

Forensic Imaging Options
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The old adage holds that a picture is worth a thousand words. Poetically this has merit, but in reality the number is far too low. How many words would it take to describe a tire track in order for an expert to compare it to a tire found in a garage? How many words would it take to describe the face of a missing child so that potential witnesses would know whether they have seen him or her? The list of these comparisons can be incredibly long, and in today's world of criminal investigations, there are, in fact, many such instances. There is little doubt that images are a crucial part of modern criminal investigations, and that imaging is growing in importance in the practice of law enforcement. Fortunately for the practitioner, technology is expanding to meet the need, creating many imaging options offering a number of advantages in certain situations. This is the good news. The other side of the coin is that the practitioner must now make choices regarding how to proceed in a number of situations, and therefore needs information upon which to decide what approach to take. This article is intended to provide guidance for the law enforcement practitioner wrestling with these decisions. In particular, it addresses comparisons of traditional silver halide film and digital cameras. In addition, it addresses issues associated with using such images as court room exhibits, and shows how Write Once Read Many (WORM) technology compact discs (CDs) can help assure proper imaging technique and integrity. Finally, this paper addresses the role of "video" Video technology in one form or another is widely used in law enforcement, but unlike the still image capture technologies, video provides dynamic image capture capabilities.

The article compares and contrasts the advantages and drawbacks of each technology against a series of categories, including: (1) resolution, (2) latitude/dynamic range, (3) sensitivity, (4) color rendition, (5) image access time, (6) repeatability, (7) image management, (8) courtroom exhibit validity, and (9) cost.

Resolution and Dynamic Range

While these two dimensions are independent, when combined they give a good indication of the amount of information contained in an image, hence, they will be considered together. One of the traditional means for measuring resolution is in terms of line pairs per millimeter (lp/m). This indicates how many black and white line pairs can be seen in images. In the case of digital imagery, where images are recorded in picture elements, or pixels, the more common measure is dots per inch (dpi). Dots are often meant to be equivalent to pixels, but this is not always the case. A pixel must contain all of the necessary image element information - color and value (lightness) while dots may, in fact, have only one color each, and only on/off values. In this case, at least three dots are needed to make one pixel. This is often a problem in reading the specifications of printing devices. In this article, we will assume pixels per millimeter as the correct metric. While it is obvious how to convert the inches to millimeters, a word on notation must be used to describe the conversion of line pairs to pixels. At least two rows of pixels are required to produce one line pair one black and one white. Thus, 10 lp/m is equivalent to 20 pixels per millimeter. One additional comparison issue film is an analog medium. That is, it has continuous scales of lightness and spatial texture. Digital devices, on the other hand, are neatly divided into fixed spatial elements, and each of these can have only discrete lightness values. As a result, direct comparisons are often subject to debate. To get a sense of the practical effects, though, in this paper, film will be "digitized" by using 1p/m as a resolution metric. Dynamic range will be considered in terms of the logarithm of exposure.

