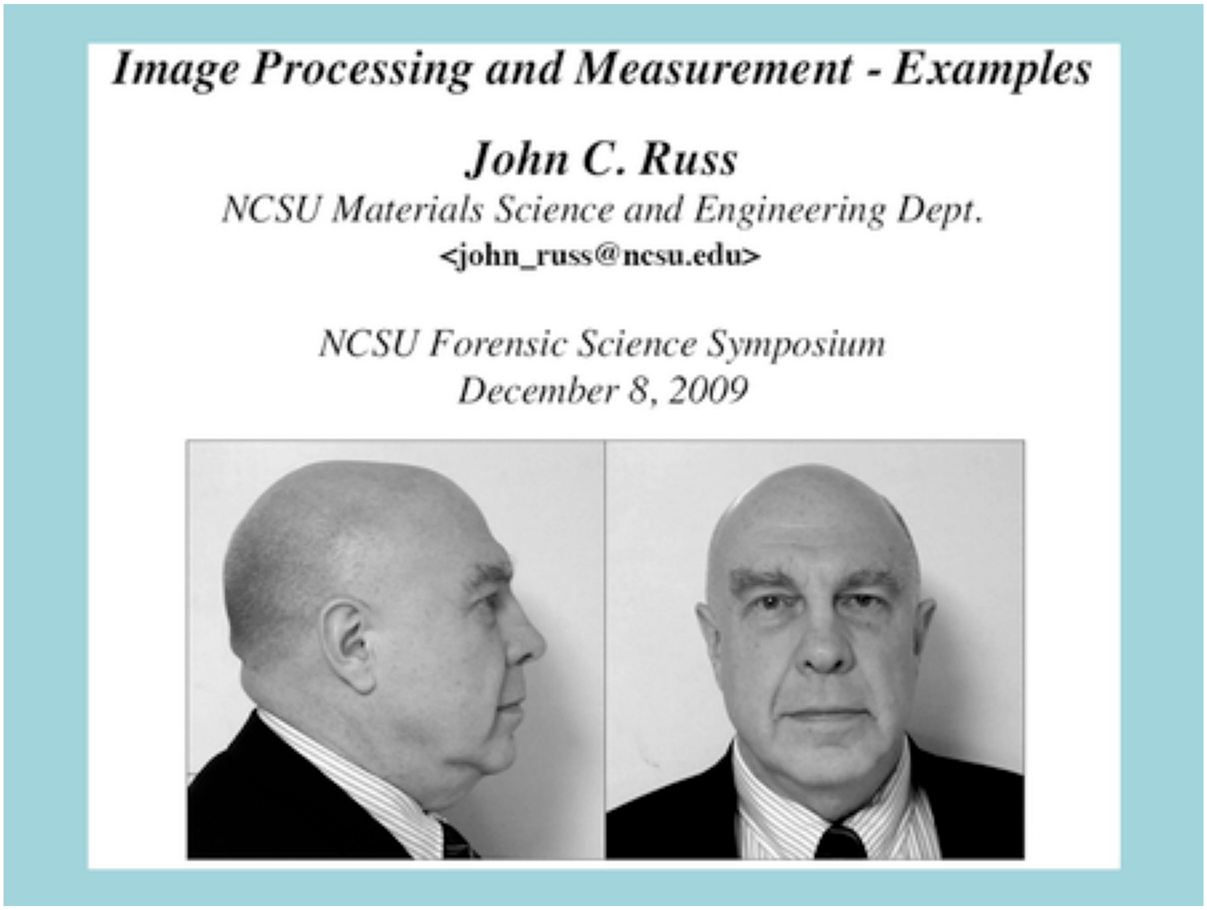

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Images are responsible for a very high percentage of the information that humans acquire about their surroundings, and it should not be surprising that they are also important in forensic applications. Some of these images come from laboratory instruments, such as microscopic examination of evidence, interpretation of electrophoresis separations, and so on. I won’t be discussing those today. Rather, I will concentrate on macroscopic images, typically from video or digital cameras.

Surveillance video
A common request is: "Please process this surveillance video image to enable identification of the criminal." Unfortunately, the quality and placement of surveillance cameras, the use and reuse of worn VHS tapes, lighting problems, etc., severely limit the information available. Sometimes the results are good enough to show on the TV news, or to identify an article of clothing, or to confront a suspect, and sometimes they can help to eliminate someone as a suspect, but rarely can the pictures provide conclusive identification. The example in Figure 1 comes from a multiple murder in Toronto. Some improvement in contrast and noise reduction was possible, but certainly not enough for identification purposes. Prosecution tried to convince the jury that the images were "consistent with" the defendant, but it was easy to show that they were also "consistent with" many thousands of other individuals.

