Forensic Image Analysis
Version 2

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SCOPE

The central theme of this review is the scientific analysis of image-based information for forensic science applications. Clearly, there is a strong link with other technologies, such as image capture, information technology and digital evidence, and these closely related technologies are considered where they either indicate a trend or have an impact on the process of image analysis. Forensic image analysis is an activity that forms part of most forensic evidential examinations e.g. documents, handwriting, firearms, shoemarks, fingerprints, etc. But as these evidence types are considered in the other Interpol reports that form this symposium, this review will concentrate evidence where the image is the primary evidence type e.g. CCTV, facial images, crime scene imaging and 3D imaging.

In particular, it is the purpose of this review to communicate the changes in forensic image analysis techniques that have occurred since the 12th International Forensic Science Symposium in 1998 by Klasén [1], which provides a benchmark for this review.

Information for this review has been requested from 246 forensic institutions and laboratories across the world primarily through a proforma questionnaire. A return of 30 was achieved with the majority of responses from Europe (see Appendix for complete list of returning institutions). Additional information has been collated from a comprehensive survey of published material in this subject since 1998.

SUMMARY

A key result of this latest review is recognition that the analysis and processing of visual information is a common activity in many areas of forensic science. Such visual information has traditionally been recorded as photographs or a sequence of images in the form of analogue video. In 1998 at the 12th Interpol Symposium, Lena Klasén highlighted the fact that digital still images, digital video and digital processing were being introduced into the forensic activities. It is reported here that over the intervening three years this trend has continued apace and today digital imaging technology has now penetrated almost all areas of forensic science activity. However, in the main this is largely for specific functions within individual laboratories, and there is little evidence for fully integrated imaging and image analysis information technology between different forensic functions at present.

This introduction of digital technology has enabled forensic scientists to do traditional forensic activities in a new way. For instance, images can be viewed at the crime scene or laboratory within minutes rather than hours whilst simultaneously making the images available to other experts via communication links. In addition, continuing advances in mathematical algorithms and the increasing processing power of computers has resulted in new hi-tech activities which generate or present a wealth of information from or about an image once it has been digitised.

The pace of technology change, has in the main, left many people having to rapidly consider the implications for their rules of evidence and this is reflected in the lack of agreed international standards for forensic image management.

Biometric technology still has, for the most part, some way to go before it will be robust enough for forensic science use although it has considerable application within the security industry at present.

INTRODUCTION

This review aims to provide a concise representation of the state of image analysis technology and activity within forensic institutions world-wide by bringing up to date the last Interpol report on the subject in 1998. As already indicated, the last 3 years has seen the continuing implementation of digital imaging technologies within forensic activities. Furthermore, there have also been advances in image processing technologies applied to such images that now allow data from more than one image to be combined providing improved data for subsequent analysis.

This review has been structured to reflect two main changes in digital images within forensic science namely, the emergence of digital imaging as the preferred method of image capture and the new image analysis technologies that have been introduced for forensic applications. The final parts of this review consider the ongoing research, and issues around image management and legislation. Finally, future developments in this sector are anticipated. A comprehensive listing of publications is also provided.

IMAGING

Digital Cameras

The dominant image capture technology pre-1998 was traditional photographic and analogue video-tapes. From the Klasén last review paper [1] and overview of photography and digital imaging [2] it can be concluded that the digital capture of images was confined to specialist activities in a handful of forensic institutes. The most common use of this technology was in digitising analogue video and fingermarks for further image processing or analysis. Since 1998, the whole of the forensic science community has either started or is contemplating the introduction of digital imaging at the crime scene, laboratory and in court [3-17]. This rapid uptake of technology can be attributed to a couple of dramatic advances. Firstly, there has been a huge reduction in the cost and secondly, cameras have got smaller and more user friendly thus, freeing them from specialists and put them into the reach of the casual user. For instance, in 1998 a video frame grabber such as the σTech M-Vision cost approximately $3000 compared to $200 in 2001 (e.g. DBS DFG LC1). A further example in the 3 to 4 Mega-pixel range, such as the Photometrics CH250 that was not particularly portable and no viewfinder did cost approximately $30,000 compared with today's Nikon Coolpix for approximately $1000.

Accompanying the spread of commodity digital cameras has been the proliferation of image processing software that allows people to process and print their images. This software has absorbed sophisticated linear image processing algorithms of the past and given the consumer the ability to make dramatic changes to their images. It is this increased awareness of the possibilities of image manipulation by the general public that has made courts and jurors conscious of the possible misuse of digital images. Therefore, this widespread consumer use of digital technology has focused the forensic community on processes and practices that maximises the integrity of the image.

It is noted that within forensic science the use of digital cameras has not negated the need for professional photographic skills at image capture and ensuring image quality output. There is also an increasing requirement for skilled engineers and computer-vision experts to process images.

It is also recognised that a range of digital camera technology is required to cope with the imaging demands of forensic science, this is similar to traditional photography where a photographer would use a range of camera formats, film, optics and filters. One way of addressing the needs of forensic imaging is to recognise the various imaging requirements. The following sections identifies four different uses of images highlighted in the survey:

Note images

Definition: A note image is a fit-for-purpose illustration of the view of interest. [†]

Figure 1: An example of the type of note taking image which is used as an illustration of the shirt examined.

[†] **The definitions used in the following 4 sections for different image types are for the purposes of this document and do not have any international recognition as standard forensic image types.**

It has emerged that low cost digital cameras e.g. Sony Mavica and Sony Handycam, are starting to replace the traditional Polaroid photograph for note keeping. It has been generally found that the resolution, colour matching and compression inherent with these types of cameras & camcorders is adequate to provide the forensic scientist with a suitable illustration of the view of interest. The primarily place for these digital images is during the contemporaneous note taking stage of casework (Figure 1). In digital form the note taking images could be incorporated into a database or into an electronic case-file system. This review found no such note taking image database currently in use within forensic institutions.

Intelligence Images

Definition: An intelligence image is visual information or data for use in the course of an investigation or series of cases.

