human body[2]. Relatively safe values of acceleration were obtained for the textile thread net, but with deflections between 2.5 and 3.5 times higher than the minimum values required by European Code [3].

References

[1] Mas, D., Espinosa, J., Roig, A. B., Ferrer, B., Perez, J., Illueca, C., "Measurement of wide frecuency range structural micro-vibrations with a pocket digital camera and sub-pixel resolution" Appl. Opt. (in press).

[2] Voshell, M. "High acceleration and the human body", at http://csel.eng.ohio-state.edu/voshell/gforce.pdf last seen in 03-16-2012

[3] EN 13374:2004 "Temporary Edge Protection Systems Product Specification, test methods". CEN (2004).

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