Modelling a crime scene in 3D and adding thermal information

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ABSTRACT

Once a crime has been perpetrated, forensic traces will only be persevered in the crime scene for a limited time frame. It is therefore necessary to record a crime scene meticulously. Usually, photographs and/or videos are taken at the scene to document it, so that later on one will know the exact place of an object. Another possibility is to construct a three dimensional (3D) model of the crime scene. A 3D model has the advantage that you can change the perspective and view the scene from all directions. We use a stereo camera to record the crime scene and use these images to construct a 3D model.

A drawback of conventional (color) cameras is that they only capture features that belong to the visible part of electromagnetic spectrum. Interesting traces with strong signatures in other parts of the spectrum could be overlooked. For example; has a lamp or computer screen been turned on previously, is there some fluid on the carpet? Such traces can be observed with an infrared (IR) camera that captures images in the IR part of the spectrum.

However, it is not well understood if these traces stay visible for a sufficient amount time. Therefore, a first set of experiments was conducted to gain some insight in the visibility degradation of different IR traces over time. The results are discussed in this paper. Furthermore, it will be shown how adding thermal information to the 3D model can improve crime scene understanding.

Keywords: Infrared, 3D modeling, forensics, crime scene, stains

1. INTRODUCTION

Forensic investigators use different techniques to record a crime scene. Standard photographs or videos are often used for recording. But it is also possible to make a three dimensional (3D) model of a crime scene. Several techniques are available to do this. A laser scan is one of the options. Another option is to use a stereo camera and reconstruct a 3D model using the stereo photographs.[1]

All these techniques make recordings in the visual part of the electromagnetic spectrum. However, not everything can be seen in this region. It could be the case that traces are missed, just because they are not visible in the region that is used. Has a lamp or computer screen been on? Is there some kind of fluid on the carpet? Questions that are of interest to the forensic investigators and police officers. Using regular recording devices these things cannot be registered. However, using a different band in the electromagnetic spectrum, things that are invisible in the visible part of the spectrum can become visible.

We have used an infrared (IR) camera to see traces that otherwise are invisible. In this paper we present a series of experiments which we performed to determine whether the use of an IR camera at a crime scene has advantages. The purpose of these experiments was to determine whether or not additional traces could be found using an IR camera. Furthermore to determine the time span of the visibility of these traces. Identification of the traces was not the subject of this research. There are numerous techniques which can be used to identify different substances. The chemical reagents used to visualize fingerprints are one example. Another example is Raman spectroscopy[2] which can be used to identify body fluids.

Another research question was how to combine the different recordings of a crime scene. The information from the IR images alone can create some awareness, but in combination with photo / video or even a 3D model it creates a better understanding of the crime scene. Another difficulty is that IR images look different than the conventional (color) images. This makes it challenging to relate structures as seen in IR to those seen in normal photographs. We have chosen to combine the IR images with a 3D model constructed from stereo photographs.

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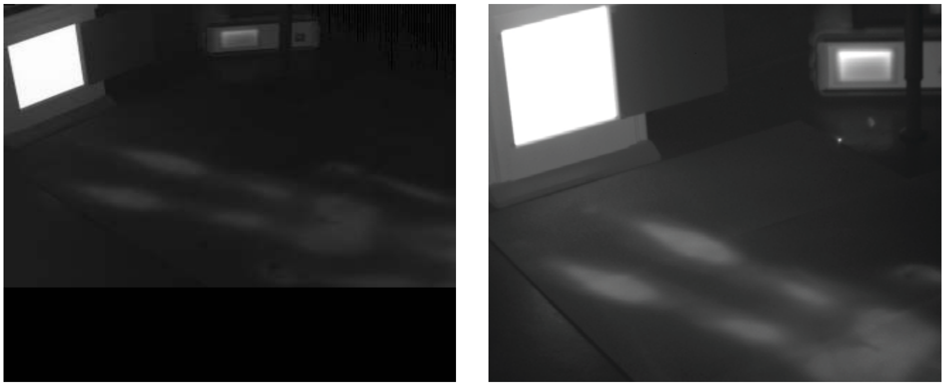


(a) (b)

Figure 1. Image of the same scene taken with different cameras. (a) Vosskühler IRC-300 camera: 8.0 - 14.0 μm, uncooled. (b) FLIR Titanium 560M camera: 1.5 - 5.1 μm, cooled.

(a) (b)

Figure 2. Photographs of a test person lying on the floor in visual (a) and infrared (b).

2. INFRARED EXPERIMENTS

It is well known that IR cameras register a temperature difference of an object and its surroundings. Usually these cameras are used to view an object / person directly. But what if one arrives later and the object / person has disappeared? Is it still possible to see traces of this object / person? Not much can be found in the literature on this topic. Due to this reason several experiments have been performed to discover how long different traces stay visible in the IR part of the spectrum.