Figure 2: An example of an intelligence image. The partial shoemark image provides information about the make and model of the shoe.

This area of image acquisition has seen the greatest increase in the use of digital cameras. Intelligence images are not used for evidential purposes, although, they can provide useful visual information to law enforcement during the course of an investigation (Figure 2). The quality of the image acquisition is determined by the operational requirement at the time. However, the main advantage of a digital intelligence image is the ability to disseminate it rapidly and simultaneously to many people. Typically, image compression techniques are used to produce practical size images for transmission. Similar technology as that used for note taking has been implemented for intelligence image capture as well as digital scanners and mini DV camcorders.

Record images

Definition: A record image is a true visual representation of an item or detail that is likely to be used for interpretation or as an illustration in court.

Figure 3: An example of a record image of a firearm. This type of image is generally used for court purposes.

These images may be exhibited (typically in an album) as an item to illustrate something in court and a statement is usually written to cover the item produced (Figure 3). In some casework the record image is the only remaining evidence as the original item, packaging, etc. may have been destroyed. The introduction of digital cameras for record imaging has enabled a faster turn-around of colour-matched prints. The price of suitable cameras and photographic quality printer (e.g. Fuji Pictography 4000) is still the prohibitive factor in this forensic activity. In addition, the resolution characteristic of digital cameras does cause aliasing effects on some detail, such as fine stripes on shirts. This will of course be depending on field of view and size of detail. A practical solution to this aliasing problem is the inclusion of anti-aliasing filters in the camera lens.

The Zurich Canton police have been using the Nikon D1 for the past year and are generally happy with its performance. In addition, the camera has authentication software that can determine whether the image has been edited after its original capture from the camera.

Identification images

Definition: An identification image is a visual representation of data for use in the process of forming an opinion about whether or not two entities have an identical source.

Figure 4: An example of a typical image (Fingermark) used for comparison

In the process of forensic identification the forensic scientist uses the image to a greater or lesser extent to do some or all of the comparison activities (Figure 4). The image is often the primary visual representation of the data of interest. It is in this activity that the true capabilities of digital cameras are being stretched. From the survey it has been found that the highest resolution camera's e.g.Kodak DCS 660, Nikon D1 are being used in the capture of fingermark data. However, these cameras can not resolve the smallest unique details in other evidence (i.e. feathering) in shoemarks whilst simultaneously capturing the whole area of interest (i.e. whole shoemark). In the commercial market there are digital backs which can be attached to medium and large format traditional cameras. These digital backs have superior resolution characteristics but cost around $40,000. This high cost has prevented their use within most of the forensic community. A different approach to digitising large areas at a resolution above 600 dpi has been tested and implemented in a pilot scheme at the FSS. This approach uses re–engineered flatbed scanner technology turned upside down to capture marks. The use of scanners and array cameras is not new for imaging marks, AFIS systems routinely scan in fingerprint details for searching.

It has been reported in several forensic institutions that they have converted or have set up special units that only use digital techniques for comparison activities. However, the actual comparison is still done on hardcopy output. This causes its own problem as the only practical photographic digital hardcopy output at present has a maximum output resolution of 400dpi (Fuji Pictography 4000).

Closed Circuit TeleVision

Closed Circuit TeleVision (CCTV) is a common source images within law enforcement. These images can be used in any of the four activities described above. The main difference between CCTV images and other forensic images are that they are often acquired on non-law enforcement system and as a result the overall quality of the image is controlled by industry.

The number of CCTV cameras is on the increase and in Britain alone cameras in public places has passed the 1million, according to industry figures [18]. On an average day in any big city, an individual could be captured by more than 300 cameras from 30 different CCTV networks. In London, a person is captured on camera at least every five minutes and in central areas is likely to be watched by cameras at least half the time (Figure 5). The same sort of figures can now be expected in other large cities around the world. With this amount of video footage there is an increasing probability that criminal activity is captured on video.

Figure 5: A typical CCTV image.

Since the last report there has been a growth in the number of organisations digitising traditional analogue video in order to take advantage of computer vision and image processing techniques. From the survey there seems to be an unwritten standard that any image captured from video should be uncompressed and the two most popular frame grabbers for this process are DBS DFG LC1 and Matrox Meteor. The DBS frame grabber is a cheap way of digitising good quality images from video, but is limited by the computer RAM. The Matrox is a more expensive option but allows large quantity of video to be captured when connected to a disk array.

An important part of any digitisation technique is to assess the resultant image quality and apply good practice for digitisation. Ross [19] breaks down the issues of image quality into five main areas: Resolution, Sharpness, Noise, Linearity and Spatial distortion and suggests useful experiments to examine the frame grabbers characteristics. In the area of good practice some good groundwork was presented by Geradts [29] on real-time digitisation and storage of uncompressed video.

A more recent emergence in the field of CCTV and surveillance is the use of digital video. The first generation of digital CCTV systems converted the analogue electrical signals from cameras or CCD array's into digital data. The image data is then stored onto a digital medium. The main advantage of the digital medium with regard to image quality is that it can be replayed and copied without any original image degradation. However, the main problem with digital CCTV recordings is in the compression used. At the moment there are no common standards for video data storage in the CCTV industry. From the review of CCTV the main compression types being used are JPEG, Wavelet and MPEG. However, there are in-house techniques being employed as well. In addition to the different compression techniques there are many methods of encryption and watermarking being employed. This has lead to a problem in retrieving digitally recorded video within the forensic environment, as it is not feasible to duplicate the systems in forensic laboratories. A further difference is that the degree of compression in most cases produces poorer quality images than traditional analogue systems. The conclusion, of the CCTV survey was that the cost and lack of standards in the digital CCTV industry has lead to consumer uncertainty. This is reflected in the current status of digital technology in the CCTV market place (<5%). It was envisaged that digital CCTV will become dominate in 3-5 years.