There are a number of "video" formats, but for the sake of inclusion in this review, it is assumed that video has 480 lines, going across each frame, and that the response of the system is sufficient to achieve a comparable number of "pixels" along each line. Normal video is really a mixed format which is digitized down the frame into rows, but analog across each row. The above assumption gives a frame of 640 by 480 pixels. Two other factors that make it difficult to compare video to still formats are (1) the interlacing of frames, and (2) the fixed shutter times. In standard video systems, the camera records information across row number one, then flies back and records line number three, then five, and so on down the frame. It does all of this during the first 60th of a second. Then on the next swing of the 60 Hz power, it starts over again to get rows two, four, six, etc. The rows are interlaced on the screen to give a full frame every 30th of a second. If there has been no motion during that 30th of a second, then the pattern of capture is not important. But, video is specifically designed to capture motion, therefore considerations of motion are usually important. If there has been significant motion during the nominal 60th of a second between the capture of row one and row two, then the image elements will not line up very well. Without getting into a lengthy discussion of this, suffice it to say that the human visual system normally compensates for this as a moving image is displayed. However, when a single frame is captured and displayed as a still image, there is no means for compensation, and the images clearly show a lack of definition. Law enforcement officials regularly go to imaging specialists to try to get their surveillance video images "enhanced" There are a number of techniques for doing this, but most involve creating data where the original record did not contain any, a practice that will often get plea bargaining started, but will probably be subjected to significant testing in court as defense lawyers catch on to the "creation of information" aspect of the process. A newer approach involves combining information from successive frames, but this is not widely available today and is of little use on still images. For purposes of the comparison table in this article, it was assumed that there are no motion related problems. When considering dynamic range, one should remember that video is designed to display on a TV monitor screen. Typically a monitor will exhibit at least a few percent of front surface reflection. The darkest a screen image element can get is the color of the screen when the power is off. If a limit of one percent is assumed, then a dynamic range greater than 100:1 is wasteful. Without going through all of the various arguments in depth, it is assumed in this paper that the practical level of dynamic range is seven bits per color, as opposed to the eight typically found in digital systems.

For the sake of reference, in this article, we will consider the the KODAK Professional DCS 420 Digital Camera (DCS 420) and the KODAK Photo CD image format for comparisons. The image obtained from a DCS 420 Camera is comprised of an array of 1,024 pixels by 1,536 pixels, each representing 256 levels of the three primary colors. The Photo CD image has 2,048 by 3,072 pixels, each with 256 levels of three colors. Films vary widely from one to the other, but a typical, high-quality color negative will be capable of at least 80 lp/m, and will have a monotonic response covering about five log cycles of exposure. It is capable of responding to a 0.01 density filter. This equates to about 500 levels of lightness per color. When all of these assumptions and inputs are combined (see Table 1), one finds that film has a significantly higher image information content than either Photo CD or the reference digital camera.

Table 1: Image information per 35 mm Frame for Various Technologies

Technology	Pixels eq mm	Pixels			Bits Pixel	Megabytes Per Image
		Frame height	Frame Width	Frame Total		
Film	150	3,600	5,400	19,440,000	27	65.6
Photo CD	85	2,048	3,072	6,291,456	24	18.9
Digital	43	1,032	1,548	1,597,536	24	4.8
Video	22	480	640	307,200	21	0.9

From Table 1, it is clear that an image of the same original scene taken on film will hold almost 16 times as much information as one taken using a digital camera, such as the DCS 420. Thus, if the photographer is able to compose the scene such that all the material is well represented in a DCS 420 frame, it will produce results that are quite satisfactory. However, if enlargements are needed later on, because the original photograph included too much information that is now known to be unnecessary, the film image will be a much more satisfying medium. In simple terms, today's environments favor film and Photo CD for most field uses like crime scene documentation, and the digital camera in laboratory applications such as crime lab work, mugshots, etc. This is because in crime scene documentation it is often difficult to achieve tight composition of pictures, fill shadows, and know all of the key factors so early in the investigation. The reverse is true in the laboratory.

Sensitivity

When using film, the sensitivity of the system is generally determined by the ISO speed rating of the film being used. Camera lenses and filters also have impact, but these are common across technologies. Color films range in speed from nominally ISO 25 up to 1,600. Some further speed increase of one or two stops can be obtained by using a "push" process. This increased speed usually is accompanied by some degradation of the image in another way, frequently higher contrast and/or graininess. Nonetheless, it is possible to get usable images at equivalent ISO ratings of 3,200. Monochrome films cover the same range on the

low end but can be push-processed to achieve much higher ISO ratings. Good images can be obtained at an exposure index of 50,000. When images are scanned to Photo CD disc, it is possible to pick up even more apparent speed because the contrast and record of an image can be electronically adjusted.