During these experiments two types of IR cameras were used: the FLIR Titanium 560M camera,[3] and the Vosskühler IRC-300 camera.[4] The main differences between these cameras are the wave lengths at which they operate and whether they are cooled or not. The Vosskühler camera operates at wave length between 8.0 and 14.0 μm and is an uncooled camera. The FLIR Titanium camera operates in the domain of $1.5 - 5.1$ μm and is a cooled camera. Fig. 1 shows two pictures of the same scene. The picture on the left (a) is taken with the Vosskühler camera, the one on the right (b) is taken with the FLIR Titanium camera.

As can be seen from the images in Fig. 1 both cameras produce clear images. The FLIR Titanium camera has the advantage of being able to measure smaller temperature differences due to its sensitivity and bit depth. On the other hand, this camera is larger and heavier (because of the cooling) and therefore more cumbersome to use at a crime scene. In the rest of this paper all images are taken with the FLIR Titanium camera.

2.1 experiments

To gain some understanding about the time span of visibility of different traces, several experiments were performed. During the first experiment different situations have been simulated and the aim was to determine the time span of visibility in the IR part of the spectrum. The situations consisted of different objects / situations which can be found at a crime scene, like a person lying on the floor, a lamp or computer screen which was turned on, or a water stain on the carpet.

Because the first experiment showed that a water stain was visible for a longer period of time, we concentrated on the visibility of different fluids poured on floor tiles in the second experiment. The third experiment focussed on the visibility of biological traces on different background materials.

During these experiments both the Vosskühler and FLIR Titanium cameras were used. Both cameras were placed on a tripod and could be turned towards any part of the experimental setup. The room temperature and humidity were monitored during the experiments and only showed small variations.

2.1.1 Person lying on the floor

In Fig. 2 a photo of the test person lying on the floor is shown. The photo on the left (a) is taken with a regular camera (Canon EOS 450D); the photo on the right (b) is taken with the FLIR IR camera. In this photo you can clearly see that the test person has an object (keys) in the left pocket of his jeans. This object (the keys) is not visible in the photo (Fig. 2 (a)) since it is covered with fabric (jeans). This indicates that an IR camera can observe things that cannot be seen by a regular camera.

The test person laid down on the floor for almost an hour. After this period he was dragged to the end of the floor tiles. Immediately after this movement an IR image was taken. This image is displayed in Fig. 3 (a). The print on the floor was monitored over time until the print became invisible. Less than an hour after the body was dragged away the prints were no longer visible in the IR region.

A temperature profile of the legs was made of each IR image (see Fig. 4). Although the temperatures are apparent temperatures, such a profile gives a good overview of the temperature differences. In the image taken directly after the body was moved a large temperature difference is observed. Two large peaks are shown, which correspond to the prints of the legs. Over time the peaks drop down to a temperature around 20° C, which is the temperature of the floor tiles.

2.1.2 Table with lamps, computer screen and cups of fluid

A table was set up with several test situations on it. A black body calibration device was placed on this table, with in front four cups containing different fluids (coffee, cold water, tea, water at room temperature). On the right side of the table a computer screen was placed with in front of it two lamps (each contains a bulb of 60 W). One lamp was turned on for two hours and five minutes; the other lamp was turned on for 14 minutes. The monitoring of the visibility in the IR region started when the lamps and computer screen were switched off and the fluids were poured into the cups. The first IR image is taken at this time. At different times after this moment an IR image was taken. In Fig. 5 some IR images taken at different times are shown.

The experiments showed that the lamps were no longer visible 20 minutes after they were switched off. It did not matter much whether the lamp had been on for more than two hours or only 14 minutes. The computer screen was visible for approximately 1.5 hours after switching it off. The cups with different fluids were visible for approximately four hours after preparing the scene. Looking at the images in Fig. 5 a clear distinction between the cups with hot fluid (coffee, tea) and those with cold fluid (cold water, water at room temperature) can be made. However, all were visible for almost the same amount of time.

2.1.3 Different liquid traces on floor tiles

In the second experiment different traces were put on to some floor tiles and their visibility in time was monitored. A photograph and schematic layout of the experimental setup is shown in Fig. 6. The photograph in Fig. 6 shows that the soil (right upper corner) and water droplets (front left) can be seen clearly. Some of the other traces are less visible. Fig. 7 shows IR images taken at different times after the start of the experiment.