IMAGE PROCESSING

The increase in the use digital image capture has presented greater opportunities for the application of image processing. The table below identifies the range of processing that is being applied to forensic digital images:

Image Processing Technique	Process Input	Process Output	Example
Image enhancement	Image A	Image B	Debluring, contrast adjustment.
Image Analysis	Image	Data	Height measurement, Speed of car.
Image Interpretation	Image	Information	Type of car,
Image Comparison	> 1 image	Correlation data	Facial mapping, shoemark comparison,
Pattern Recognition	Image	Classified Data	shoemark pattern coding.
Image Reconstruction	Data, Images, and/or information	Image	Crime Scene computer model

Image enhancement

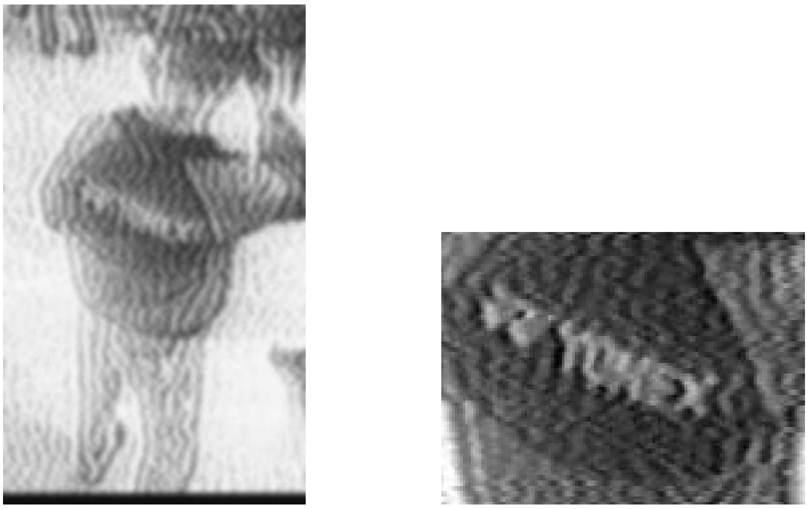
Definition, grey scale, and signal-to-noise ratio are fundamental criteria that apply to all imaging systems. More often than not, an image will require some form of image processing to improve its appearance for aesthetic reasons, or to improve the ability to extract data from it. The majority of digital image processing done in the forensic environment is to improve the aesthetic appearance of the image using digital tools that replicate photographic processing such as brightness and contrast changes. Whilst these simple enhancement techniques can sometimes produce improvements in image detail it should be noted that it can not recover information that was not recorded.

Single Image Enhancement

The inherent natural of images means that they often require some form of enhancement to match the appearance of the original scene, improve the aesthetic appearance of the image, or to extract non-visual data from the image. Digital image processing is enabling the forensic scientist with a greater range of tools that are easier to use compared to analogue techniques. The most popular products being used for this single image enhancement are Image Pro-Plus, Adobe Photoshop and Corel Photopaint.

More sophisticated and complex spatial filtering operations [20-25] are being employed to "tease out" and refine visual information. The well-known linear and non-linear filters (such as low pass, high pass, median filters) reduce or increase the rate of change that occurs in the intensity transition within an image. The most common activity that uses these filters is fingerprint analysis where they are used to enhance ridge details. It must be pointed out that this type of filtering is not new to forensic science but the usage is more widespread since the digital capture of images.

Recent developments in non-linear methods allow the simultaneous reduction of noise levels whilst preserving image sharpness and boasting contrast. Using classical filters the image would be blurred to reduce the noise or the noise would be increased when sharpening edges. Techniques using Partial Differential Equations (PDEs) and coupled non-linear PDEs produce a natural way of efficiently optimising the image (Figure 6). Depending on the application, one or several of these have to be achieved in the same or different areas of the images. The use of filters can not recover information that has not been recorded so in essence they only use is to make the image detail more aesthetically pleasing.



(a) Pre-processed (b) – processed
Figure 6 : The result of a low quality image (a) being processed using a coupled non-linear PDE (b). Note that the process only makes the image more aesthetically pleasing (subjective) and does not recover data that has not been recorded.

Multiple Image enhancement

Enhancing single images only allow the operator to process the information recorded for that image. Therefore, to retrieve the maximum information about an object captured it has been found that using multiple images provide a more efficient enhancement or restoration technique. The two main areas where multiple images are being used in the field of forensic science is to remove unwanted background from a mark and to enhance image and detail resolution whilst removing large noise degradation in the image.

The most common image processing technique that uses multiple images is frame averaging. This technique has been shown to reduce noise levels effectively [26-28] and is routinely performed in some laboratories [29-30] to attenuate noise incurred from video and frame-grabbing equipment. The processing of averaging gives the same result perceived by the eye when a video is played at high speed. It is also possible from this technique to combine fragmented information present in several images into one image that contains the information previously spread between images. Unfortunately, the use of frame averaging is limited to static image content as any motion has a detrimental effect on the desired outcome. However, multi-frame averaging and homomorphic filtering [27] has been used to equalise the effects of different illumination conditions across an image. This is accomplished by applying a spatial high-pass filter. By following frame averaging with homomorphic filtering, it is reported that details obscured by shadows may be clarified without losing important foreground information.

It is now possible to generate a high resolution of a moving object from images (typically, video frames or fields) once they have been digitised. This particular task is known as frame fusion or frame stabilisation [41a, 41b]. Unlike frame averaging techniques, frame fusion allows for significant motion and other geometrical changes in the video (Figure 7). There are two aspects to frame fusion: firstly, tracking the moving object in order to obtain image correspondence. There have been several interesting papers on the topic of object tracking with dedicated software being produced to solve forensic problems [31-32]. The second part of frame fusion is the modelling of degradation (a combination of motion blur, focus blur, and discreet sampling) in order to facilitate the restoration. This type of functionality is only now being taken utilised by forensic establishments because of it inclusion in commercial image processing package. The most popular package for frame fusion is Cognitech Video Investigator, with a few using Detail Explorer.

a) (b) (c)

Figure 7: (a) and (b) are two images from a sequence of a van captured on video. (c) The result of stabilising the van's licence plate and then averaging the images.

The process of registering image information together can also be used to produce mosaic images. The production of mosaic images involves stitching a video sequence together to produce a panoramic scene reconstruction. This method can be used to complete a view of a dynamically occluded object.