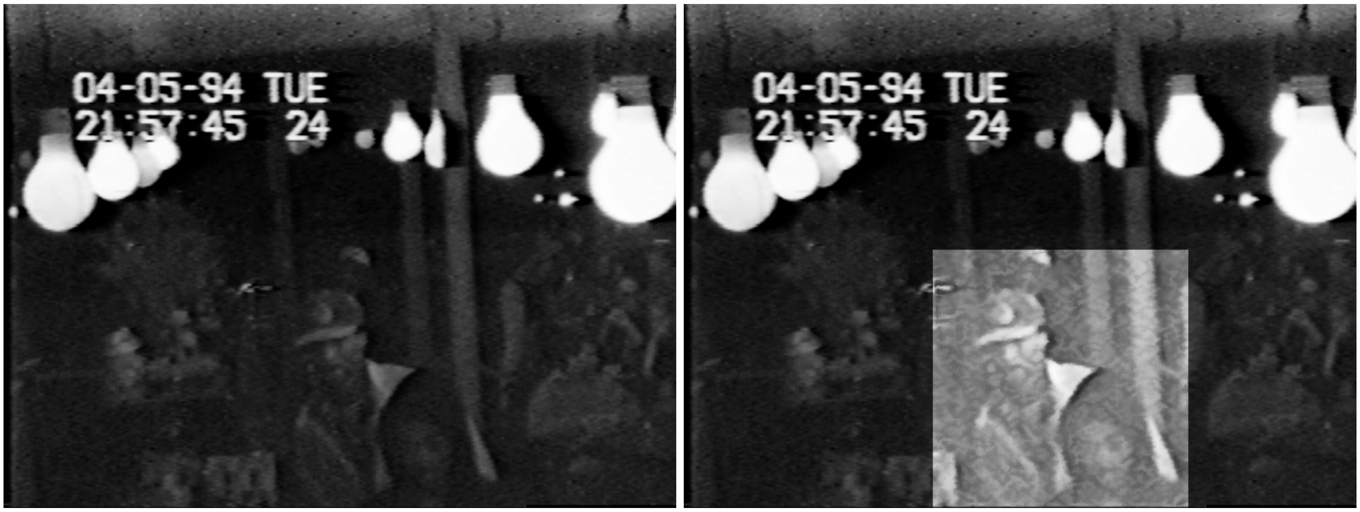

Figure 1. Surveillance video from a restaurant showing murder suspects. On the left, the original image is dark because of the inclusion of ceiling lights in the frame. On the right, the region including the suspects has been contrast-adjusted and noise has been reduced with a hybrid median filter.

Another typical problem with surveillance video is that the cameras are too far away from the people, and use such wide angle lenses that the people are reduced to a few pixels in size. The example in Figure 2 shows the individuals who were responsible for the school fire in Fayetteville, seen leaving the building. Unfortunately, there is no useful information in the pictures.

Figure 2. Surveillance video from the parking lot at Douglas Byrd High School, showing the perpetrators who set the fire.

Photogrammetry

Surveillance video is, however, adequate for some measurement purposes. In a case from Little Rock, Arkansas, the attorneys for person arrested and eventually convicted and sentenced to death for a murder in a laundromat claimed that the wrong person was apprehended, because the pictures showed someone 66 inches tall and the person arrested was 69 inches tall. That estimate was based on a faulty manual measurement procedures.

Careful automatic measurement of the images using standard image processing tools (Kuwahara maximum likelihood filter for noise reduction, Canny edge detector to locate edges, Hough transform to fit lines to points), and based on the known height of the tables in the laundry as a reference ruler, showed that in fact the person in the images was 69.2 ± 0.4 inches tall (Figure 3).

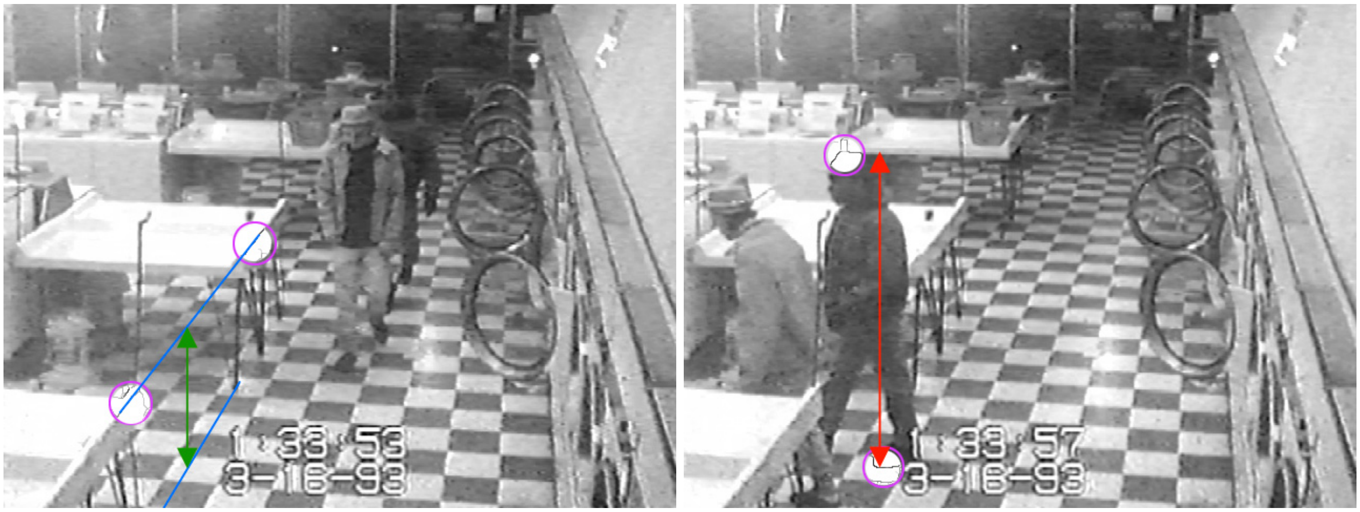

Figure 3. Using the height of the tables (measured at the location where the suspect later passes by) as a ruler to determine his height. Automatic processing tools were used to accurately locate the table edges and feet, and the top and bottom of the suspect without human intervention or bias.