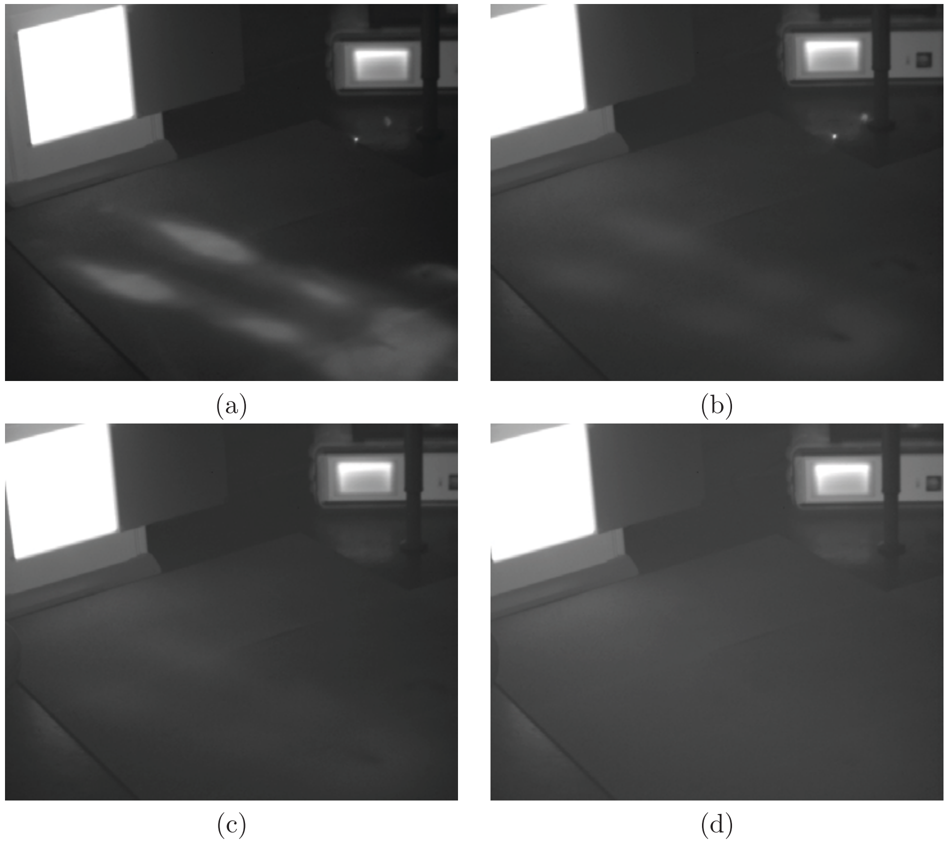


Figure 3. Infrared images of prints of a person who laid down on the floor for almost an hour and was dragged away afterwards. (a) - right after dragging away; (b) - 13 minutes later; (c) - 24 minutes later; (d) - 58 minutes later.

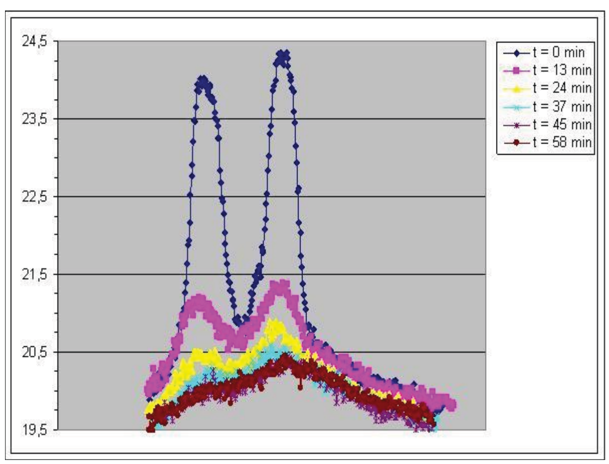
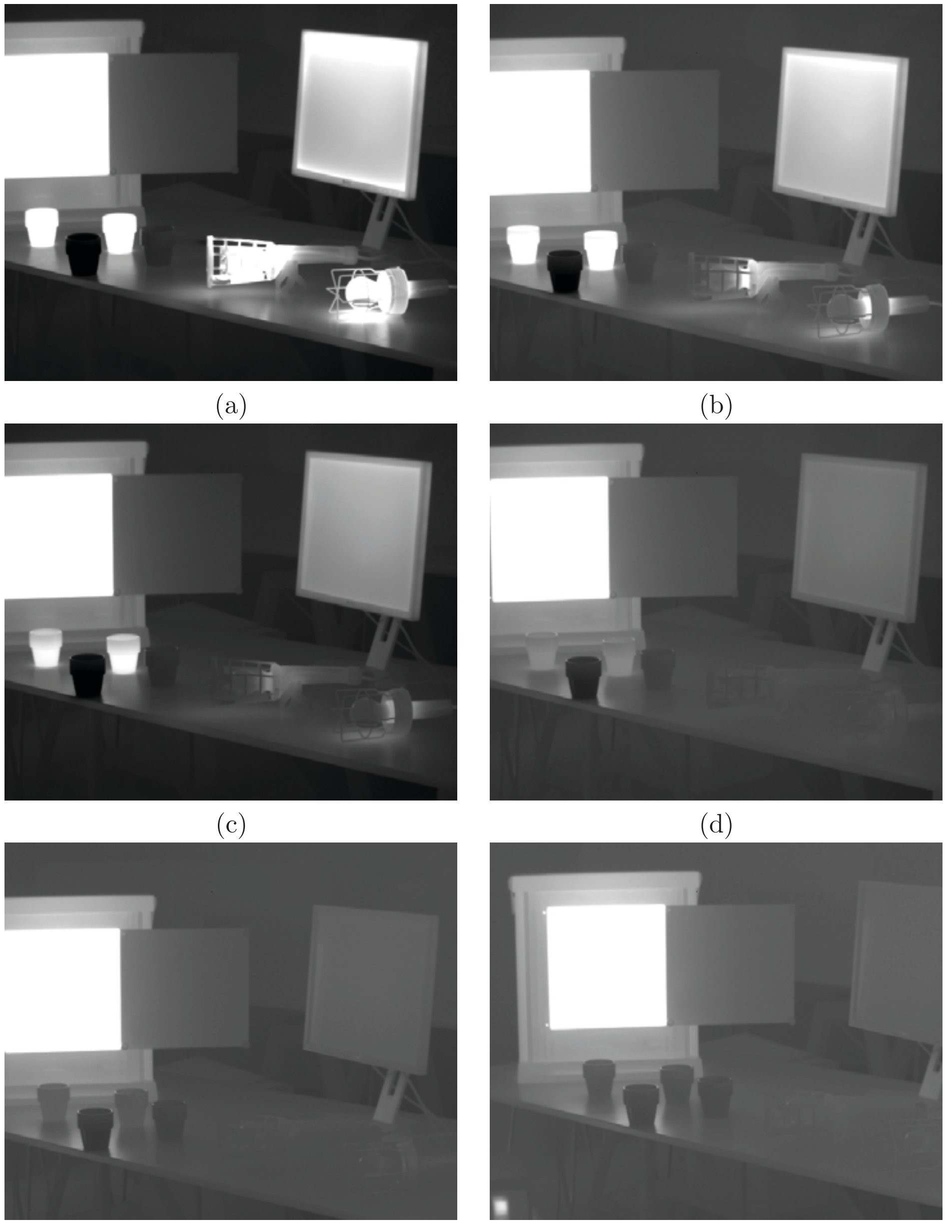


