10-2014

Timing Mark Detection on Nuclear Detonation Video

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ABSTRACT

During the 1950s and 1960s the United States conducted and filmed over 200 atmospheric nuclear tests establishing the foundations of atmospheric nuclear detonation behavior. Each explosion was documented with about 20 videos from three or four points of view. Synthesizing the videos into a 3D video will improve yield estimates and reduce error factors. The videos were captured at a nominal 2500 frames per second, but range from 2300-3100 frames per second during operation. In order to combine them into one 3D video, individual video frames need to be correlated in time with each other. When the videos were captured a timing system was used that shined light in a video every 5 milliseconds creating a small circle exposed in the frame. This paper investigates several method of extracting the timing from images in the cases when the timing marks are occluded and washed out, as well as when the films are exposed as expected. Results show an improvement over past techniques. For normal videos, occluded videos, and washed out videos, timing is detected with 99.3%, 77.3%, and 88.6% probability with a 2.6%, 11.3%, 5.9% false alarm rate, respectively.

1. INTRODUCTION

During the 1950s and 1960s, the United States conducted and filmed over 200 atmospheric nuclear tests. Recently those films are being digitized by Lawrence Livermore National Labs(LLNL) [1] allowing computer vision-aided analysis to review and revalidate the fundamental nuclear explosion models on explosions that will likely never be conducted again because of environmental concerns and prohibition treaties.

Each nuclear detonation(NUDET) was documented and recorded with videos of differing size and speed to measure different results. Some were 35mm film focused on early fireball growth that had a nominal 2500 frames/sec speed. Others were focused on the mushroom cloud and were 100 frame/sec film. To assist the analysis of the videos, a timing system was used that shined a small element of light on the film exposing a portion of the film at 5 msec intervals producing a small, circular exposure in the edge of the video frame. A critical component in reviewing the video is the detection and extraction of these timing indicators embedded in the videos. An example of a timing mark is shown in Fig. 1. These timing marks stay relatively stable, showing up every 5-15 frames in the same vertical column for a given video.

The problem is to identify images that include a timing mark. The goal is to achieve the highest rate of detection for any given situation (normal video, occluded video, washed out video) with the highest rate of detection possible and the smallest false positive rate possible. The problem would be trivial if not for the wide variation of image quality as a result of the impacts of the explosion on the film. Nearly all videos have a noticeable change in ambient light caused by the explosion. Other videos are washed out because of over exposure. Some videos have the explosion growing and overtaking the timing column creating occlusions and interfering with the clear viewing of the timing mark. This paper investigates two methods of extracting the timing from the images and measures their effectiveness.

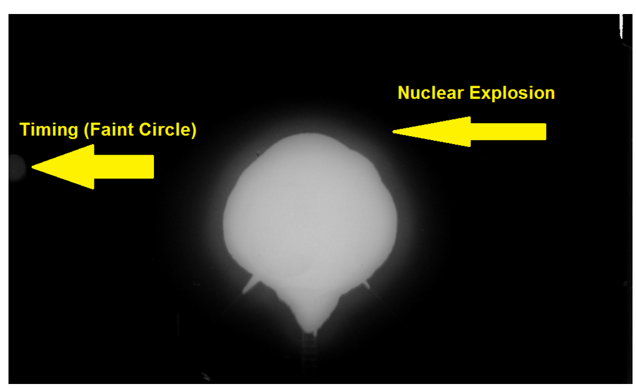

Fig. 1. An example timing mark

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2. BLOCK DIAGRAM OF NUDET TIMING DETECTOR

Fig. 2 shows the block diagram for the Nuclear Video Timing Detector. Along the left is the input of the sequence of images representing the video. Inside is a computer running the detection algorithm. Along the top are the parameters that have been discussed in Section 3. The outputs coming out of the right side of the diagram include whether a detection has occurred on a particular frame, the y-coordinate location of where that detection is in the frame, and the interval from the last successful detection.