If image analysis had been performed immediately, before extensive remodeling of the laundromat and relocation of the camera had been performed, reverse projection photogrammetry would have been easy and conclusive, by capturing video of a measurement scale placed at the location of the suspect, and overlaying that image directly onto the original video image. Figure 4 shows an example in which a scale was placed at the location occupied by a bank robber to determine his height, and the confirming photo after he was taken into custody.

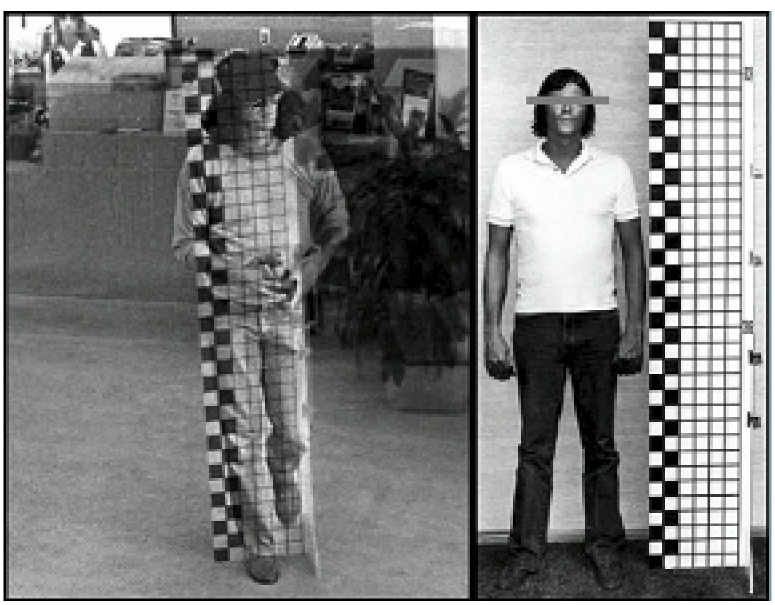

Figure 4. Reverse projection photogrammetry superimposing an image of a measurement scale onto a surveillance image of a bank robber.

Measurement of video images is often important for photogrammetric reconstruction of a crime or accident scene. With a known camera placed in one or several fixed locations, this process can be straightforward using triangulation, and there are commercial systems that perform the process and produce excellent trial graphics showing the spatial arrangement of a scene.

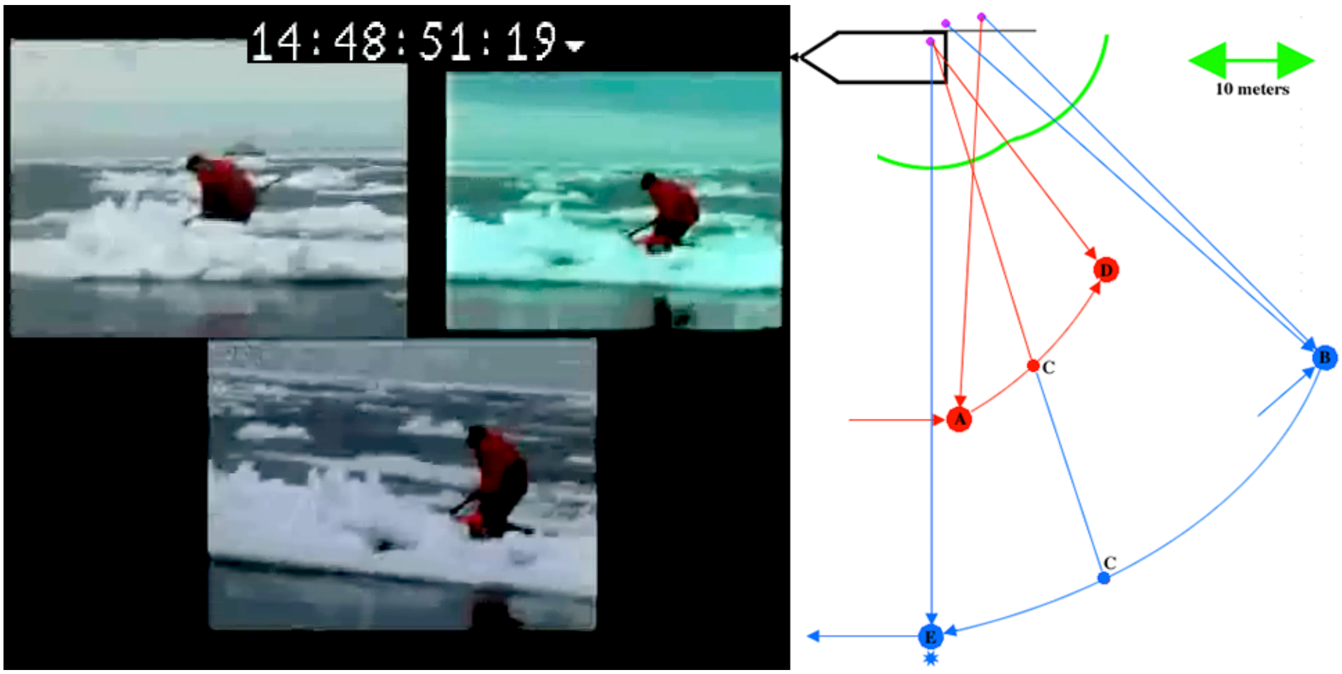

Figure 5. Display showing three different camera views of a seal hunter that have been synchronized. Measurements on the entire sequence allowed construction of a diagram showing the positions of the boats throughout the incident, proving that they never came within 10 meters of the hunter.

