INVESTIGATIVE IMAGE PROCESSING: THE WACO INVESTIGATION

Lena Klasén

Division of Lasersystems, Department of Sensor Technology
Defence Research Agency, FOI, Linköping, Sweden
Orlunda Agro & It, Skänninge, Sweden
lena@foi.se, lena@orlunda.e.se

ABSTRACT

This paper presents some of the the image processing techniques that were applied to seek an answer to the question whether agents of the Federal Bureau of Investigation (FBI) were shooting at Branch Davidian sect members in the tragic event in Waco, Texas, U.S., 1993.

The "flashes" seen on one of the surveillance videotapes were, by several experts, concluded to be gunfire. However, there were many reasons to question the correctness of that conclusion, such as the fact that some of the flashes appeared on a regular basis. The hypothesis for this work was that the flashes instead were caused by specular reflections and the technical approach was to analyze and compare the flashes spatial and temporal appearance. The result showed that the flashes were mainly caused by specular solar reflections and thereby they could not form evidence of gunfire.

Further, the result highlights the importance of considering the characteristics of the imaging system within investigations that utilizes images as information source. This is to separate real data from other phenomena (such as solar reflections), distortions and artifacts in a correct manner.

1. INTRODUCTION

In 1993 a confrontation between federal law enforcement officials and Branch Davidians at the Mt. Carmel complex, Waco, Texas, U.S., resulted in a 51 days long siege. The siege ended in a tragedy and about 82 sect members died. In September 1999, the Attorney General of the United States appointed former United States Senator John C. Danforth to investigate the events at the Branch Davidian complex on April 19, 1993, which was the last day of the siege. The Office of Special Counsel, St. Louis, Missouri, U.S., was established shortly afterwards.

As one major part of the investigation, the Office of Special Counsel retained several experts to perform different investigations. Among those were three Swedish experts and the author's task was to perform image analysis of the videotapes recorded by a surveillance aircraft on April 19, 1993. One of the four major questions the Office of Special Counsel was established to clarify, was whether agents of the United States directed gunfire against the Branch Davidian complex. The task for this investigation was to provide a scientific opinion that clarified the cause of the questioned events, denoted "flashes", that can be seen on one of the surveillance videotapes. This paper is based on the final report [1] and presents some of the techniques used when analyzing these flashes.

Special thanks to professor Haibo Li, Digital Media Lab., Department of Applied Physics and Electronics, Umeå University for his contribution and support.

1.1. FLIR videotapes

A FBI Nightstalker surveillance aircraft recorded several videotapes of the Branch Davidian complex during the standoff. The FBI Nightstalker that was used on April 19, 1993, was equipped with a Sea Owl long-range infrared (IR) imaging system. This imaging system had as its core a SPRITE-TED IR detector. Thermal images from the FBI Nightstalker FLIR were simultaneously recorded onto VHS videotapes on April 19, 1993. Seven recordings formed the major source data for the investigation. However, two of the FLIR videotapes turned out to be copies. The remaining five videotapes were concluded to be original recordings. The Branch Davidian complex appears on the surveillance videotapes from a variety of viewing angles and distances as the FBI Nightstalker circled above the complex during surveillance. The thermal images are based on temperature difference of naturally emitted light, which depends on the objects' energy exchange with the environment, self-heating, emissivity differences or reflections of other sources. Conventional photos were also taken on April 19, 1993, from both aerial and ground views. Media covering the standoff also made video recordings of the events from morning to afternoon. Figure 1 is an image from the FLIR videotape where the flashes appears, a duplicate aerial color photo and a simplistic three-dimensional (3D) model of the complex.

1.2. Hypothesis

Quite immediately after an initial and substantial visual review of the videotapes, it was clear that the flashes appeared on a regular basis and that the appearance of several of the flashes could actually be predicted. For example, some flashes on the single-story roof of the Branch Davidian complex occurred approximately every two minutes, figure 2. These flashes also occurred when the same part of the complex was in the FLIR sensor field of view and the FBI Nightstalker was in a similar position relative to the complex. Further, the flashes were short in duration time and only occurred in a few fields, but with varying duration time. The main hypothesis was that the flashes were caused by *specular solar reflection.* Other possible factors that was investigates were *similar kind of reflection*, *sensor artefact or distortion* or *other cause*.