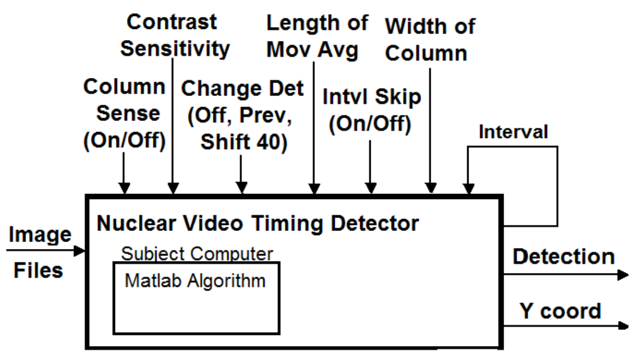

Fig. 2. NUDET Timing detector Block Diagram

3. DESCRIPTION OF APPROACHES

To accomplish the timing detection, two major approaches are used which are called Column Sum and Circle Detection. Some algorithms also used a Change Detection approach to maximize the detection rate. Some features were also added including sensing the timing column and skipping images based on predicted intervals. Each of these approaches and subapproaches will be described in detail in sections 3.1-3.4.

3.1. Column Sum

The column sum approach takes advantage of the fact that the timing marks are expected to be repeated in the same vertical column. The existence of a timing mark in the column should raise the overall pixel values of that column. The difference in the amount of additional pixel value could be used as the discriminator to distinguish frames that have timing marks from frames that do not. Timing marks are about 40-60 pixels wide and need to be reduced to one number that is used to determine if it is in the acceptable range (a timing mark without a frame), or out of the acceptable range (a timing mark in a frame). Equation (1) shows how to arrive at the overall pixel indicator value from an M row, n column subset of pixels of the timing column $\mathbf{S}$.

$$ColumnAverageLight = Mean(\sum_{m=1}^{M} \mathbf{S(m,n)}) \qquad (1)$$

One shortfall of this approach is that the timing lane needs to be determined ahead of time. Initially this was done with human intervention, however Section 3.2.1 discusses an automated approach to this. Now that we have a value to measure the overall light in a column, an approach must be defined for a threshold to determine if that value is a detection of a timing mark or not.

3.1.1. Relative vs Global Thresholds

Initially it was believed that an average of all the pixel sums could be used as a baseline for a non-detection, and a certain distance (i.e. 2σ) away from it might indicate a detection. This global threshold worked well for the first few detections, but once the explosion occurred, the explosion influenced the pixel values in the timing lane. The light from the explosion would go up and down throughout the explosion further complicating detection. A local average needed to be established that could improve detection rates.

A relative threshold would be a moving average that "forgets" information that is too far away from it. It might be an average and σ of the last 25 frames. This would allow the overall baseline to adjust quicker while still being representative of the overall average pixel sum.

3.2. Circle Detection

The second major approach for detecting the timing marks is to leverage the fact that their expected shape is a circle. A Hough transform [2] might be able to detect the circles. Sometimes the circles are faint and the image contrast can be adjusted so that the boundaries of the circle are more pronounced. Furthermore, once the region of the timing column is detected, the region that circles are searched for can be reduced from the entire image to just the timing column.

Through testing, it was discovered that the width of the timing column has an impact on the sensitivity of the circle detection. It might be thought that restricting the image to the smallest column possible would be most beneficial as to avoid false detections out of the column. Alternatively, the timing column needs to be wide enough to contain enough of the edges of the circle for the Hough transform to detect. Through testing it was determined that the sweet spot for the 40 pixel diameter timing marks was between 40 and 60.

3.2.1. Column Sensing

The column sensing feature uses a Hough transform to detect the circle of expected size and restricts the search region based on that detection rather than requiring human intervention. This feature is sensitive to false detections. If the first circle of correct size is not a timing mark, then the region is restricted incorrectly resulting in the processing missing detections in the entire video.

3.3. Change Image

Another approach that can be combined with either Circle Detection or Column Sum is to use a change image. By subtracting two images pixel by pixel, the changes are more pronounced with the hope being that they are easier to detect.