Figure 4. Temperature profiles of the IR images of the body print.

From the experiment it became clear that the spray oil was no longer visible approximately three hours after spraying it on the floor tiles. The soil had dried up and was invisible four hours after putting it on. Around this time the benzene and ethanol had disappeared as well. Approximately seven hours after the liquid traces were put on the alcohol became invisible. The window cleaning spray was no longer visible after 11.5 hours. Around this time the stain from the hand soap disappeared as well. The water disappeared approximately 22 hours after



(a) (b) (c) (d) (e) (f)

Figure 5. IR images of two lamps, computer screen and 4 cups with fluids. (a) - right after switching off the lamps and computer screen and filling the cups; (b) - 12 minutes later; (c) - 21 minutes later; (d) - 1 hour 4 minutes later; (e) - 2 hours 3 minutes later; (f) - 4 hours 5 minutes later.

putting it on the floor tiles.

2.1.4 Biological traces on different backgrounds

The visibility degradation of several biological traces was the research topic of the third experiment. The biological traces used in this experiment are: blood, urine, saliva, and sperm. These traces were put on to different materials. In Fig. 8 a photograph and schematic layout of the test setup are shown. The materials used as a background are: cotton (t-shirt), wood, MDF (laminated), metal, tiles, glass, floor tiles, concrete, concrete covered with wall paper.

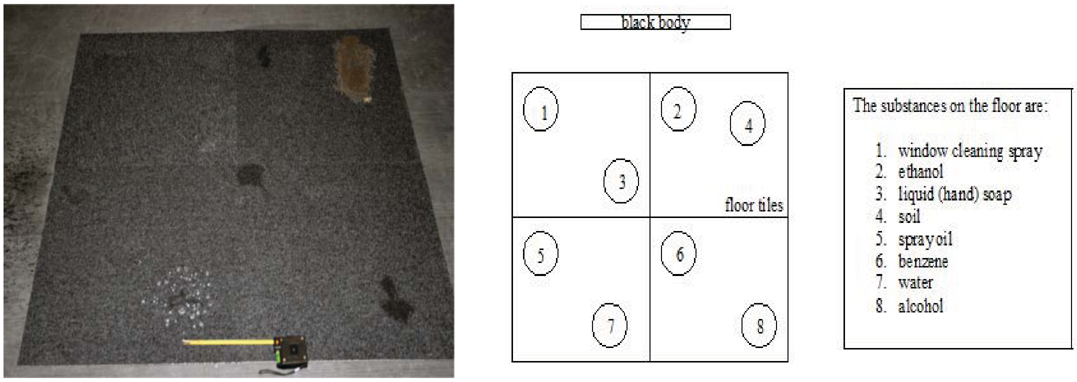


Figure 6. Photograph and schematic drawing of the floor tiles with the traces put on to them.

The experiment lasted two days. Before putting it on to the materials the blood was heated (in a heat bath) to a temperature of 37°C. The sperm had a temperature of 32°C in the beginning. The saliva and urine were put on to the materials right after they were produced. The water used in the experiment was at room temperature. In Fig. 8(b) the arrangement of the traces on the different materials is shown schematically. Here the green dots correspond with sperm, the orange ones with saliva, the yellow ones with urine, and the red ones with blood. The blue dots correspond with water, where light blue was on the first day of the experiment and dark blue on the second day.