Another application which frame/image registration has been successfully implemented from the IMPROOFS research project (See section 7) is in the removal of distracting background patterns from forensic evidence so that the evidence is rendered more visible [34]. An example is the image of a fingerprint on a non-periodic background. The method involves a precise registration of the evidence image with a control image of the background pattern. A photometric registration is then required to allow for colour difference between the two images. These differences may be caused by the lighting environment at time of capture and by the chemical treatment used to enhance the mark. Once the two images have been geometrically and photometerically registered a statistical comparison is performed that compares both images on a pixel-by-pixel basis in order to render a difference image of the mark (Figure 8). (other digital enhancement techniques are being employed on marks [35-38])

(a) (b) (c)

Figure 8: An example of removing the non-periodic background from an evidence mark. The evidence mark (a) is registered geometrically and photometrically to a sample image of the background (b) before being subtracted (c).

All of the processes described above will modify pixel values in the resultant image compared to the original value. In changing the pixel values it is important to ensure, via validation, that no artefacts are introduced into the detail of interest. A good illustration of the need to validate a process was shown by Geradts work on super-resolution [39]. Where from preliminary experiments using frame fusion he found that under certain conditions some known letters in a low-resolution image of a car registration plate could resemble numbers after processing.

De-multiplexing

A common problem encountered by law enforcement agencies is the difficulty in viewing or restoring a single camera view from a time-multiplexed video recording from CCTV system. The proprietary nature of the coding procedure by the multiplexer manufacturer for identifying the camera usually requires the same make and model to be used for playback of one camera view at a time. The variety of reported multiplexers in use makes it difficult for law enforcement agencies to keep a compatible model on hand during the investigation. There are so-called universal hardware de-multiplexer units that can de-multiplex approximately 80% of systems. The problem with these units is keeping up to date with the codes as manufacturers change the coding when updating the product. Therefore, the recent software de-multiplexing of the digitised video is a more effective approach. Of the various software approaches the content-based method is the most common [40-41]. A single frame from the specified view is used as a reference to which subsequent frames are compared. Frames matching the reference within a specified similarity threshold are passed on to the de-multiplexed output. Unfortunately, this approach does not adapt itself well when there is movement in the reference part of the frame or camera movement. The most recent de-multiplexing software is free of any threshold difference between camera views, and does not depend on the presence of quiet zones [41]. The method applies energy minimisation to de-multiplexing which also compensates for interference noise, local and global motion and contrast changes.

Image Analysis

Measurements taken from photographs has been the traditional method e.g. ratios, and scaling, of performing any marks comparison. The introduction of digital imaging has not changed the nature of the comparison activity. However, it has enabled the scientist to extract information more easily including other sources of imagery e.g. video. Computers have also enabled the scientist to extract measurement information from objects that are not parallel to the camera plane. The underlying mathematics behind these measurements, or photogrammetry techniques have been around since the times of Leonardo da Vinci, but digital technology has made them more accessible. The biggest advance in this particular forensic area in the last three years has been the ability to visualise and extract image detail in three-dimensions (3D). The use of 3D for visualising crime scene has lead to a change in the way information is disseminated in the investigation. In addition, the 3D acquisition of image detail has been shown to add more weight in a mark's comparison case. The following section will review the advances in image measurement and 3D reconstruction in the forensic community.

Photogrammetry

Photogrammetry is the process of obtaining measurements from images. Image measurements are being used to provide useful information about the course of events and the size of items and persons in a crime scene. The two most commonly reported forensic activities that involve photogrammetry are human height analysis and accident analysis of motor vehicles.

In the case of calculating the height of an unknown individual in an image there are a number of techniques [41-46] available to aid the scientist, some reported in the last report. This height information could be used as an alternative means of providing useful information about the individual. However, any information taken from an image must be scrutinised for its reliability and then assessed in the context of the customer's requirements, whether it is for intelligence or corroborative evidence. In Compton's paper a methodology and procedure for calculating heights from images in a forensic environment has been presented [47]. To support the methodology it is recommended that all metrology techniques should be validated for their reliability and repeatability within the criminal justice system using appropriate measuring standards where possible. In addition, a standard operating procedure should also be put in place together with competent operators to ensure the continuity and integrity of any results. More importantly, the paper highlighted possible sources of uncertainty in the generic metrology process. These uncertainties will propagate through the metrology technique and have a significant effect on the reliability of associating a calculated height to the true static height of an individual. From experimental results it was found that the most significant uncertainties were associated to the stance and gait (Figure 9) of the individual in the image [42, 47-48]. However, these findings need to be substantiated for other photogrammetry techniques. It is therefore important that the sources of uncertainty are understood and can be accounted for in the final measurement, this also includes the calibration uncertainties.

In addition, knowledge on the uncertainty of any real world measurement must be known and wherever possible standards should be used to ensure the validity of the data. It is also worth noticing that the "true" height of a crime suspect also can be an uncertain value, which is being used for comparison to a height measured from images. In the worst case, it is even unknown whether this value includes the shoes or not.

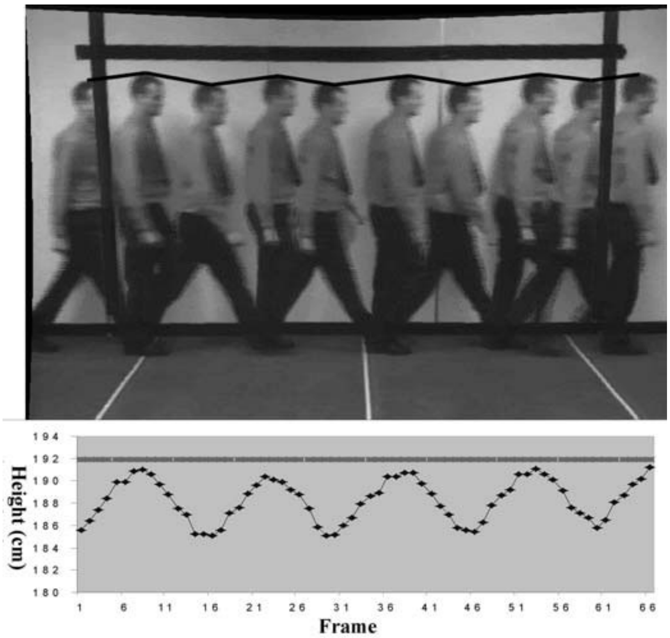


Figure 9: An example of the variation in height when an individual walks.

