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Extraction of Metric Information from Video Sequences of an Unsuccessfully Controlled Chimneys Demolition

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Abstract

Spremberg Germany, 10th July 1999: in the power plant Schwarze Pumpe, three old chimneys are going to be blown up. The first two fell in the prevented directions; the third ones had to fall onto the other two, but something went wrong and it fell onto the nearby building damaging it extremely.
The scene was recorded on videotape by the demolition company and some TV networks. To inquire the responsibilities and causes of the accident, our institute was asked to analyze the video sequences and extract metric information. Moreover, the demolition of three other chimneys on the same plant and with the same dispositions was planned for the month following the accident. It was therefore essential not to repeat the same errors. The presumed cause was that the base of the third chimney was covered with protections to prevent the new-built adjacent pipelines from flying particles; when the explosive charge blew up, an overpressure was generated inside the chimney causing the complete destruction of the base; the effect was an uncontrolled falling. To prove this presumption, the following open questions had to be answered: (1) how long was the time interval between the detonation and the falling? (2) did the chimney fall first vertically down and then sideways? (3) if yes, how many meters did it fall vertically?
The data in our posses to answer these questions were analog videotapes with different sequences of the scene and the detailed plans of the power plant and chimneys. The quality of the stored sequences was very bad and only few sequences were useful for metric purposes. In addition most of the cameras were shaking, panning, tilting or zooming. The close field sequence acquired by a fix control camera of the demolition company was used to answer the question (1). Using some dimensions extracted from the power plant plan, we could apply a simple image-to-space transformation to obtain the requested metric information. The results were obviously not very accurate (~0.2 meters) but sufficient to prove the correctness of the presumed causes. In fact, from three different sequences, it resulted that the chimneys fell firstly vertically down of about 3.4 meters and then sideways.
The works done by our institute was very useful for the demolition company; the controlled blowing up of the following three chimneys was in fact successfully conducted without any damage.

Keywords: Tracking, Uncalibrated Video Sequence

1 Introduction

During the demolition of three old chimneys on the area of the power plant Schwarze Pumpe on the 10th of July 1999 one of the chimneys fell in a wrong direction causing damages on the surrounding buildings (see figure 1).