The first day of the experiment blood, saliva, urine and water (at room temperature) were put on to the different materials. Fig. 9 shows images at different times after putting these traces on. Table 1 shows a matrix with the times it took before the traces on different materials became invisible.

Material	**Blood**	**Saliva**	**Urine**	**Water**	**Sperm**
Coton (t-shirt)	-	2.75 h	2.5 h	5.5 h	5.5 h
Wood	2.5 h	3.5 h	1.5 h	3.5 h	5.75 h
MDF (laminated)	-	3.75 h	$>$ 20 h	19.75 h	7.5 h
Glass	1.5 h	2.75 h	3.5 h	5.25 h	3.25 h
Floor tiles	11.5 h	8 h	16 h	16 h	9 h
Metal	$>$ 20 h	-	$>$ 20 h	11.25 h	-
Tiles	-	4.5 h	2.25 h	6.5 h	10.75 h
Concrete	0.5 h	-	-	0.75 h	1.25 h
Concrete with wall paper	-	3.5 h	2 h	-	-

Table 1. Traces and materials and the time it took before the traces were invisible.

On the second day fresh water (at room temperature) was put onto the wood, floor tile and concrete. The water was also poured over the blood put on to these materials a day earlier. After one and a half hour the blood and water were no longer visible on the concrete. Also on the second day traces of sperm were put on to the materials. These traces were visible for one hour and 15 minutes (concrete) up to almost 11 hours (tiles) (see table 1). In Fig. 10 two IR images with traces of sperm and water, taken at different times, are shown.

3. 3D MODEL AND INFRARED

A novel approach is presented in this section that provides a more intuitive method for exploring both visual and IR data simultaneously. It consists of a virtual 3D crime scene reconstruction that is compiled from various sources. Because all the information is visualized in a single reference frame, investigators can explore the data freely without having to switch between the different sources. To illustrate this idea, we have performed an experiment were IR temperature data was integrated into a 3D reconstruction. A mock up of a crime scene was staged indoor and consisted of a body lying on the floor. The IR data was captured by the FLIR Titanium