In a recent case in the Magdalen Islands off the east coast of Canada, three video cameras were in use by personnel moving about in rubber zodiacs. An expert in video technology, Grant Fredericks, was able to synchronize the three tapes using software from Avid Technology so that I could perform measurements. Using the known focal length of the camera lenses, and the dimensions of the boat and the hunter's weapon as references, a diagram showing the location of the boats as they moved throughout the incident was constructed using straightforward principles of surveying (Figure 5).

Extracting detail

Processing images to improve detail visibility is a widespread technique in many areas of science, including forensics. Modern digital and film cameras can capture much more detail with a greater dynamic range than the human eye can encompass. Of course, corruption introduced by JPEG compression must always be avoided in any scientific or forensic imaging application. Techniques such as local contrast equalization or homomorphic filtering (Figure 6) reduce the overall contrast range while increasing local contrast to make details visible in both dark and light areas. This method is particularly used for tool or wear marks such from firing pin or extractor marks, and tire or footprints.

Figure 6. In the original image (left) the interior of the car is too dark to see important details. Processing (right) reveals sunglasses on the floor and even the settings on the car heater and radio.

Surface marks and scratches can often be used for identification. To better see these marks, processing can enhance local contrast. Rendering images as surfaces takes advantage of human familiarity with the appearance of surfaces, and applying false color also helps visibility (Figure 7).

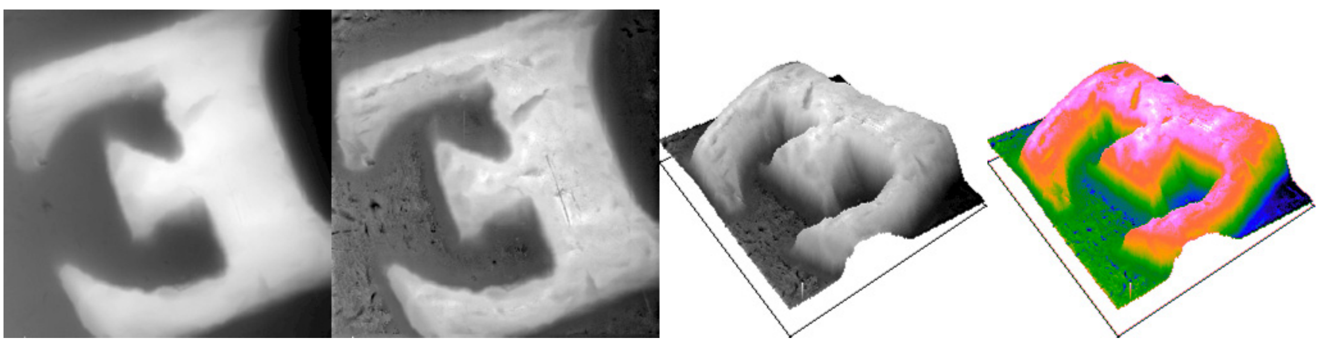

Figure 7. Surface scratches on the raised letter on a coin (left) are enhanced for greater visibility by local contrast enhancement, surface rendering, and false color.

Fingerprint images often require processing to enhance the visibility of the friction ridge markings. Figure 8 shows an example of a print on a magazine cover. Suppressing the contrast between the dark and light areas of the background allows seeing the pattern. The Automated Fingerprint Identification System (AFIS) uses the location of minutiae such as end points, breaks, islands and bifurcations in the pattern. Skeletonizing a pattern, as shown in Figure 9, assists with this by marking pixels with one neighbor (ends) or more than two (bifurcations).

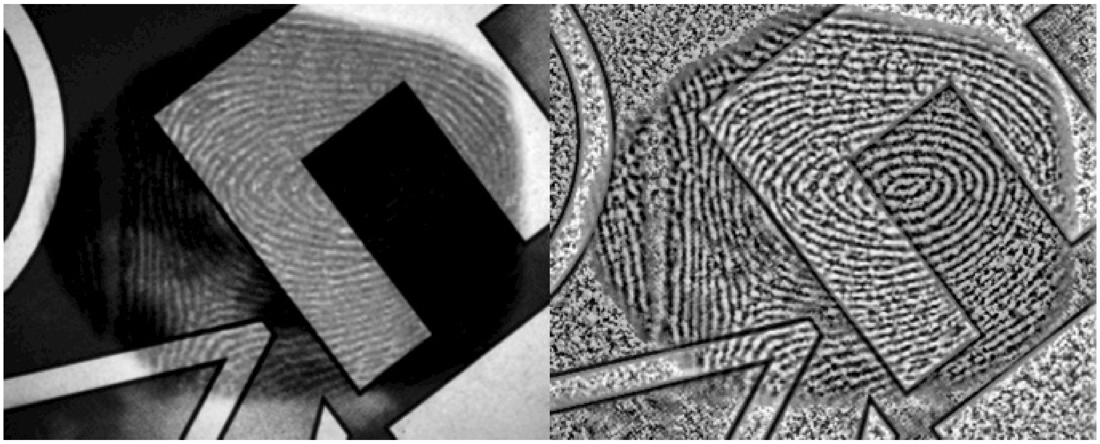

Figure 8. Fingerprint (left) and the result of local equalization to suppress overall contrast and enhance visibility