Within the forensic activity of vehicle accident analysis the reconstruction of events is of prime importance [49-51]. Therefore, a detailed collection of scene data (such as, vehicle positions, road marks, and personal injuries) forms the basis for a high-quality reconstruction. It is also important, when formulating the physical and mathematical model of a car, to take into account the fact that many parameters are not well known when reconstructing the accident. The traditional process of performing the investigator and testing scenarios was very time consuming using sketches and calculating figures. In recent years the increase performance of personal computers has made it possible to use more sophisticated reconstruction or simulation algorithms to study accidents. Several computer programs have been developed especially for the calculation of vehicle motion and collisions based on various physical models. As part of this process photography techniques are being used. PC-CRASH has been reported [50] to be one the most popular programs with a world-wide distribution. It uses a kinetic time forward simulation of vehicle dynamics and combines it with a momentum based collision model; accidents can be reconstructed, starting from the point reaction to the end position. The final advantage of this type of software is the ability to reconstruct the accident in 3D from the calculated results.

Another forensic activity that has benefited from computing processing is bloodstain pattern analysis. The main idea is to identify the bloodstains impact directions and back-project to the source of the blood. The traditional method involved taking measurements of bloodstains, calculating angles and using string to back-project at the crime scene. Over the last few years software (Back Track) is now being used to reconstruct the flight paths of blood droplets and visually produce the result of a collection of virtual strings that converge towards the location of the source of the projected blood [52]. The use of this software has resulted in high quality rapid results and is in routine use in Canada and is currently being validated for use in the UK.

Image reconstruction

In many industries three-dimensional (3D) information has been used for many years. 3D computer generated models of scenes (in particular crime scenes) and objects present complex and diverse information in a visually informative manner (Figure 10). Consequently, over the last three years law enforcement agencies have been increasingly developing this technology to assist in the investigation and presentation of crime scenes and related evidence. From the literature review [53-54] it seems that 3D computer modelling, image based modelling and panoramic imaging are being developed and implemented for use in the Criminal Justice Systems.

To create a 3D model both measurements (tape measure/laser range finder) and photographs (digital camera/scanner) need to be acquired from the crime scene. The operator then uses these measurements to produce a scale representation of the scene, using textures extracted from the digitised photographs for the object surfaces (3Dstudio Max / Adobe PhotoShop). The model can then be used for presentation and scenario testing. There are several police forces and research units (AIMES Research Unit, University of Nottingham, UK; Virtual Reconstructions Ltd, UK) that are using 3D studio Max to produce models. This type of reconstruction has been presented in court and used to aid the visualisation scenes [55-70]. However, there is concern over the power of 3D models as they can potentially misguide the courts if not used responsibly as they can have a powerful impact and are often memorable.

Figure 10: A 3D model of a crime scene

In addition to the 3D reconstruction being used as a visual aid it has been used for testing scenarios. One such case was the use of 3D modelling to determine whether a camera could have been concealed using recovered camcorder footage data [71]. Image based modelling works directly from photographs where 3D geometry is 'pinned' to shapes in images and like-points are matched between photographs.

Although, a 3D model can be obtained from one photograph, better results are obtained from multiple photographs. Textures are taken directly from the image. A 3D model created using this approach (in a software package called Canoma) can be used for briefing and intelligence purposes.

There has been a high occurrence of image based modelling used for crime scene representation in the USA, particularly accident investigation (using software called 3D Builder Pro / Image Modeller).

Panoramic Imaging involves the use of two fish-eye digital images to create a 360^o spherical representation of the scene that the operator is able to view (using Panoramic Tools Plug-In for Adobe PhotoShop). The process is very quick and the resulting images can be sent from the scene to a remote location (Figure 11). This technique can be used for briefing, court-room presentation and to assist in the investigation. Queensland Police, Australia, originally used this technology in crime scene investigation. (note: should add – "IMOVE is a company that is marketing a 6-camera system that creates real-time 360-degree views. Interested parties may investigate the company at www.imoveinc.com ".)

Figure 11: ***An example of a panoramic view in 2D form. Several images of the scene have been stitched together to produce image of the whole room.***

3D reconstruction or modelling is also being used for Face Recognition and Reconstruction. It is reported that facial reconstruction is being used as a routine procedure in reconstructing facial detail from skulls or producing a 3D model from 2D images (discussed later). There are several systems and techniques available that acquire the basic structure from optical laser scanning systems or by photogrammetry means using multiple image correspondence [72-79]. The main advantage of computerisation is that it offers a greater potential for easy revision of images i.e. Identikit, ageing and environmental lighting and the production of a 3D mugshot, dental comparisons [145-149] and cranofacial reconstruction [150-152]. Several pilot schemes for 3D mughots have been undertaken, in particular by the Belgian Police. However, the use of 3D faces for comparison has yet to be adopted world-wide. More detail on facial comparison is covered in the section on person identification.

A few cases have been reported [82-94] where 3D images have been used for comparison of mark detail. These cases (fingerprint detail, handwriting, tyre tread) have used the depth information together with the normal 2D information to provide extra information and increase the discriminating power of the comparison. The validity of such comparison is not covered in this report, although there is a working committee looking at this in Europe (ENFSI 3D working committee). The limiting factor for the acquisition of 3D traces and marks images is the cost of the equipment. For such comparison it is necessary to capture detail of 1mm and the only equipment capable of this are lasers. The cost of 3D laser systems in around $70,000, this cost restriction is also limiting factor for scene reconstruction

Image Identification

The responsibility for any forensic image interpretation within different establishments is mixed. In some instances there are dedicated imaging experts who deal with the technical aspects of the images and also the interpretation of events or objects in the image. Other organisations draw on a pool of experts from different forensic areas to interpret and address different aspects in the case. This combined approach prevents experts straying from their area of expertise.