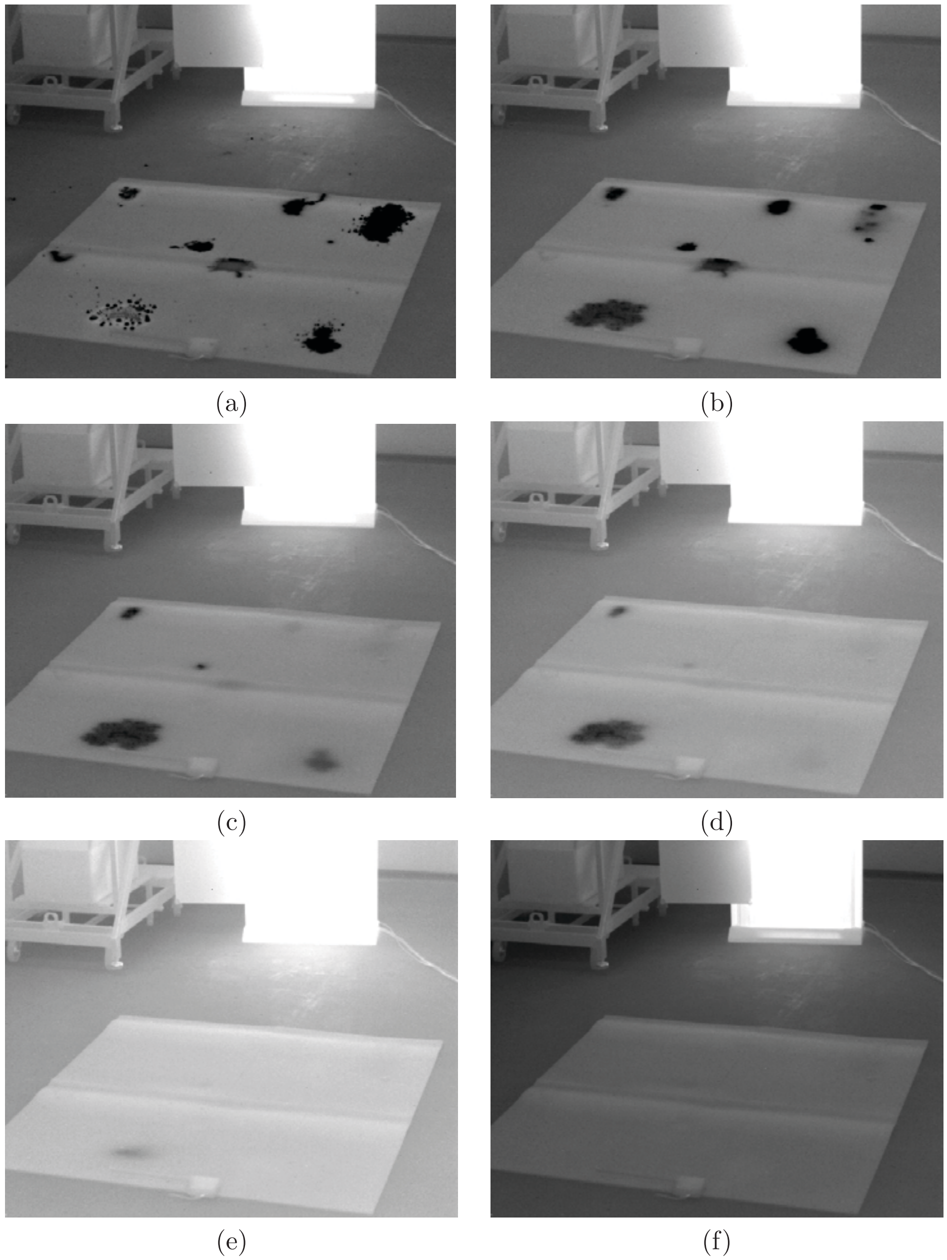
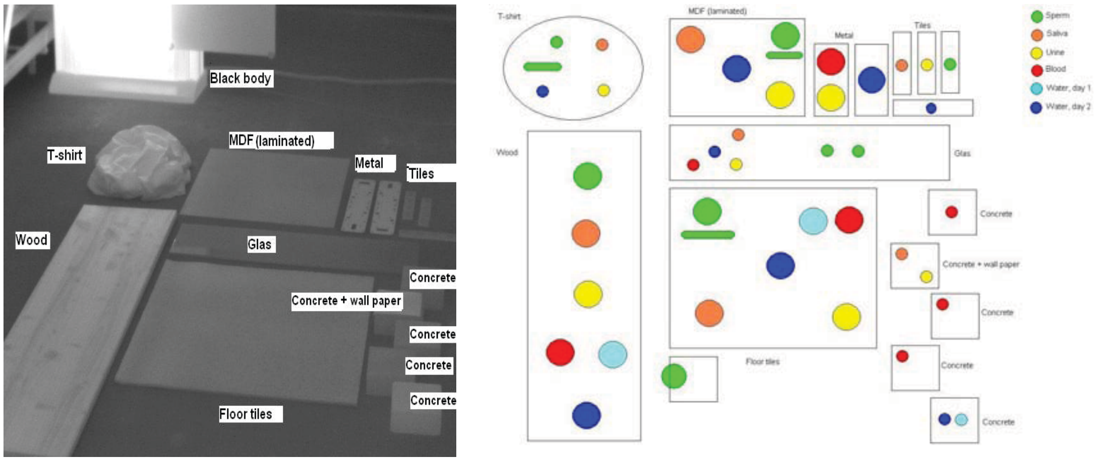


Figure 7. IR images of several traces on floor tiles. (a) - right after pouring the traces on to the floor tiles; (b) - 1 hour later; (c) - 4 hours later; (d) - 7 hours later; (e) - 18 hours later; (f) - 24 hours later.

560M camera. Color images were gathered using a Point Grey Bumblebee XB3[5] stereo camera. Both cameras were mounted on the same tripod, as can be seen in Fig. 11. Color and IR images of the scene were captured by placing the tripod at different viewpoints.

The 3D scene structure was recovered with a method that was originally developed at TNO for capturing 3D real-world scenes using a hand-held stereo camera.[1] It uses a sequence of stereo images of the scene captured from different viewpoints as input. Firstly, image features are detected and matched in both stereo images and between succeeding frames. Based on the 3D feature positions from stereo triangulation, changes in camera 3D position and orientation are estimated using a robust and accurate estimation method.[6] Then, for each viewpoint a dense disparity stereo map is computed to recover the local 3D structure of the scene. The resulting set of 3D



(a) (b)

Figure 8. Experimental setup with biological traces put on to different materials. (a) - photograph; (b) - schematic layout.

points for each viewpoint can be merged into a single reference frame based on the estimated changes in camera position and orientation. The result is a large set of 3D points. Because color images are used, each point can be assigned a RGB color value to visualize textures. Example screen shots of the resulting 3D scene reconstruction are shown in Fig. 13.

Infrared data is incorporated into the reconstruction by replacing the RGB values of 3D points with those that represent a temperature. To sample a temperature value for an individual 3D point it is necessary to locate its position in the IR camera reference frame. Because the 3D points are reconstructed in the stereo camera reference frame, they first have to be transformed to that of the IR camera. This involves applying an Euclidean 3D transformation, consisting of a rotation matrix and translation vector that are also known as the extrinsic camera parameters. The resulting 3D point is projected onto the IR image using the pin-hole camera projection model.[7] This requires the camera's intrinsic parameters, such as focal length, principal point and radial lens distortion. To obtain both extrinsic and intrinsic camera parameters, we use a calibration procedure.[8]