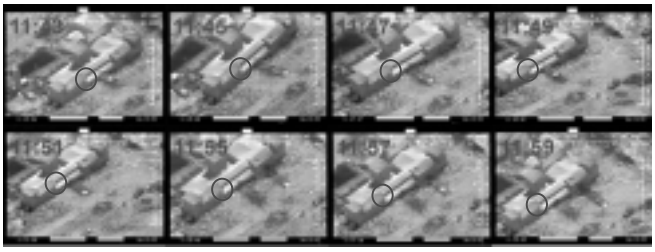

Fig. 2. Regular appearance of flashes from the same location at 11:43:36, 11:45:20, 11:49:02, 11:51:00, 11:55:46, 11:57:26 and 11:59:03. At 11:47:07 the roof was partially clouded and a flash was only faintly visible. At 11:53 no reflection was detected. At 12:01 and 12:03 the roof was only partially seen. At 12:05:15 a flash appeared again from this same part of the roof.

2. TECHNICAL APPROACH

To test the reflection hypotheses, the technical approach was to reconstruct the spatial position of the sun, aircraft/sensor and complex. Thereafter, the relation between the flashes reconstructed spatial data and temporal variations were analyzed.

2.1. Video Authentication

First of all, is was necessary to determine whether the recordings were authentic or if they had been technically altered or tampered with. Although this seems obvious, surprisingly often this phase is neglected in investigations where the source data is some kind of image media. The electrical signals stored on the April 19, 1993, the FLIR recordings were successfully used to authenticate the videotapes.

2.2. Imaging Technologies

As "*nothing is as good as the original*" regarding imaging technologies in forensic applications, analyzing these low quality video recordings required specific methods to avoid further degradation. Overviews on methods for analyzing evidential images are found in [2] and [3]. Variations in image quality can originate, for example, from the varying performance of the equipment used during the investigation such as video recorders, video systems, equipment used to digitize and display the video, computer frame grabbers, image storage format, monitors, projectors and computer screens. Each of these systems will introduce some kind of degradation to the image.

Fig. 1. A FLIR image (left), a duplicate photo (middle) and a simplistic 3D-reconstruction model of the Branch Davidian complex based on GPS stake coordinates (right), distances in meter [m].

It was also necessary to obtain as much knowledge as possible, of all imaging phases and the behavior of the system components within the FBI Nightstalker imaging system. The reason for this is to be aware of how objects in the real world are represented and where, and how, the information from the real world might be degraded by the systems components. Imaging technologies are normally designed to achieve an optimal image quality, but features like noise patterns and deviations in signal-levels are often key issues in forensic investigations. This turned out to be the case for this investigations.

2.3. Choice of Analytical methods

The next step was to analyze the FLIR images in depth by first analyzing the FLIR sensing system and in particular the detector elements. Some typical fixed pattern noise induced by the scanning mechanisms, among other factors, was immediately detected and recognized from the FLIR images. The results from this examination provided valuable input to the digitizing process, noise reduction phase and for estimating the error in the reconstructed data. The findings of the complementary systems examination were also quite important to explain why small objects could not be trusted to be correctly represented in the thermal images from the FLIR system. The main part was, however, the 3D recon-

struction. Beside the technical analysis, a literature review was conducted.

3. 3D RECONSTRUCTION OF REFLECTION GEOMETRY

Although several flashes appeared on a regular and predictable basis, some were more intermittent. In the case of solar specular reflections, the variation in FBI Nightstalker's flight path gives one logical reason for the flashes intermittent appearance. The appearance of the flashes then becomes closely related to variations in the sensor's spatial position. Moreover, the duration-time of the flashes then becomes closely related to the instantaneous speed of the FBI Nightstalker. To further investigate these assumptions a 3D model was needed, see figures 1 and 3. One of the problems encountered when reconstructing 3D information from the FLIR videotape was the lack of detailed platform data. Fortunately, the SPRITE-TED sensor is well described in research literature. Additional information required, were reliable measurements of the complex and the weather conditions for April 19, 1993, which was available to the investigation. The parameters incorporated in the model were the

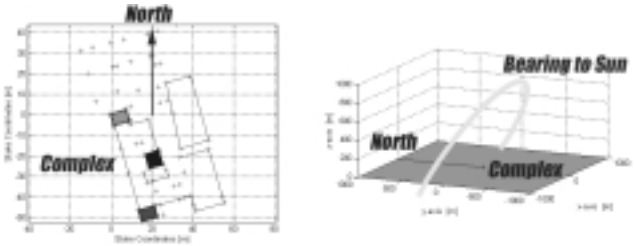

Fig. 3. A simplistic 3D model of the complex (left), [m], seen from above, which has been oriented towards north and incorporates the bearing to the sun (right).

aircraft's position relative the complex, the *aircraft ground speed* and *wind strength, heading and variations at altitude*. The *time* was set within the model based on the time information in the FLIR images and on the audio channel and the reliable frame rate of the video standard.