An illustration of the different types of image interpretation which have been carried out over the last two years are Expert reports by Klasén [95] and Vector Data Systems [96] in the WACO investigation and Vorder Bruegge [97] work on comparing jeans.

Vector Data Systems (VDS) used a host of image processing tools to extract data and images from video footage taken at the WACO incident. From this data VDS experts were able to address the questions of when the first visual evidence of firing appears at a specific building and whether personnel can be seen on the ground. In addition, VDS supplied external dimensions and orientation of specific buildings from the video footage.

Other image interpretation work carried out in the WACO investigation was by Klasén and Madsen to investigate the flashes seen on the video tapes and to determine the authentication of the video tapes. The investigation included several of the analytical methods already discussed in this survey, authentication, image enhancement, 3D reconstruction, image reconstruction and identification. The video footage was digitised into three hour uncompressed video sequences and from a painstaking 3D reconstruction of the geometrical relationship between the sun, aircraft and the flashes ground position in the period of interest, Klasén found that they were caused by solar or heat reflections from debris. In order to address the originality and authenticity of the videotape Madsen analysed the characteristics of their electrical signals of the videotapes.

As part of any comparison from imagery some form of interpretation is required. During Vorder Bruegge's investigation on the photographic identification of a pair of denim trousers from bank surveillance film, he first had to determine the reliability of image detail in the photograph. Vorder Bruegge recognises that motion blur and resolution of the image can be a major factor in causing fine detail to be absent in the image. Depending on the level of detail recorded it might make it impossible to make an identification or elimination based on that detail. Once determining the limitation of the imagery a comparison was made with a recovered pair of jeans. The comparison looked at the individual identifying characteristics that are generated in the manufacturing process and during normal wear and tear.

The majority of any image interpretation and comparison activities in law enforcement establishments are subjective. However, automatic image interpretation methods are being looked at that produce a more consistent and repeatable assessment.

Person Identification

There are many ways of identifying an individual and Bertillon was probably the first to look at the work in a scientifically sound process. Over a hundred years ago he began to tackle the question of identification through a system that involved around eleven measurements of the human anatomy. As Bramble explained he chose those parts of the body that could be measured accurately, however it was beyond the ability of most police officers to record such measurements with sufficient accuracy to make the system widely applicable [98]. Another limitation of his method was that criminals did not leave their measurements behind at a crime scene unlike fingerprints. This is where things have changed in the intervening century. The advent of CCTV and surveillance system means criminals are now leaving a 'trace' of their body behind at the scene. As a consequence there are many research projects which are now looking into identifying individuals by biometric technologies.

There are two types main of biometric systems, namely: identification and verification, with the type of system chosen for a specific purpose would depend on the information required. An identification system works by asking the question, 'Who is this individual', the biometric is compared to a database of known individuals and an identification is suggested. The performance of such a system is measured by the number of correct identifications the system produces [99]. Alternatively a verification system checks that an individual is who they claim to be by comparing the biometric with the known biometric of that person held in a database. The performance of a verification system is measured in terms of the number of false acceptances of the identification and the number of false rejections of the identification [99].

In 1999, the book, 'Biometrics: Personal Identification in Networked Society' was published [100]. This book discusses current work being carried out in the different areas of biometric research. It also examines the advantages and disadvantages of each of the types of biometric technologies and discusses whether these techniques could or should be applied within society. However, over the last three years there have not been any great advances in the casework activities of identifying and individual from their recording in an image. This is because in the main the technology is really only robust enough for security applications at present. The lack of image capture control within forensic science means that the quality of image is usually too poor for such systems to perform effectively. The greatest advances have been in the interpretation of these techniques.

The following section will discuss the impact of digital imaging technology in the areas of identifying humans images by faces, cranofacial detail, face reconstruction and other biometrics methods including height and gait.

Therefore, this section will discuss how digital imaging techniques are used in identification of human remains and to examine injuries, identification of human images by faces, cranofacial identification and face reconstruction. In addition, it will cover interpretation issues concerning identification by other biometrics methods including height and gait.

Facial Recognition/Identification

The problem of automatic face recognition is a complex task that involves detection and location of faces in a cluttered background followed by normalisation and recognition. There has been some interesting research that examined how humans actually recognise individuals. Bruce and Burton [101-102] have continued their work in understanding how people recognise one another and found by experiments that in poor quality images it is through the combination of head, body and clothing information. More recently, it is noticeable that there are many commercial face recognition systems (FaceIt, Mandrake, Marlin etc) are being sold around the world. The systems are based on several different mathematical approaches such as Principal Component Analysis (Eigenfaces), Component Feature comparison, and Feedforward Neural Networks [103-109]. Many of these systems and techniques have been tested using the FERET (Face Recognition Technology) database have achieved levels of 96% and above. From a review of such techniques Gurin states that it was impossible for any single currently available approach to achieve 100% accuracy due to the complexity of the face [110]. In addition, he decided it was impossible to select a 'best' face-recognition method. This is probably why these systems have limited application within law enforcement and forensic science. The systems are either set up for one to one matching (verification or authentication) or one to many matching (identification). In general, both processes compare two faces and determine a match value. In verification mode a certain confidence level is set so if the match value exceeds this values the match is successful and identity is verified. In a one-to-many comparison the systems compute the degree of overlap between the captured face and those associated with known individuals stored in database of facial images. It then returns a list of possible individuals ordering them in diminishing score. From this shortlist an operator will determine whether or not the individual is present in the database. The shortlist is just used to minimise the time of the operator looking through the face database. This type of application for face recognition system is being used by law enforcement as an intelligence tool. One of the most publicly known schemes is in Newham, London where they are looking out for known petty crime operators through CCTV to inform officers on the ground [18].