3.3.1. Change from previous image

Deriving a change image using the previous image is one change image approach. The timing marks are never in less than 5 frames away, so a change image will still preserve the timing mark. The change image will also reduce the effect that gradual ambient light has on the overall bias of pixel sum. Lastly, a change from the previous image can help reduce occlusions if they are slow moving occlusions (like a cloud of smoke). The downside is that they can potentially magnify undesired changes like scratches or imperfections in the film.

3.3.2. Change from shift image

A change image can also be derived from the same image if the image is shifted by a certain number of pixels. A change image derived from the same image would subtract out most of the ambient light. If the amount that the image is shifted is set to be large enough so the timing mark is shifted so it no longer overlaps itself it would be the maximum benefit related to detecting the maximum change. This would occur at about 40 pixels, the anticipated diameter of the timing marks.

This change approach is not as beneficial as changing from the previous image in the situation of occlusions. Shifting the image also shifts the occlusions resulting in the occlusions still existing in the change image. This is potentially helpful when an image is washed out because of overexposure. In the overexposure case, the overexposure is subtracted out, making the timing mark more pronounced because the overexposure noise is reduced.

3.4. Interval sensing and Interval skipping

Once an approach can effectively detect most of the timing marks, it is possible to speed up the processing by skipping over images that are likely not to have timing marks because they are too close to the previous timing mark. One simple example might be taking advantage of the fact that there are at least 5 frames between timing marks. If a mark is detected, then the processing can jump forward at least 5 frames before resuming. This would speed up the processing considerably because the image processing is the largest consumer of processing resources in the algorithm. It also reduces the potential for a false detection because images that are known to not have marks are not even checked.

This basic case can be adapted to increase the timing interval over time to fit the film interval better. The timings marks gradually spread out in frames as time passes. That's because the timing interval is consistent, but the film spins faster as the weight on the spool of film decreases. While the nominal speed of the film is 2500 frames per second, this effect can have effects of increasing the speed to over 3000 frames per second.

Consider an approach that calculates the previous timing interval based on the two most recent timing detections and applies this interval to the future. This allows the timing interval to adapt but it is also sensitive to the effect of missed detections and false detections. There are some cases where the interval decreases by one because of where the detections fall within the frames. For example, when detections are occurring from the middle of one frame to the middle of another the interval might be eight. But if the detection occurs late in the first frame and early in the later frame, that same interval would be seven frames apart. So to be conservative, the interval should be reduced by one to make certain detections are not skipped over.

Even with this correction, a missed detection would be catastrophic. If a detection were missed that would mean that the interval would double. The result of a doubled interval would skip over every other timing mark. Successive missed timing marks would increase the timing interval further compounding the problem. Fortunately, the spreading out of timing marks is gradual, and this can be used to counteract this. Intervals should never double and if they do, it can be assumed that a detection was missed and the interval reduced appropriately.

3.5. Combining approaches

It is intuitive that combining some approaches would be beneficial when the approaches dovetail, while other approaches do not combine well. Interval skipping would not work well with an approach that is only detecting about 50% of timing marks. However, interval skipping may work very well in reducing false positives on a detection scheme that is already detecting over 90% of timing marks. It is also apparent, that if change images are used, only one of the change image approaches can be used, not both of them.

The two major approaches (column sum and circle detect) were tried as $\mathbf{AND}$ combinations and $\mathbf{OR}$ in attempt to create one superior model. While the $\mathbf{AND}$ case had less false detections, it was at the expense of missing good detections. The $\mathbf{OR}$ case was similar, except while it maximized good detections, it also increased false detections.

Table 1. Workload of videos

Type	**Videos**
Normal	Wasp Prime videos 2, 3, 4, 6, 9, 10, 17, 18
Occluded	Tesla videos 6, 7, 9
Washed Out	Wasp Prime video 12

Table 2. Combinations of approaches used

Alg	Column Sum				Circle Detect			
	Gbl Avg	Mov Avg	Chg Prev	Chg Shift 40	Col Sense	No Col Sense	Chg Prev	Intvl Skip
1	X							
2	X		X					
3		25	X					
4		25		X				
5		15		X				
6		15		X	OR			
7		15		X	AND			
8						X		
9					60			
10					60		X	
11					40		X	X
12					60			X

4. TESTING AND RESULTS

The NUDET films come from the Wasp Prime and Tesla nuclear detonations recorded and digitized by LLNL [1]. They were split into three groups (see Table 1) to cover the cases of 1) videos with occlusions, 2) videos that are washed out, and 3) videos that do not have occlusions or are washed out (i.e. normal).