With digital cameras, the speed of the system is dictated by the materials comprising the sensor chip that is built into the camera. These, in turn, have their sensitivity largely determined by the physical size of the pixels and the physics/chemistry of the sensor itself. Typically, digital color cameras have one of two ISO ranges: 100, 200, 400; or 100, 200, 400, 800. The higher speed cameras are much more expensive because of the increased size of the sensor chip that results from a comparable number of larger pixels. Monochrome cameras, compared to the reference color camera, support a top ISO rating of 1,600. Video cameras can have sensitivities about the same as digital cameras, but since the exposure times are fairly long (1/30th of a second), they appear to work well in low light.

Image Access Time

When one takes a picture with film, it is necessary to process the film, and in many cases make prints before the photographer, or anyone else for that matter, can see what is in the image. If a minilab is available, this process takes about one to two hours. If the image is to be scanned to Photo CD, the elapsed time is practically the same. Digital camera images are available for preview in a few seconds, and can be available for full viewing in about a minute, depending upon the power of the computer being used. It takes about four minutes to print an 8 x 10 inch image once the printing process is started. Photo CD prints can be made from the disc in about the same time—four minutes. Photographic prints will require at least half an hour, assuming facilities are right at hand. Two of the biggest advantages of digital photography are rapid access to images and no need for a wet lab. These are important when the photographer is trying to obtain pictures that show particular artifacts and intends to use test images to adjust lighting, viewing angle, etc., in order to get the best rendition. Where the images have already been acquired, and the operator wishes to show particular parts of the image, or has to enhance certain aspects of the image, the Photo CD image and the digital camera image are both advantageous. Video images can be viewed in nearly real time.

Color Rendition

For normal color images, it is generally held today that if each pixel is capable of reproducing 16.7 million colors, the eye will be satisfied. All three of the still technologies under consideration are capable of meeting this requirement. In order to do this, however, certain other factors must also be met. In the case of film, the laboratory must be kept under control and the photographer must have set the exposure within the range of one stop underexposed to two stops overexposed. In the case of Photo CD, the technician making the scan must use the correct conversion data and properly balance the image. The equipment recommended for this work has many safeguards built in to assure that this is done correctly. In the case of the digital camera, the exposure range is from one stop underexposed to the proper setting. Fortunately, the image is immediately viewable, and if exposure corrections are needed, they can be made on the spot without wasting costly materials.

One advantage of film-based photography is the wide range of films with different color reproduction characteristics. For example, some films have a "warm tone" and give good rendition of most facial tones. Other films are more "blue" and so on. There are also a number of specially sensitized films designed to work in the infrared (IR), the ultraviolet (UV), and to give "false color sensitization" (the IR appears as red, for example). Digital cameras offer less flexibility in these areas. The KODAK DIGITAL SCIENCE 420 Color Infrared Camera provides some of this capability. In most digital cameras, each of the pixels has a color filter coated directly on to the sensor to provide a mix of red, green, and blue pixels. Then there is usually an internal processor to interpolate the raw data and provide a normal color image. In the case of this camera, the blue filter is not coated on the pixels that would normally be designated as "blue" Therefore, there are red, green, and native sensitivity pixels. If a filter is placed over the lens to block out infrared, and a processor is used to subtract the green and red signals from the native pixels, one can derive the blue record for them. If a filter that blocks blue is used, then the signal for the infrared can be derived in a similar fashion. UV sensitivity is more difficult to achieve because of glass elements in the camera and the relatively low sensitivity of silicon to short wave lengths. Video systems are similar to digital cameras in many respects, but since they are designed to capture motion, they have dynamic light metering and adjustable exposure while taking pictures. Color quality will, therefore, have a tendency to change as the action proceeds.