The limiting factor of the face recognition system in forensic comparison is that there is no known correlation between the match values and the probability value of any comparison. Therefore, it is not possible to know if anyone else has a better match value or how many other faces have similar match values. This problem was recognised by the Phillips [111-112] of the FERET Program who wrote: "Face Recognition in a world of billions of people is a difficult problem since researchers have only a few thousand images of individuals, and only a small number of images for each individual".

From the survey it seems that there has been limited advance in the actual techniques used to compare faces of skulls. There are two basic methods of photo-comparison widely used, firstly, a method of matching faces by trial and error [113] and secondly, the more mathematical approaches [114]. These techniques were discussed in the previous review so will not be covered again. However, there have been some pilot schemes where 3D models are compared with 2D photographs. The Forensic Laboratory of the Netherlands has looked at the positioning of a person or skull for photo comparison using three-point analyses and one-shot 3-D photograph [114]. They acquired the 3D images using system developed under the IMPROOFS project and now marketed by Eyetronics. Another project at the National Research Institute of Police Scene, Japan has looked at 3D to 2D photo comparison [115]. The 3D model is aligned into the same position as the 2D image. The distance and angle between predefined selection points on the 2D and 3D images are automatically measured and a comparison is performed on the point-to-point difference between both images. However, it is reported that further work (effects of disguised face and quality of photograph and video images) is required before it is ready for casework.

Figure 12: A 3D model of a face taken using two images and a software package called 'D me know'

Facial Reconstruction

Within the field of forensic anthropological investigation, there are a number of techniques being used to determine the personal identification of skeletalised or semi-skeletalised remains. The most powerful method of identification would be the comparison of DNA or dental records but when this information is not available then a range of facial reconstruction techniques have are used. In recent reviews of all facial reconstruction techniques it appears that the two and three-dimensional computer-based reconstruction systems have been developed to make the reconstruction process faster, more flexible and to remove some of the subjectively and inconsistencies associated with the traditional approaches (illustrative identikit and 3D clay based reconstruction) [116-121]. It seems that optical laser scanning capture systems together with several different software packages [122-126] are used to produce a 3D digitised image.

The reliability of the reconstruction of tissue onto skull was questioned, as the accuracy is dependant on the understanding the relationship between the bone and soft tissues of the face [118]. Without the recognised scientific data there have been much discussion, controversy and pessimism surrounding facial reconstruction in the past that has contributed to it failing to make a serious impression on the forensic community. However, in recent years the availability of new, more powerful computational resources, combined with ever-increasing quantities of scientific data has seen the visualisation and analysis of volumetric data emerge as an important new application of computer graphics. The efficient and accurate visualisation and interpretation of this data such as volume rendering is currently under investigation by media and scientific institutions.

Height comparison

The process for calculating a height measurement on a individual from a image has already been covered in the photogrammetry section. However, the forensic value of the height measurement depends on the way it is interpreted and also on background information. It is clear that there are two possible uses of any calculated measurement, intelligence and comparison purpose. The most common use of any height measurement in the law enforcement is to provide an estimate height from measurement obtained from the photogrammetry technique and consideration for uncertainties (measurement errors, uncertainty in locating points in image, effects of gait and stance, etc.). This information is often used for screening and elimination of suspects.
For comparison or evidential purposes Compton [47] explained that it is necessary to make some sort of comment on the probative relationship between a suspect's height (including uncertainties in the real world measurement) and the calculated measurement (including uncertainties such as process error, effects of gait and stance). In his paper he presented, through a Bayesian approach, a balanced way of obtaining the weight of the evidence. This method of interpretation takes into account two propositions; firstly, that the unknown person in the image is indeed the known suspect and secondly the alternative proposition that this person in the image is someone else. In order to do this, knowledge of relevant height population statistics are required together with the probability distribution of uncertainties.

Other Biometrics

A biometric is defined as, "using a biological feature or characteristic of an individual that uniquely identifies them from anyone else" [127]. There have been several research projects that have looked at the gait as a possible identifying metric. The term gait analysis is defined as, " a systematic analysis of locomotion" [128]. The gait of an individual is a complex system controlled by the motor cortex of the brain and comprises a process of muscle stimulation resulting in the appropriate movement of the joints of the body. The pattern of movement associated with gait is a series of rotational movements of both the upper and lower limb joints. Movement of the lower limbs provides the locomotion of an individual whilst movement of the upper limbs and torso provides a weight balanced energy conserving counterbalance. Thus, when examining gait, the movement of all body parts should be considered as possible methods of identification between individuals. A review of identifying through gait analysis was discussed in Biometrics: Personal Identification in Networked Society' [129]. The authors concluded that there is indeed potential for using gait as a biometric recognition system, however, it is also noted that there are limitations for the use of gait such as changes in human gait due to clothing, pregnancy, illness or ageing as well as the limitations imposed by current technology systems. Before gait can be applied to a forensic situation these limitations need to be identified and studied. Other work [130-144] has been carried out on using gait to identify individuals and the main conclusions agree with Nixon *et al* that more work is required before gait can be a reliable identifier.

There have been a few unique cases which have gone through courts that have involved biometrics or anthropometry interpretation. The most publicised cases involved the identification and conviction of a suspect by his ear print. The topic of ear prints is a common topic of conversation in the forensic community with several groups working in the area. However, there has been evidence given in a trial in England that a suspect was identified from a CCTV image by the fact that he had bowed legs. It was reported that bowed legs only occurs in 5% of the population.

Pattern recognition

Many areas of forensic science involve pattern recognition such as questioned documents [158-161], handwriting [162-166] and firearms [167-170]. These areas have been utilising digital images and computing power to search and compare for specific characteristics. It is assumed that the development of pattern recognition techniques in these areas will be covered in their own dedicated Interpol review.