After projection, it is checked if the point falls within the image borders. If not, its original RGB values are retained. For points that do fall within the image, the nearest IR pixel is located. Its intensity value is used to compute the absolute temperature in degrees Celsius. Fig. 12 shows the input IR image with an absolute temperature scale. At the right side of the image there is also a bar that encodes the different temperatures of the scale using the Matlab[9] "hot" colormap. Based on the values retrieved from the IR image and the map colors are assigned to the 3D points. The result is shown in Fig. 14. It can be observed that the added color reveals temperature differences, for example a warm face and colder ears. In contrast to the 2D IR image of Fig. 12, the temperature differences can now be inspected in 3D. Furthermore, our 3D visualization software also allows for switching between the color and temperature data with a simple key stroke. This enables comparing temperature and image data in a single frame of reference. Using this approach it will be more easy to locate traces in the virtual crime scene reconstruction, such as liquid stains, that are only visible in IR.

4. CONCLUSIONS

All experiments were intended to get a better understanding of the possibility to use an IR camera on a crime scene to detect more or different traces. During the experiments the visibility of several traces (biological and other) on different background materials has been monitored over a longer time span. Besides this the visibility of lamps, a computer screen and cups with fluids was monitored over time as well. Also a print from someone who had been lying on the floor was investigated. All experiments show that the traces stay visible for some time after they have been introduced. The range of visibility varies from half an hour to more than 20 hours.

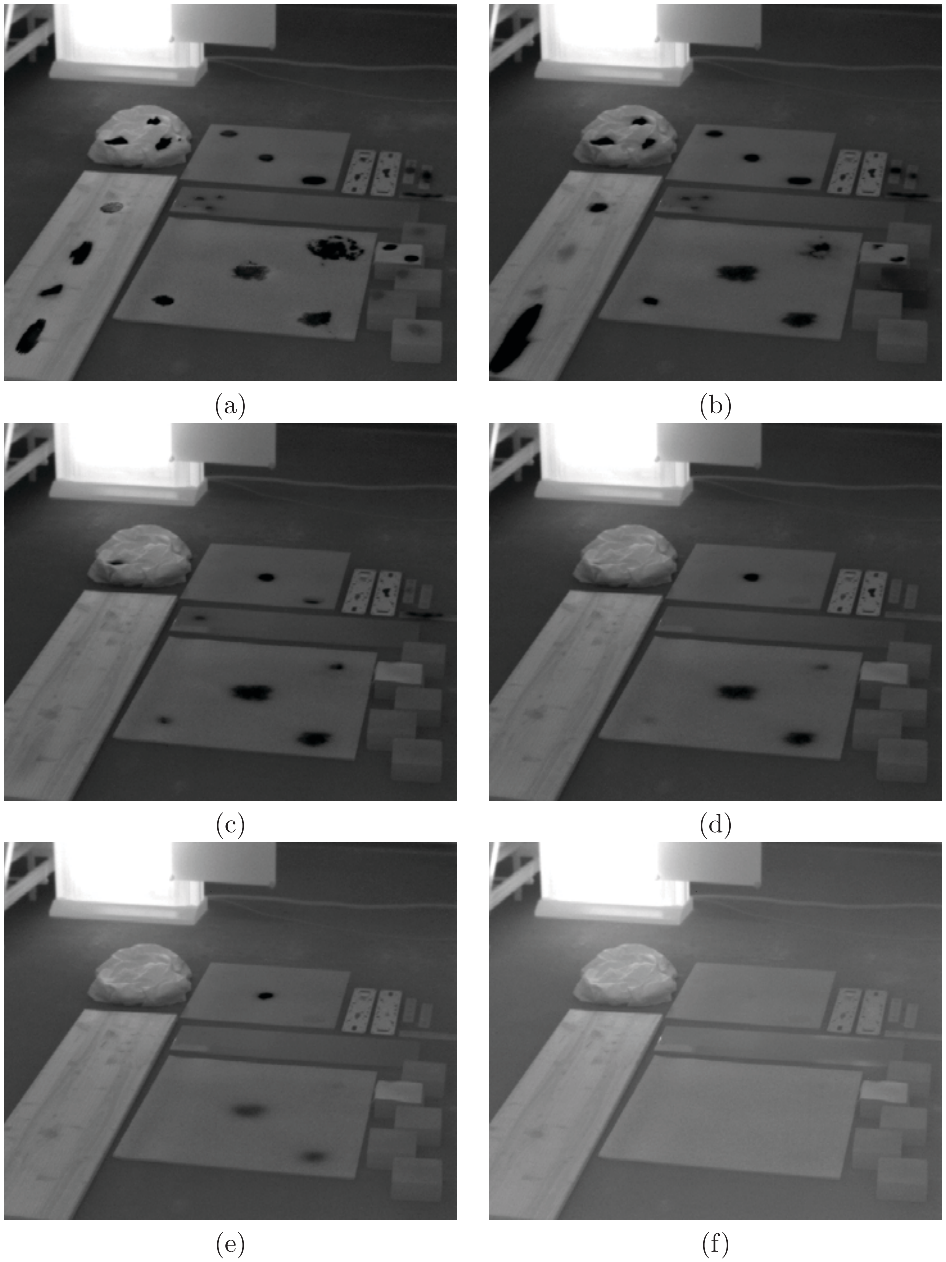


Figure 9. IR images of biological traces (blood, urine, saliva) on to different materials. (a) - right after putting the traces on the materials; (b) - 1 hour later; (c) - 4 hours later; (d) - 6.5 hours later; (e) - 11 hours later; (f) - 19.75 hours later.