By reconstructing the FLIR sensor position for three two-minute sequences, it was seen that the aircraft ground speed (GS) varied for the turns, see figure 4. This provided verification that the FBI Nightstalker circular movements had varied both in altitude and distance relative to the complex. The strong wind probably caused the FBI Nightstalker to drift off from an ideal path and thereby caused the variation in positions of the aircraft relative to the Branch Davidian complex. The variations in aircraft altitude are realistic altitude variations in such weather conditions. The FBI

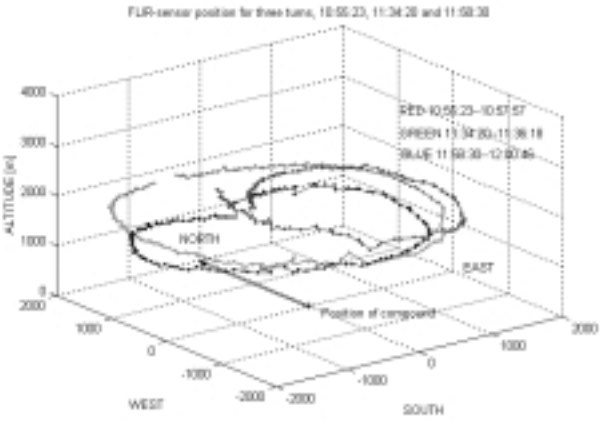

Fig. 4. FBI Nightstalker circular movements relative to the complex at 10:55:23 –10:57:57 (dark grey), 11:34:20 – 11:36:18 (light grey) and 11:58:30 – 12:00:46 (black).

Nightstalker ground speed was calculated from the reconstructed data and varied between $(120-200)\pm 20$ knots GS. From reconstructing the FBI Nightstalker's flight path it was concluded that the position, altitude and ground speed of the aircraft relative to the Branch Davidian complex have varied significantly. This supported the solar specular reflection hypothesis and that the variation in FBI Nightstalker's flight path contributed to creating the flashes intermittent appearance.

A 3D reflection model, based on the physical laws of reflection, formed the basis for comparison of the flash geometry. One simple way to model light reflection components, widely used to create lighting effects in virtual images is seen in equations 1 and 2. In this simplistic reflection model of one light reflection, the intensity I, of a pixel at column x, row y and time t summarizes the reflection components of a light source; ambient, diffuse and specular reflection components.

$$I(x,y,t) = I_{ambient}(x,y,t) + [I_{diffuse}(x,y,t) + I_{specular}(x,y,t)] \quad (1)$$

$$I(x,y,t) = I_a(x,y,t)K_a + [I_i(x,y,t) * K_d(L \bullet n) + I_i(x,y,t)K_s cos^g \phi] \quad (2)$$

I_i is the intensity of the light source. K_a and K_d are surface reflection component. K_s is a color-independent specular coefficient. The angle ϕ represents the observer **V** offset from the reflection ray **R**. **L** is the direction to the light source, **n** the surface normal and **L** • **n** denotes the scalar product. g is the materials reflection component and the factor $cos^g \phi$ describes how the observation angle affects the intensity of the specular reflection component. The angle θ