Figure 9. Analysis of fingerprint patterns depends on locating minutiae such as ends and bifurcations. The skeleton of the markings locates these points based on the number of neighbors around each pixel.

Images often contain important evidence. However, the photographs are not always acquired under ideal circumstances and image processing may be required before measurements can be made. In Figure 10, the tire tread image was taken at an angle. The resulting image is adequate to identify the manufacturer and model of the tire, but in order to measure the locations of wear marks that can be used to match the tread to a specific tire, it is first necessary to rectify the image so that it is viewed perpendicularly. Image processing software such as Photoshop can accomplish this.

Figure 10. Image rectification on a tire tread pattern. Marking a region on the original photo at left allows it to be adjusted to show a perpendicular view.

Color images present special opportunities and challenges. Digital camera images can be adjusted to get accurate color representation if the scene contains some known colors. In Figure 11, locations were identified as being neutral in color (equal intensities of red, green, and blue) enabling adjustment of the overall colors.

Figure 11. Using the inside of a tire to define black and the asphalt paving to define neutral gray allows corecting the colors in the image so that the car in the foreground is seen to be blue, not green.

Principal components analysis (PCA) provides a method for separating colors so that, as in Figure 12 (image courtesy of George Reis), a background pattern can be removed to reveal the fingerprint clearly.

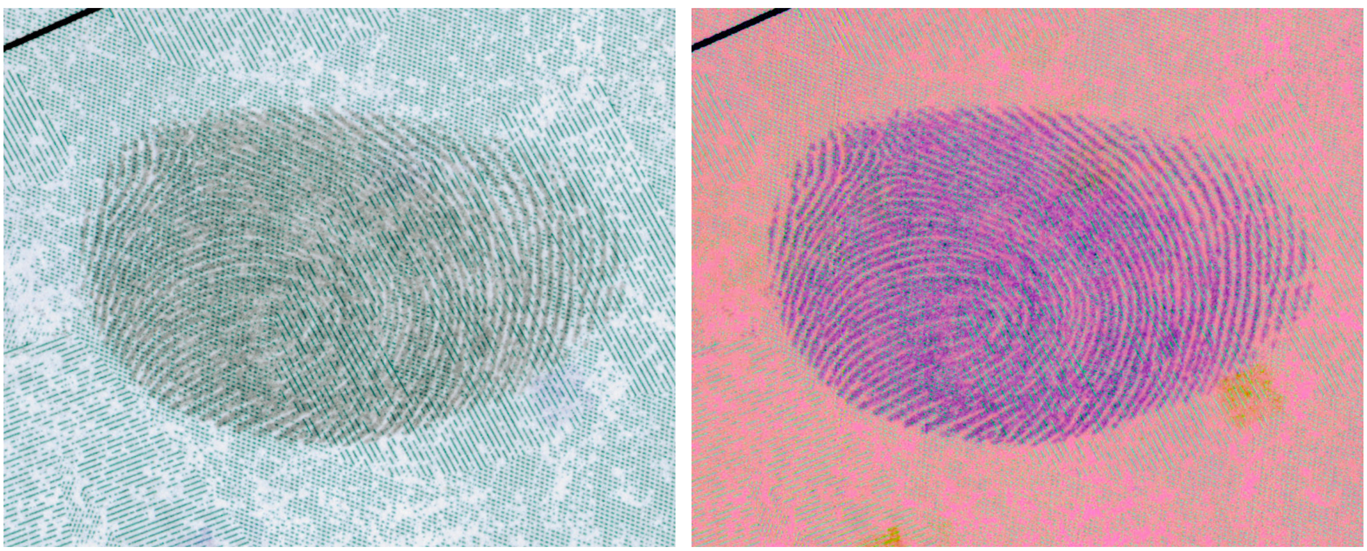

Figure 12. The printed pattern on the back of a check makes it difficult to extract the fingerprint pattern. Principal components analysis recombines the colors to produce maximum contrast for the details.

Measurements

Computer analysis of images is often concerned with measurements. Parameters that describe the size, shape, position and color of objects and structures present can be quickly and automatically measured, and data from many individual measurements combined for characterization and comparison.