Repeatability

In the case of film photography and/or digital photography in the field with no access to a computer, repeatability is very important. The photographer must be able to measure the lighting conditions, make some camera settings, and be assured that good images will result. Today, film manufacturing technology makes products available that can produce very good results under a wide range of conditions. Also, as indicated above, film has a wide latitude, it can be used by novices and still produce very acceptable results most of the time. Using Photo CD technology adds even more reliability, because total curve shapes can be corrected to compensate for gross error in exposure.

Digital cameras require more accurate exposure measurement and control because they have less practical latitude. Fortunately, most of the time these cameras are used in conjunction with a computer, so it is easy to preview the images and make sure that they show the scene as intended. If not, additional pictures can be taken immediately and at virtually no additional cost. Video systems are similar to digital cameras, except that video is often chosen because it can record motion, and in these cases, it is usually impossible to recreate the original motion if the original image was missed for some reason. Real-time metering can sometimes help and sometimes hinder. This is due to "subject failure" For example, if one is photographing a person, and that person moves in such a way as to allow a bright object (such as a lamp, or window, or snowy background) to enter near the center of the frame, the camera will adjust in such a way as to render the person merely a silhouette.

Image Management

To manage a set of film images, one must set up a physical file with a separate index system. The more images under management, the more difficult and complex the task. The index will probably be put on a computer, but the negatives and/or slides must be kept in file drawers or the equivalent. In addition, the pieces of film must be protected from high temperature and high humidity. If there is any fear of tampering, the file must also be secured. It usually takes several minutes to retrieve an image, and if prints are required, it takes at least an hour to produce them. If a negative is incorrectly filed, it is almost impossible to ever retrieve it again, particularly if the file is large.

To store digital camera images, it is recommended that they be written to a WORM, serial-numbered CD, or equivalent technology. This takes the previously ephemeral image and converts it into an easily managed physical record. The better recordable CD media are expected to have a usable life of at least 100 years in storage, and with man/machine readable serial numbers, are easily managed and controlled. In addition, CDs are also quite tamper resistant. Photo CD is similar in principle to recording digital camera images on a recordable CD.

To manage the records, there are a few good multimedia database management software products such as KODAK QUICKSOLVE Software, that contain image processing and viewing features. Using these products, images can be managed in the same software environment that controls documents, spreadsheets, video clips, and so on. This ability allows the user to add value to stored items by setting them in context.

Video is usually recorded on magnetic tape and stored in cassettes, such as the familiar VHS format. While each tape holds a very large amount of data at a very low unit cost, there are several problems that need to be considered. First of all, access to a particular portion of this tape is serial. That is, one must search through the tape to find the proper location. Discs, by comparison have random access - one can go directly to the spot on the disc that holds the sought after information. Secondly, magnetic records deteriorate over time. Over a period of five to 10 years, images will acquire ghosts and noise, ultimately becoming useless. Third, video tapes can be easily erased by stray heat, magnetic fields, or by hitting the wrong button at the wrong time. Fortunately, in most forensic applications, only a short segment of any video recording is really of value in a case. In these situations, it is possible to digitize the video record and write it to a CD. This solves most of the problems of managing video images.

Courtroom Exhibit Validity

Not too long ago, Scientific American magazine exhibited a cover showing a picture of Marilyn Monroe walking arm in arm with Abraham Lincoln. Every day we all see movies like "Jurassic Park" and special effects advertisements on television. It is well known that the new digital technologies make it relatively easy to manipulate images. This makes digital imaging technology suspect in the courtroom. But, such images are not really any more suspect than any images shown in a modern courtroom. This is because it is the integrity of the witness presenting the image that must be demonstrated. Physical items themselves are not "evidence" The testimony of a witness is evidence, and the image is an "exhibit" to that testimony. An image, all by itself, is totally unacceptable. A person, testifying under fear of perjury, must explain what the image is a picture of, why it is relevant, how it was acquired, how it came to be in court, and what it implies. Thus the issue is much greater than the image per se. The key to successful use is in control of the procedures employed. As a result, an agency planning to acquire digital technology should develop standard operating procedures (SOP) and then assure that all staff follow them. This, alone, can go a long way to dispelling doubt. Video images are regularly used in court today and these are even more easily modified than digital images, in most cases, since there is no

reference record that is not easily modified.