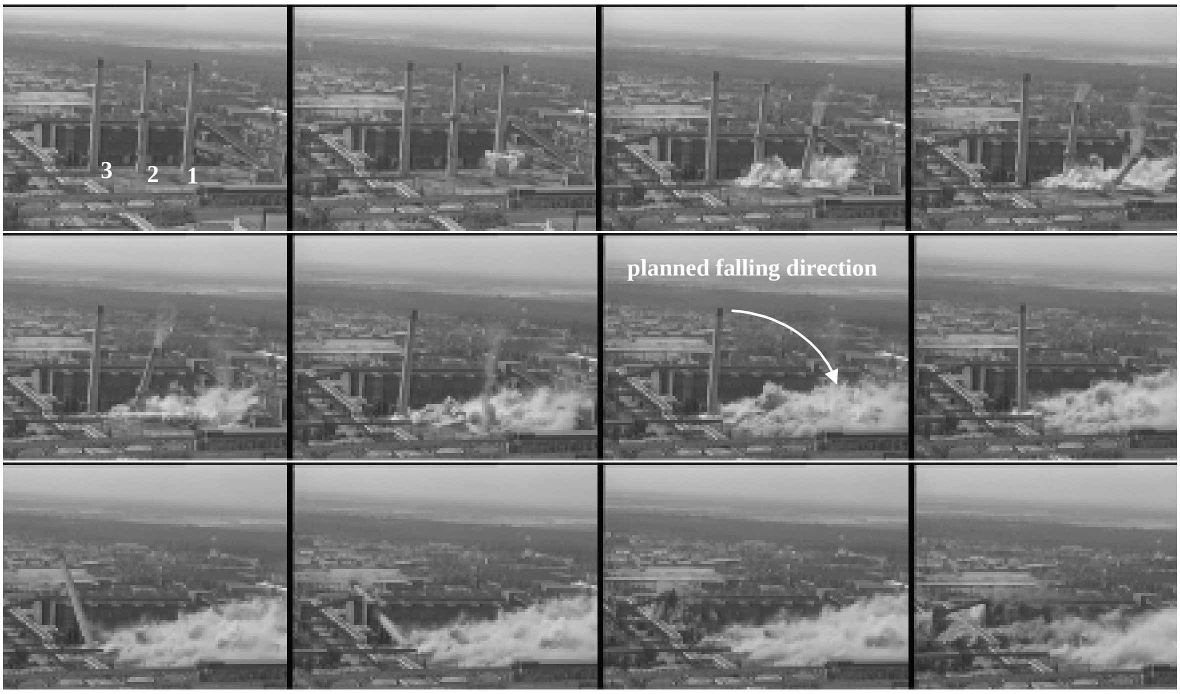

Fig. 1: Unsuccessfully controlled chimney demolition, Spremberg Germany, 10th July 1999; the third chimney was planned to fall to the right direction, but fell instead over the building.

To clarify the cause of the accident, our institute was asked to analyze video sequences of the demolition process acquired by several TV networks and the demolition company. Additional data sources were the construction plans and some information from experts about the detonation process. Moreover, the executing demolition company needed our results very quickly, because three further chimneys constructed in the same way had to be demolished on the power plant area.
The planned manner to demolish the three chimneys was the following:

1. because of the limited space around the chimneys two of them had to be shortened in a first step by demolishing the lower part of the smokestack before felling in a planned direction
2. the third chimney could then be overthrown in its full length falling onto the two chimneys already demolished

According to this plan, the third blasting can be considered the less problematic one. However it was exactly this chimney which fell uncontrolled. In fact the explosive charge, placed at the base of the chimney, should have destroyed a sector of the wall that lay in the planned falling direction (see figure 2). The reason of the accident could be found in the insulation of sand and mats that was placed at the lower foundation in order to protect the surrounding installations and buildings from exploding parts. In fact, the demolition experts presumed that the layer of insulation was too thick; so that the explosive charge was not powerful enough to destroy only the scheduled piece of the wall, but instead caused a rebound effect which demolished also the opposite area of the chimney wall or even removed the complete foundation wall. Under this assumption the chimney would have dropped in vertical direction first and then after standing for a short time on the irregular lower part of the foundation wall, would have toppled in an accidental direction.

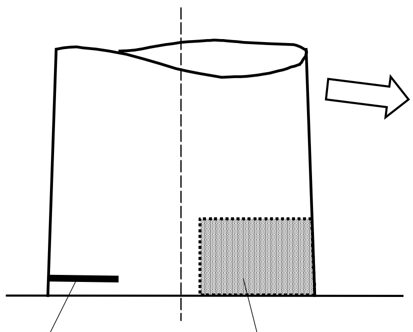

Fig. 2: The explosive charge was placed at the base of the chimney

The planned falling process was just a simple toppling movement and would have not shown up a vertical dropping immediately after the explosion. The image sequences served to clarify the question whatever this dropping took place and, if yes, how many meters it dropped vertically.
Due to the fact that the image sequences were acquired with non-metric zoom cameras with unknown camera parameters, several suppositions and simplifications had to be made. Nevertheless, it was possible to extract spatial information from the available data.
The paper shows the image processing, the image based extraction of metric information and the conclusions which could be derived by the yielded results.