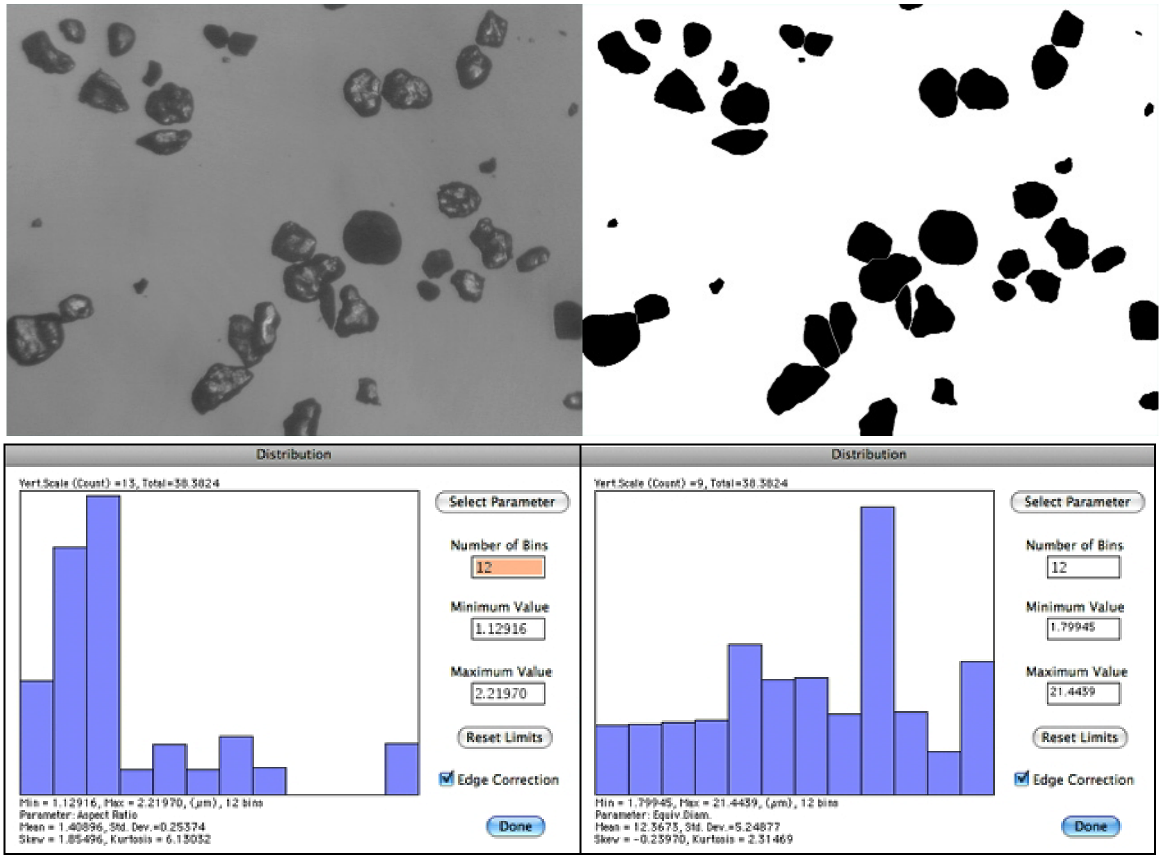

Figure 13. Measurement of sand grains from a suspect's car. The image is thresholded to delineate the grains, and segmented to separate those that touch. Each grain is measured to produce the distributions shown for the size and shape.

Grains of sands and soils vary from place to place, and measurement of a few dozen grains often allows locations to be matched. Figure 13 shows an image of sand grains from the floor mat in a suspect's car, imaged with a low power microscope. Measurement of the size and shape distributions characterizes the sand so that it can be uniquely matched to sand from the location where the body was found, evidence that the suspect had been there.

In Figure 14, measurements of between 12 and 20 individual leaves from nine tree species were analyzed by linear discriminant analysis using the SAS JMP software to determine the minimum set of measurements needed for conclusive identification. The shape factors roundness, radius ratio and convexity were found to be sufficient. This is an example of the ability of automatic classification software to sort through data sets to extract significance.

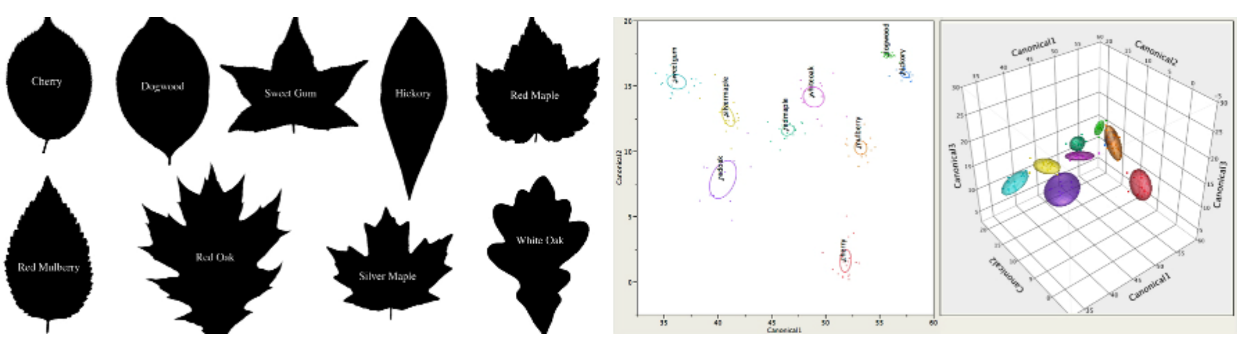

Figure 14. Linear discriminant analysis of measurements of the size and shape of nine species of leaves found that two or three shape factors were adequate to completely distinguish the various trees.