It is recommended that in a crime lab where a digital camera is being used, the operators should take their pictures, preview them, delete those that do not show the intended artifacts, and then preserve the others by copying them to a recordable CD along with any archive pack that the camera might write. (The better digital cameras have internal circuitry that reads the camera's settings, keeps track of time and dates, and writes that information to an archive pack attached to the image file. Some even include GPS, compass, and laser range finder information.) This procedure has the effect of creating a point of reference, or "reference image" The disc should have an unalterable serial number and be such that once data is written, it cannot be removed. The result is a uniquely identifiable disc that either has the right information in the right place or it does not. If not, there is immediate suspicion of tampering. If it does, tampering is virtually ruled out. Film images can be preserved in a very similar manner via the Photo CD conversion process. Film images that have not been preserved must be kept in a secure and well managed physical file to accomplish the same degree of protection.

Once a reference image has been created, it is a good idea to keep track of all steps followed in preparing images for use in court. This can be done either by keeping a manual log or by using a "macro" recorder in the software package, if there is one. In any event, the contents of the log should be stored along with the presentation image. Image processing steps that are specific and manually applied to selected areas of an image should be avoided. It is better to use global, or area independent processes, such as edge sharpening, color balance, contrast adjustment, despeckling, etc. These preferences should be written into the SOP, and SOP specifics should be developed relative to the technologies acquired or used.

There is one last twist of logic that has been considered. Because the new technology is so widely available, one does not have to own it to be suspect. In other words, an operator with malicious intentions could easily take a film negative to a professional photo lab, scan the images into a computer, modify the images electronically, and write the new images to a strip of the same type of film. The new fraudulent film strip could be made highly undetectable. The dinosaurs in the film "Jurassic Park" were very believable, even when blown up from a piece of 70 millimeter film to fill an entire movie screen. The technology has come a long way since the days of "King Kong" The point is that it is the integrity of the witness that is in question, not the technology in the lab. And the best way to alleviate this suspicion is to be able to say, "We have standard procedures, and we followed them in preparing these images."

Case Studies

There are two cases in particular that supply significant testimony to verify the admissibility of digitally enhanced evidence photos; they are the *State of California v. Phillip Lee Jackson* and the *State of Washington v. Eric Hayden*.

In the *State of California v. Phillip Lee Jackson*, Mr. Jackson was charged with two murders and one attempted murder. The San Diego Police Department obtained fingerprints from two of the crime scenes which were enhanced using traditional processes and proved to be those of the defendants. Fingerprints from the third scene were difficult to focus on as the ridges were seen as "tonal reversal" Using a computer and working with a digital image of these prints, the examiner was able to adjust brightness, contrast, size, and color tone, without damaging the integrity of the prints. They matched those from the other two crime scenes.

This evidence was disputed and a "Kelly-Frye" hearing was requested to establish whether this digitally enhanced print was admissible. It was ultimately admitted and the defendant was convicted.

In the *State of Washington v. Eric Hayden* case, the defendant was charged with the murder of a young missionary. A sheet with faint prints was recovered from the crime scene, however, due to the faint ridge detail and the elaborate fabric pattern of the material, attempts to compare existing prints were not possible. The prints were then sent for digital enhancement. After review, all three prints were determined to belong to the defendant. Again a "Kelly-Frye" hearing was requested, raising the questions of tampering, whether intentional or inadvertent.'

Since no one on the team had seen the direct prints of this defendant, it would have been impossible for them to deliberately manipulate the images to make them reflect a match. As for any inadvertent changes to the prints, a review of the examiners' strict SOP and a courtroom demonstration using the actual fingerprints from the crime laid to rest any doubts, and the question was dismissed.