2 Available data

To validate the hypothesis about the unsuccessfully controlled demolition of the third chimney, the following data were available:

- 7 video sequences recorded on VHS tape (Figure 3)
- ground plans of the power plant
- detailed plans of the 3 chimneys

As can be seen in figure 3, the 7 video sequences were acquired from different positions and had different characteristics (table of figure 3). Only two sequences (seq. 3 and 5) have a fix camera, which simplifies the extraction of metric information. In the other sequences, where the camera moves, we have two cases: sequences where the camera has only a pan movement and sequences where the camera is also performing zooming. Two sequences (seq. 6 and 7) present so large movements that no reliable metric information can be extracted.
The quality of the videos has to be considered too. The sequences were indeed recorded on analog VHS tape as 2nd, 3rd or even more copies, therefore the quality was in general very low and in two cases (seq. 4 and 6) it was too bad to extract metric information. After the analysis of the video sequences, we concluded that only the first three sequences were useful for our purposes.
Before starting the analysis process, the video sequences had to be digitized and transformed to image sequences that could be processed on computer. The analog videotapes were firstly digitized to miniDV tape. The advantages of the DV (digital video) format are the simplified and lossless conversion of single frames in common image formats (e.g. bmp) and the on-tape integrated timecode, which allows a time read for each frame. This functionality was essential to answer the questions regarding the time development during the chimney demolition.

sequence	1	2	3	4	5	6	7
fix camera			yes		yes		
panning	yes	yes		yes		strong	strong
zooming	yes					strong	
quality	good	bad	good	very bad	bad	very bad	bad

Fig. 3: Shots of the 7 video sequences and their characteristics (table)

We extracted from the detailed plans the dimensions of the third chimney (height and the diameter of the base) that were used to determine an image-to-space transformation, which could be applied to the measurements performed on the images.

3 Methods to extract information from the video sequences

As explained in the former paragraph, we decided to use three image sequences. Theoretically, the application of multi-image photogrammetric techniques would offer the possibility to extract object space metric information, but, due to time restriction (we had to deliver the requested information very quickly), we decided to use the three image sequences separately. However the achieved results were indeed completely sufficient and satisfactory for the demolition company.
Three specific questions could be answered after our analysis of the video sequences:

1. how did the third chimney fall?
2. how many meters did it fall vertically down?
3. how many seconds after the detonation did it begin to fall?

The following paragraphs depict in detail the processing steps to extract the required information from the three video sequences.

3.1 Trajectory of the third chimney

The most relevant question was the first one: how did the third chimney fall? In order to answer the question, the full trajectory of the chimney had to be extracted from the three video sequences. A least squares matching based tracking algorithm was used for this

purpose. This tracking process could track natural points without using special markers, which was an indispensable requirement for this particular application. For the detailed explanation of the algorithm, we redirect the reader to the given reference [1].
In two sequences the camera wasn't fix during the acquisition. For both cases, a transformation of the images was therefore required to extract information about the trajectory of the third falling chimney. The result of this transformation had to be an image sequence looking like as if it had been recorded with a fix camera. The transformed sequence could then be used both for the extraction of metric information as well as for a simple visualization of the event, which was necessary to understand the real movement of the chimney.
Since the panning and zooming effects in these sequences were not so strong and since the camera was, in both cases, placed far away from the chimneys, we could assume that a 2-D similarity transformation was sufficient for our purposes. Two fix points were used to transform each image of the sequences.
For the first sequence, two points on the ground, one at the top of a antenna and three points on the chimneys (see figure 4) were tracked with the least squares matching based tracking algorithm. One point on the ground and the point at the top of the antenna were used as fix points for the 2-D similarity transformation. The transformation was applied to the three tracked points on the chimney and to the entire image sequence, which could then be interpreted in a clearer way without the camera movement.
To extract metric information, a linear image-to-space transformation from pixel to meter was assumed to be sufficient. To establish the linear transformation, the exact height of the chimney provided by the detailed plan was compared to the same distance measured in the image. Due to the combination of tracking precision, image quality and measurement errors on the image, the resulting precision could be assumed to be in the order of 2 pixels.
Figure 4 shows the three points tracked on the chimney (pt4-pt6), the three tracked fix points (pt1-pt3) and the information used to establish the pixel-to-meter transformation. For the measurements in the image space, 1 pixel corresponded to 0.28 meters in the object space with a precision of 0.5 meters.