Measurement is also important for blood spatter patterns, where the size of droplets, their aspect ratio and orientation angle can be used to determine the originating point. In the example of Figure 15, each droplet on the wall is measured to collect the data. In Figure 16, processing the image of the face allowed isolating the spatter pattern, and measurements of size and aspect ratio identified two (marked on the image) that were different quantitatively and qualitatively from the rest. They represent two droplets that did not come from the aspirated blood but fell onto the face from above, providing evidence that the death was not a suicide.

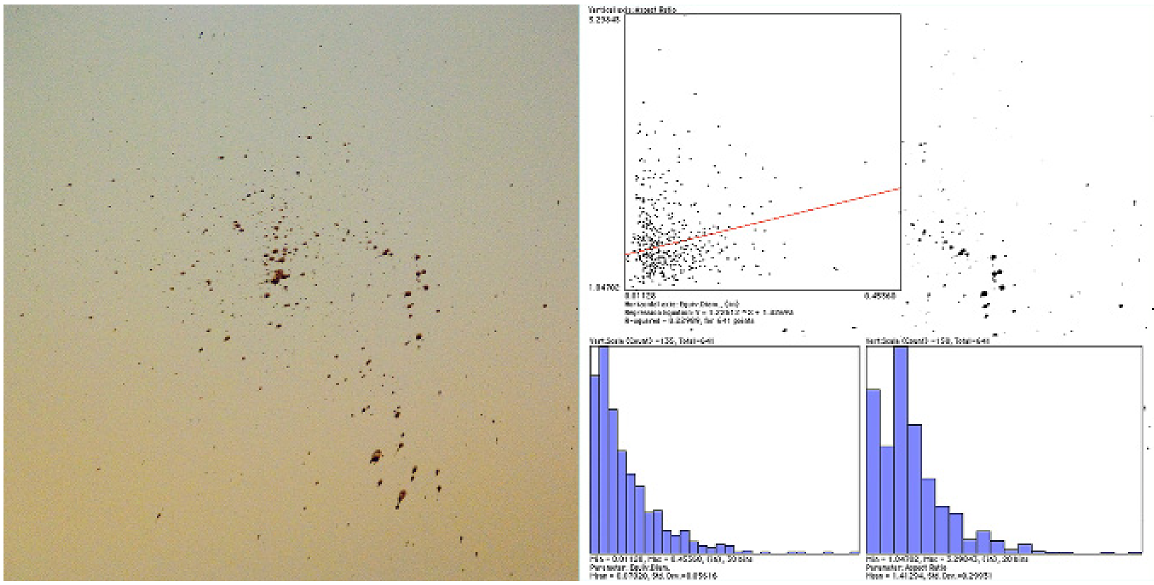

Figure 15. Blood spatter pattern on a wall, with the measurements of the size, shape and angle of each droplet.

Figure 16. Image processing made it possible to correct the shading and remove the image of the face, to obtain just the blood spatter pattern which was then measured. The two outlined drops are different in size, shape and point of origin from the rest.

Focus correction

Image resolution is often limited by imperfect focus, which may be corrected by deconvolution. This is the same method that was used by NASA for the blurred images from the Hubble telescope due to incorrect mirror curvature. In the case of astronomical pictures, a direct measure of the point spread function can be obtained from the image of a single star, which should appear as a point but is instead recorded as a blur. Removing that blur from the entire image can then be accomplished in the computer. Figure 17 shows an example, in which the point spread function of the optics was measured by placing a small flashlight bulb at the approximate location of the car and recording an image, which was then used to deconvolve the image so that the license plate could be read.

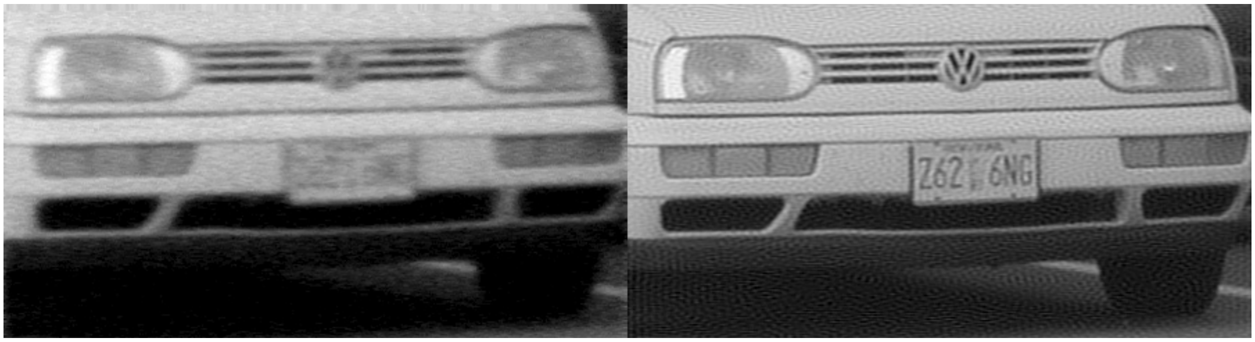

Figure 17. Deconvolution of a noisy and out-of-focus surveillance image from a national security site, which made it possible to read the license plate and identify the intruder.