Cost

Just as it is difficult to compare the performance of digital and analog imaging systems, it is difficult to compare the costs associated with them as well. This is because the film systems have relatively inexpensive equipment and moderate per-image costs. (Note, the exceptions to the rule are processors and printers. These functions, however, are usually purchased as a service.) Digital imaging utilizes more expensive equipment, but the cost of each image captured is very low while the cost of prints is a bit higher. The cost per image kept and/or printed is a bit higher than that for traditional film and, by comparison, considerably lower than that for instant film. With digital cameras, images captured are stored on a magnetic disc until moved to a permanent medium such as a CD and/or a hard copy print. All of the images on the magnetic disc will eventually be erased and the media reused. In addition, there are always several images that are captured and not used. Combining all these factors, the average cost for digital and video imaging are comparable because of print and storage costs. They are higher than that for traditional film and lower than that for instant film where one must pay for all captured images, whether they are used or not. In summary, the three technologies that provide instant viewing are more expensive than the one that does not. The one that requires processing and is the lowest cost system, is the one with the highest image quality. See Table #2 - but please note that prices can vary considerably depending on features, quality, and the availability of short-term promotions. It is interesting to note that with many production systems, as the volume of usage goes up, the cost of equipment becomes a very small part of the total cost of ownership.

Table 2: Comparisons of Costs of Ownership (assumptions detailed in appendix)

Images Saved	10,000	50,000	100,000
Prints Made	50,000	250,000	500,000
Technology			
Film & CD	40,600	155,000	298,000
Digital	80,500	292,000	535,000
Video	61,500	251,000	511,503
Instant	100,200	460,200	910,200

Conclusion

To select the right imaging technology, start with the application. If one will be in the field taking many high-quality pictures, and then working with them and making enlargements later on, film has many advantages. Whereas, if one is in the laboratory taking many pictures in an interactive mode, and keeping only the ones that show the right artifacts, the digital camera becomes increasingly advantageous as picture volume increases. When film is used, it is possible to save picture printing costs by scanning negatives directly to Photo CD, and only printing those that need to be printed. This streamlining also saves operator and investigator time.

As more and more images move into the courtroom for presentation on a computer monitor, the value of the digitized images will greatly increase since much less operator time is needed to prepare the materials for court. Finally, as enterprise-wide information systems allow the movement of multimedia information among personnel within a department and then among departments, agencies and jurisdictions; the cost and effectiveness of digital imaging is becoming increasingly significant.

Appendix: Cost of Ownership Assumptions

Traditional Film Imaging: Each negative costs \$0.16, including processing. For each image saved, there are five prints made and two negatives were consumed. Each print is in 5 x 7 inch format and costs \$0.50 each. In addition to negatives, CDs are saved at \$0.05 per image. The camera kit costs \$2,000, and a \$10,000 computer system is used to write the images to CDs.

Digital Camera Imaging: The camera costs \$8,000 and the accompanying computer system to provide the processing, printing, and CD writing capability costs an additional \$22,000, with software. There is no cost for images captured (the magnetic media cost is included in the cost of the camera and is reused). Prints are in the 5 x 7 inch format and cost \$1.00 each. Images are stored on CD at a cost of \$0.05 each. There are five prints per image saved.

Video Imaging: The video camera kit cost is \$1,500 and a \$10,000 computer system is used to capture frame images and print them. The video tape holds one hour of material at a 30 per-second frame rate and a roll cost of \$3.00. Prints cost \$1.00 each, and there are five prints per image saved.

Instant Film Imaging: The camera kit costs \$200 and the film sheets cost \$1.00 each. Four images are captured per image saved. Prints are made by scanning film images and then printing on-line. The cost is \$1.00 per 5 x 7 inch print and the computer system for doing this costs \$10,000.

* Erik Berg; *Forensic Image Processing, An Introduction to Image Enhancement*; 1996.