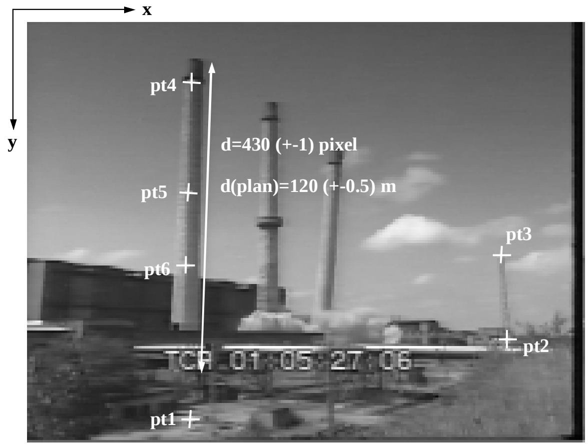

Fig. 4: Sequence 1, pt1-pt3 tracked fix points, pt4-pt6 points tracked on the chimney

In figure 5, the trajectories of the three tracked points on the chimney are shown in the transformed coordinate system (fix camera system). The graph plots show clearly that the third chimney first fell vertically and at the same time a little to the right (1-2), stayed in balance for some time (2) and then fell to the wrong direction (2-3).

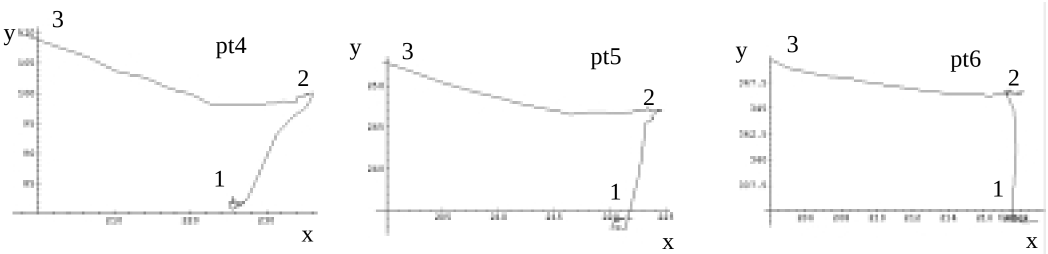

Fig. 5: Transformed pixel coordinates of the 3 points tracked on the chimney

To validate the results, the same process was performed on the other two image sequences. Especially the third one was very useful because the camera was fix and closer to the chimneys. For this case it wasn't necessary to apply a 2-D similarity transformation. Figure 6 shows the four points tracked on the chimney (pt1-pt4) and the distances used to establish the image-to-space transformation. The diameter of the base had to be used because the chimney wasn't imaged entirely. In this case, 1 pixel in the image corresponded to 0.17 meters in the object space and the precision of the measurements 0.3 meters.

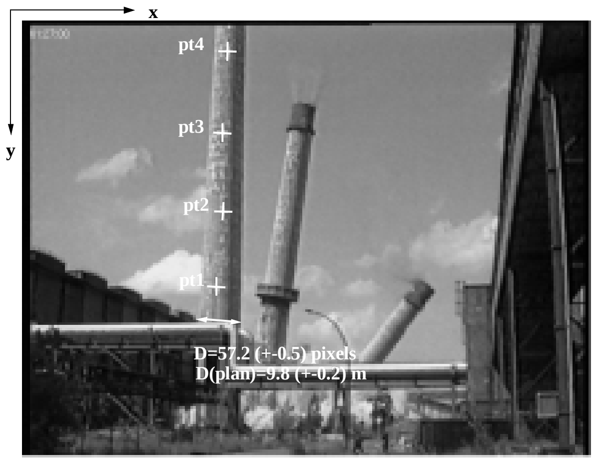

Fig. 6: Sequence 3, pt1-pt4 points tracked on the chimney

This sequence was used as primary source to extract the metric information because the quality of the images was higher and the view of the third chimney closer. A higher accuracy of the measurements could therefore be achieved. However, the side view of the chimney limited the extraction of information to the vertical dropping. After the analysis of the tracking process, it could be determined that the third chimney dropped vertically 3.4 (± 0.2) meters.