In the example of Figure 18, determination the cause of death of a young boy in Miami, FL, was made possible by the fortuitous photography of his watch, placed face-up on his stomach at the medical examiner's facility. In the original image (which was not in perfect focus when it was originally photographed on a color slide, which then accumulated scratches and dirt due to poor storage for several years), the watch face cannot be read. Knowing that the lettering on the boy's waistband should actually be sharp-edged enabled the point spread function to be modeled, which in turn allowed the image to be deconvolved and reflected glare from the ceiling lights to be removed so that the time when the watch stopped could be read. Initially, the attorneys thought this was not useful information, since the police report indicated that the death probably occurred sometime around 10 o'clock. But it was later discovered that the time on the watch when it stopped (9:37) corresponded within one minute to a lightning strike recorded very close to the site where the body was found.

Software

All of the techniques illustrated meet Daubert criteria and have been accepted by the courts. The processing and measurement tools used in the examples shown used Adobe Photoshop as a platform, with the Reindeer Graphics Fovea Pro and ClearID plugins. In addition to writing books, consulting and providing evidence as an expert witness in civil and criminal proceedings, the author leads hands-on workshops using these programs and teaching the basics of image processing and measurement.

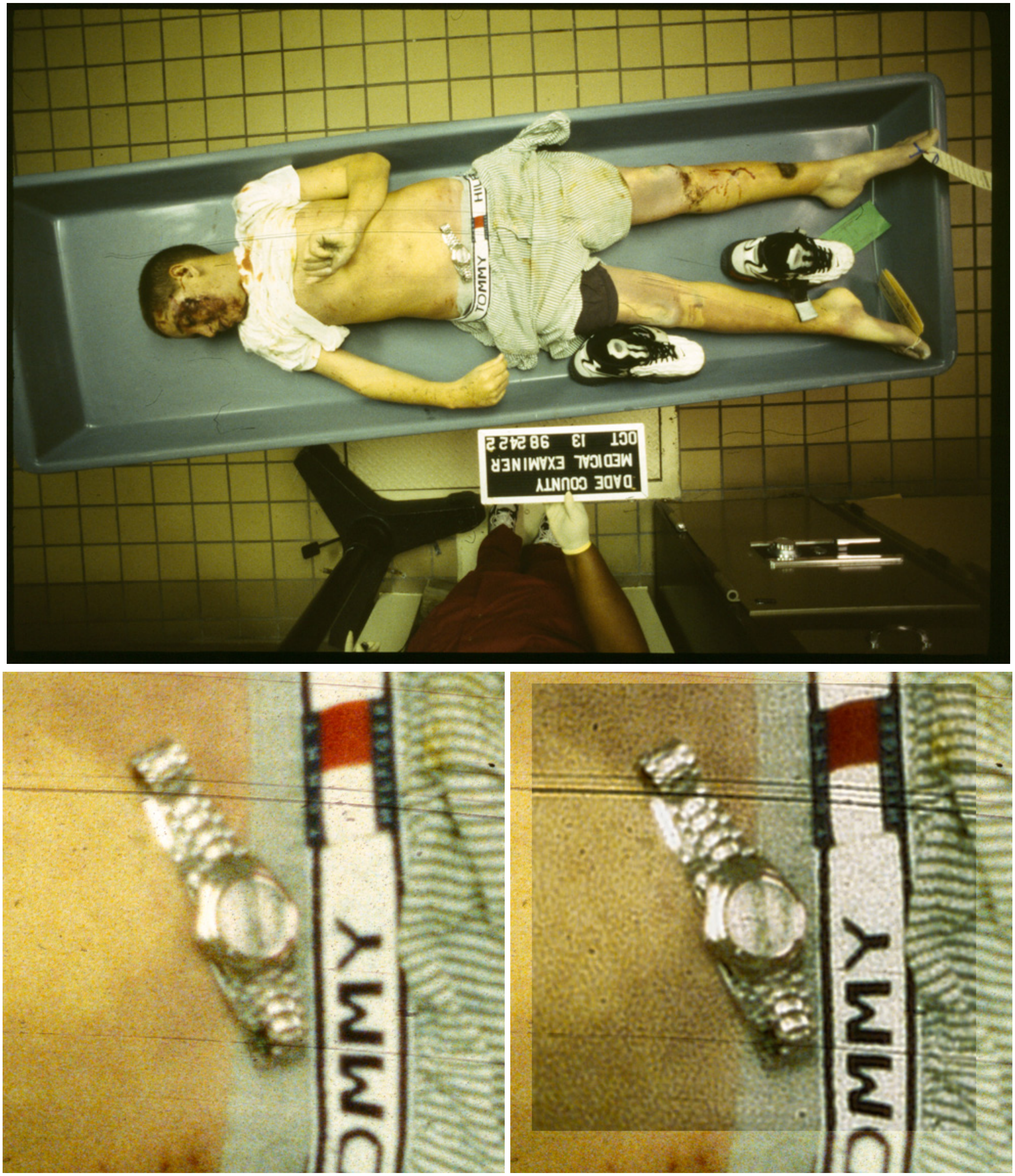

Figure 18. The original 35mm slide (top) was digitized at 4000 points per inch and 16 bits per channel (producing a file greater than 100 MBytes). The region around the watch was sharpened by Fourier deconvolution and glare from reflected ceiling lights removed, enabling the time to be read.