Overall, twelve different combinations of approaches were tested with parameter tuning. These are listed in Table 2. Preliminary testing was accomplished on a subset of the data to determine the best parameters for the width of the column and the best length of moving average to use with a relative threshold. Moving average lengths were tested between 10 and 40 with the best length of moving average found to be 15. This makes sense because most of the videos have a largest interval of about 15. With a moving average equal to that, there is a relative low in the average pixel value right about the point in time where a detection is about to occur making it slightly more likely to detect the change in pixel values. The column width generally performed best when the width of the column was 60. The exception was with the occlusion algorithm number 11 that performed best with the column width set at 40.

The approach of only circle detect (Alg. 8) were the results of a previous smaller scale study on the same topic [3]. It is shown with the other top performing algorithms for each type of video in Table 3 with the best overall values listed in boldface. Referring to the table, Algorithm 8 is improved on normal cases with Algorithm 12 by only 0.1% in the Probability of detection, but improves the probability that a detection is real (correct, not false) by 26.1%. Algorithm 11 improves over algorithm 8 in the occlusion case by increasing the probability of a real detection by 78.8% although the probability of detection decreases by 1.5%. For the washed out case, algorithm 6 is similar to algorithm 8 by improving detection probability by 0.9%, however the probability that a detection is real decreases by 1.7%.

Table 3. Combinations of approaches used

Alg.	Video Type					
	Normal		Occlusion		Washed Out	
	P_D	P_{Real}	P_D	P_{Real}	P_D	P_{Real}
5	95.3%	97.9%	59.1%	41.7%	**88.6%**	**94.1%**
8	99.2%	71.3%	78.8%	9.9%	87.7%	95.8%
11	34.6%	81.2%	**77.3%**	**88.7%**	44.9%	99.1%
12	**99.3%**	**97.4%**	60.6%	38.6%	19.5%	97.9%

Table 4. Execution time of algorithms

	Algorithm Num			
	5	8	11	12
Avg Time/video (sec)	65	320	118	122
Avg Time/detection (sec)	0.39	1.76	0.71	0.73

Table 4 shows the time performance results of the algorithm. Generally speaking, the circle detection algorithms take longer than the column sum algorithms because the Hough transform is more computing intensive. The fact that the column sum takes 1/5th the amount of time than the original circle detection algorithm is significant. The reason why the other circle detection algorithms run faster than the original is attributed to the interval skipping.

5. CONCLUSIONS AND FUTURE WORK

This paper explored several approaches to detecting timing marks in nuclear detection video. We determined that the previous best method of basic circle detection can be improved upon in normal occluded videos by adding interval skipping which reduces the false positive rate by 26.1% and reduces the processing time by a factor of 2.5. When detection in occluded videos is required, an approach that includes both a change detection from the previous image and interval skipping reduces the false positive rate by 78.8% and cuts processing time by a factor of 2.5. When detection in washed out or overexposed videos is required, the processing time can be cut significantly with similar detection results.

Future work in this area includes incorporating the algorithms demonstrated into a graphical user interface where it would be more accessible to nuclear physicists. Also, analysis can be done on streak films (continuous film) rather than shuttered frames to detect timing on those type of films. Improvements might also be possible in the column sum approach that improves on taking the average of the sum of the column with better models.

6. REFERENCES

[1] Spriggs Gregory D., "Film Scanning Project," Lawrence Livermore National Laboratory, Aug 2011.

[2] R.O. Duda and P.E. Hart, "Use of the hough transformation to detect lines and curves in pictures," Tech. Rep. 36, AI Center, SRI International, 333 Ravenswood Ave, Menlo Park, CA 94025, Apr 1971, SRI Project 8259 Comm. ACM, Vol 15, No. 1.

[3] Joseph McKinney, "Nuclear test filmstiming marks," Air Force Institute of Technology, Oct 2013.