One should bear in mind that these experiments were conducted at one room temperature and humidity and all in doors. Whether the conclusion holds for traces in an outdoor environment is to be determined.

We also demonstrated a method that can be used to incorporate IR information into a virtual 3D reconstruction of a crime scene. It is expected that such an approach would be more insightful for locating and investigating IR traces.

(a) (b)

Figure 10. IR images with traces of sperm, water and blood with water on different materials. (a) - right after putting the sperm on to the material; (b) - 5.5 hours later.

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Figure 11. FLIR Titanium 560M IR camera (blue) with two stereo cameras (yellow). The bottom camera is the Point Grey Bumblebee XB3 stereo camera.

Figure 12. IR camera image with temperature indicated in pseudo colors. An absolute scale in degrees Celsius is given as a color bar on the right side.

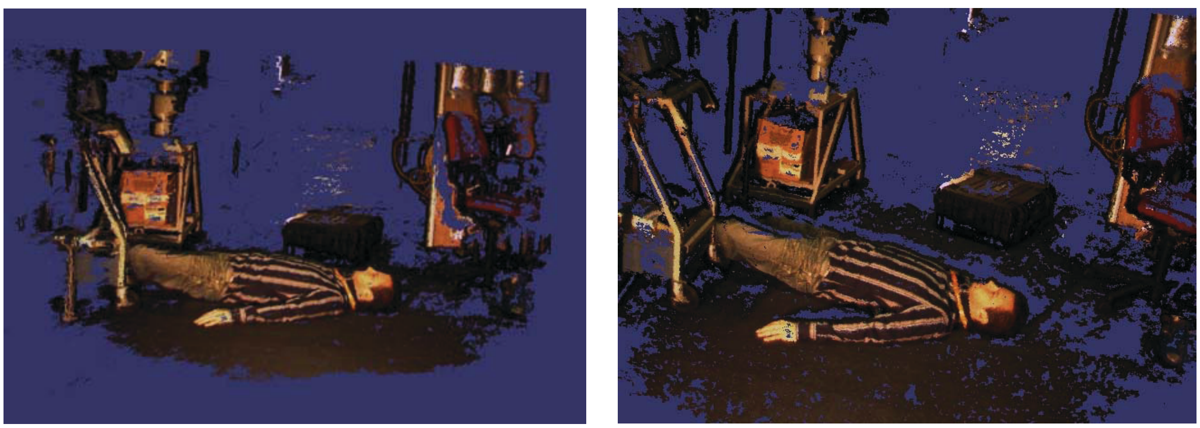

Figure 13. Two views of the reconstructed 3D scene with the original RGB values from the color images.

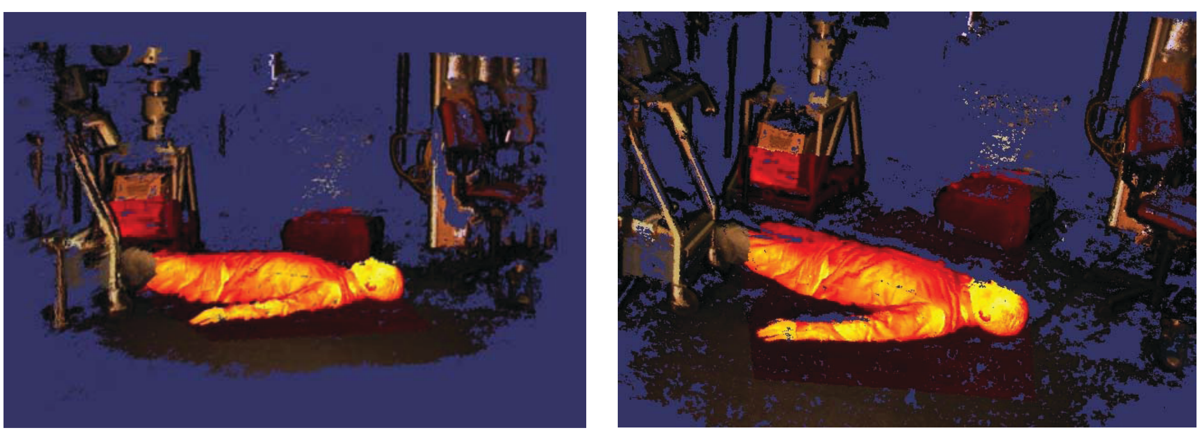

Figure 14. Two views of the reconstructed 3D scene with IR temperature indicated in pseudo colors.