3.2 Time analysis

In order to clarify how long was the time interval between the detonation and the falling of the third chimney, we used the second and third sequences. Analyzing the single frames, it was possible to establish the exact moment (with 1/25 seconds precision) when the charge was lighted (t0 point). In the figure 7, this moment can be clearly recognized as black smoke appearing at the side of the base.

On the following frame, an interesting event could be observed: white dust appeared at the lateral side of the base of the chimney. This fact was also an element to prove the presumption that the base was completely removed by the overpressure generated by the explosion.

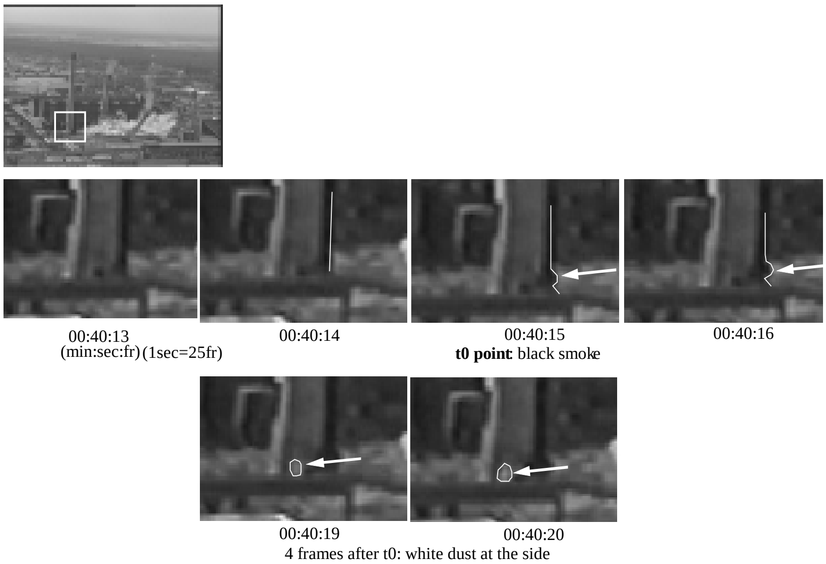

Fig. 7: Charge lightning time (t0 point) and white dust at the side of the base of the chimney

3.3 Results

From the tracking processes performed on the three image sequences and the time analysis, we could draw the following results:

- the third chimney dropped first vertically down and at the same time a little to the planned direction, stayed in balance for some time and then fell to the wrong direction
- it dropped 3.4 m (± 0.2m) vertically
- it began to fall 1.72 seconds (43 frames) after the detonation
- it reached the ground 2.92 seconds (73 frames) after the detonation

These were the answers to the open questions posed by the demolition company. In this paper we don't present the results drawn after the analysis of our extracted metric information, but it must be stressed that the controlled demolition of three further chimneys on the power plant was indeed successfully conducted without any damage. We can therefore affirm that our goals were entirely achieved.

4 Conclusions

In this paper we have presented methods to extract metric information from uncalibrated video sequences with poor quality. In this special case an unsuccessfully controlled chimney demolition had to be analyzed to derive additional information for the validation of the hypothesis about the causes of the accident. Our work was very useful for the demolition company which planned to demolish three further chimneys on the same power plant.
We can therefore conclude that photogrammetric techniques can be used in manifold cases and that matching and tracking algorithms can be successfully applied in non-metric image sequences with sufficient accurate results.

References

1. D'Apuzzo, N. et al., 2000: *Least Squares Matching Tracking Algorithm for Human Body Modeling*. Int. Archives of Photogrammetry and Remote Sensing, Amsterdam, The Netherlands, 2000, Vol. 33, Part B5/1, pp. 164-171