represents the angle of the reflection, which depends on the substance of the surface among other factors. This reflection model defines the intensity of image pixel values for an illuminated object as a function of the position of the camera and the intensity contributions from ambient, diffuse and specular reflections, see figure 5. If the ambient and diffuse components makes little contributions and if the factor g is high, which are assumed for the flashes, the model can be further simplified $I(x, y, z,) = c_1 + c_2 \cos^g \Phi$. The direction of such a specular reflection ray is more or less unique and determined by the orientation and properties of the reflective surface. For the reconstruction Realviz MatchMover was used, which successfully recovers the camera position from a set of images. In parallel, software was developed based on the perspective projection model. The results from the two methods were, however, very similar. The relation between the duration of a specular solar reflection and the speed and position of the FBI Nightstalker was also analyzed, utilizing the reconstructed data. The results clearly showed that the majority, but not all, of the flashes reconstructed geometry aligned very well to the model of specular solar reflection. Specular solar reflections are unlikely to appear in the far IR spectral range, but the conditions were a bit special that day as there were lots of debris and broken glass from the demolished building. In all probability, the air was filled with "reflection cones" and the aircraft sometimes flew through such a solar specular reflection and sometimes flew beside the same reflection.

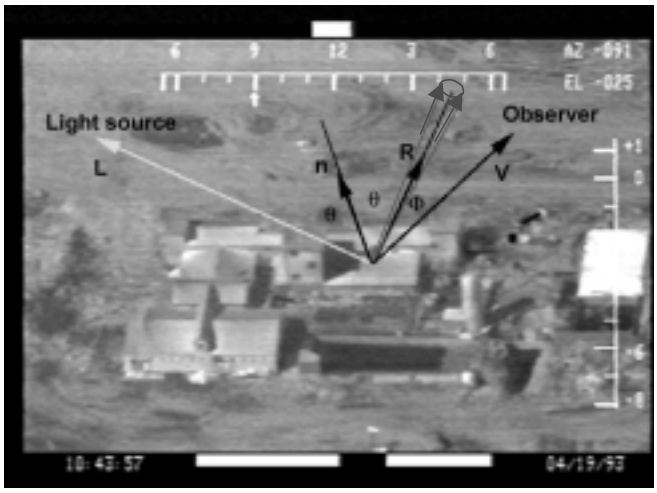

Fig. 5. An illustration of the geometrical reflection model.

4. DISCUSSION

The main focus of this part of the investigation was to reconstruct the flash geometry, with special reference to the problem of representing small objects, considering the specific imperfections of the FBI Nightstalker FLIR system. The image analysis confirmed that the analyzed flashes were specular solar reflections or similar kinds of heat reflections from single or multiple objects. However, this conclusions were based on several additional parts of the investigation. In the case of alleged gunfire, it is reasonable to assume that persons would have to be present to fire the subject weapons. After a careful analysis of the areas surrounding the flashes and careful tracking of movements of any type of objects near the flashes, it was concluded that no human type movement or activity occurred near any of the flashes. Moreover, the FLIR- and video recording system induced image distortions, which affected several of the flashes seen on the FLIR images. The flashes elongated shape is an example of this. It was concluded that the FLIR system could distort the image representation of small objects such as the flashes. The results from this investigation were also confirmed by conducting an experiment and also by analyzing the video recordings from a flight trail conducted on March 18, 2000, Fort Hood, Texas, U.S. The flashes from the Waco videotapes were not similar to the gunfire seen on the Fort Hood videotapes, but similar to the flashes caused by solar specular reflections on the Fort Hood videotapes. Due to the many contradictory conclusions by experts concerning the cause of the flashes, reports, statements, videotapes by Branch Davidian and government experts and related literature were reviewed. This review supported the results from this investigation, as the gunfire hypothesis was found to be based on several wrongful assumptions. For example, it was based on wrongful assumptions regarding specular reflection geometry, suffered from neglecting the FLIR sensor characteristics and scanning mechanism and assumed a constant airspeed and distance to the complex.

Finally, is was concluded that the flashes seen on the FLIR videotape can not form evidence of gunfire.

5. REFERENCES

[1] L. Klasén and S. Madsen, "Waco investigation: Image analysis and video authentication," in *Final Report to the Deputy Attorney General Concerning the 1993 Confrontation at the Mt. Carmel Complex, Waco, Texas*, J. Danforth, Ed. 2000, Office of Special Counsel, St. Louis, USA, Appendix H.

[2] L. Klasén, "Forensic image analysis," in *Proceeding of the 12th Interpol Forensic Science Symposium*, R. S. Frank and H. W. Peel, Eds., 1999, pp. 261–302.

[3] L. Klasén, "Digital imaging and photography-an overview," in *Encyclopedia on Forensic Science*, J. Siegel and et. al., Eds. 2000, pp. 1254–1264, Academic Press, Vol. 3.