Database Retrieval

Pattern recognition is the underling mechanism behind database searching, whether it is by text, content based or shape matching searches [153-155]. Klasén [2] breaks automatic methods into statistical and learning-based techniques. The main difference between these two approaches is that statistical interpretation often requires prior knowledge and that learning based systems require sets of images for training purposes. One example in use in operational casework is the child pornography database, successfully used by the Swedish National Police. This database is to be used in cooperation with other European countries. However, further research is required before image interpretation can move from a subjective to objective analysis. A review on the early years of Content-Based Image Retrieval is presented by Smeulders [156]. There is a wealth of forensic databases being established around the world (discussed in a later section). The concept of content based image retrieval is being utilised to automate the searching process. An example of this was presented by Geradts [157] who has been evaluating the effectiveness of several commercial available and research software packages on a database of logos from drug tablets. The conclusion from this research was that MPEG-7 provide the optimal results for speed versus ranking on the hit list.

Other forensic areas that involve levels of pattern recognition are in documents [158-161], handwriting [162-166] and firearms [167-170]. These areas have been utilising digital images and computing power to search and compare for specific characteristics in their evidence type. The development in pattern recognition in these areas will be covered in their own dedicated Interpol review.

Image Authentication

In the last report Klasén reviewed the forensic methods used for authenticating analogue video and audio tapes. There were two types of analysis one looking at the electrical signals on the tape and the other the magnetic fields. The expertise involved in this activity is in the capturing an image of the electrical or magnetic signal and then analysing the patterns subjectively for specific characteristics. Since the last report, the analysis of the characteristics has not changed and is essentially a pragmatic approach. However there have been some development in the way to capture the signals. Read [171] presented a new instrument which produces a 2D image of the magnetic fields on a segment of magnetic audio tape. This process was a lot quicker and easier than using traditional Ferro Fluids and it also did not destroy the tape. This concept was taken further by Pappas [172] to produce a scanning magneto-resistive microscope that allows high resolution imaging (non-invasive) of magnetic tapes and digital media.

With the increase in digital cameras now on the market there are a number of questions that are being asked about the digital images. Firstly, courts and police wish to know if the images are original and have not been manipulated (e.g. child pornography cases) and secondly if they can be associated to particular cameras. The first question is complex and difficult to answer if there are no significant signs of manipulation, for instance missed placed objects in image, images stored on computer contained components of the questioned image, different noise levels across image and differences in lighting and shadow.

A new approach for identifying images acquired by particular digital cameras has been investigated by the Netherlands Forensic Institute and the National Research Institute of Police Science in Japan [173-174]. Both institutes are jointly looking together at different methods of examining the cameras to determine if a specific image has been made with a camera: defects in CCDs, file formats, noise introduced by the pixel arrays and watermarking in images used by the camera manufacturer. From this work they have found that there are more visible errors in the pixel arrays of cheaper cameras but the more expensive cameras have fewer errors. Further work is required to determine the significance of these errors when comparing an image with a digital camera.

IMAGE MANAGEMENT

There has been concern within forensic institutions (and wider law enforcement) arising from the migration from photography to digital over the security, integrity and continuity of digital images [184-198]. In the UK a project has been set up to introduce operational guidelines to law enforcement agencies for the handling of digital images and has recently published a first issue. It is interesting that many of the questions raised by the introduction of digital cameras were not always necessarily addressed whilst photography was in use where 'historic' practices had grown up around its use and had not been scrutinised as closely as digital is now. It would be interesting to see what would have happened if digital was replaced by photography!

A major concern over digital images has been the fact that the 'original' or 'master' image is not so easily defined; there is no digital 'negative' that neatly corresponds with a photographic negative. This lack of a physical entity has led to debates over what is the 'original' image and this in turn has led to a lack of clarity over what needs to be retained as best evidence for the courts. In some cases, the storage media e.g. CDROM, Flashcard etc., has been retained as it represents the first permanent record of the image. Others are contemplating the storage of a an identical 'copy' of the first permanently recorded image where this is more practical and relying upon appropriate operating procedures/technology to ensure an identical (bit-for-bit) and reliable copy is produced.

If image processing is required, emerging best practice suggests that a bit-for-bit copy of the 'original' or 'master' image is produced and this becomes a 'working copy'. It is this 'working copy' that is used for any subsequent processing or analysis and an audit trail tracks all changes to the image. The audit trail needs to be of sufficient detail to replicate the processing carried out. The processed image may become an item or evidence within the case and requires the standard approach taken with such entities. In particular, back-up and archiving of images is required and to date a Write Once/Read Many (WORM) type medium is the preferred choice. Some institutes are already thinking of Storage Area Networks as a solution. It is important to consider issues such as mirroring data storage as a contingency for data loss.

In the UK the approach by the Criminal Justice System has been less towards the admissibility of evidence but rather a concentration towards the maximising the weight of any evidence. Clearly, by having standard operating procedures, authentication protocols and audit trails it is possible to increase the weight of digital images, and subsequent analysis, as evidence. It is noted that digital image analysis is no different to other areas of forensic science where there is considerable weight given to the integrity of the scientist involved in the work. No system can replace the need for a person to verify that the original image is a true and accurate representation of their observation.

Language has also been an issue with digital capture as terms such as original, primary, master, etc. have yet to have agreed international meaning. Although, the FBI, ENFSI, FSS and others are attempting to move these issues forward on this issue through open publication and internal projects [199, 201]. www.theiai.org/swigit/index.HTML

Image files also need to be named on computers and this needs to be thought through carefully. Alpha-numeric keyboard entry of names is prone to error and other issues such as name uniqueness need to be addressed. Image file migration is also a process that needs addressing since the integrity and continuity of the image content is dependent upon have tight control of procedures and checking.

Wherever digital images are being implemented their management is requiring institutions to address the needs of their respective Criminal Justice Systems in particular, the rules of evidence, including: hearsay, disclosure, continuity and integrity.

At present, fingerprints are alone in having any recognised international standards for digital capture [193] http://www.eeel.nist.gov/810.02/detection.html. Although, even with fingerprints this only relates to custody type data that traditionally was recorded by ink and card. There has been little evidence of any progression on agreed quality for latent marks where the variation in image content and visualisation is much wider than inked impressions. Those involved in imaging fingerprint evidence are also having to take account of the possible requirements for level 3 detail such as pores. As for other forensic evidence there is still much work to be done on determining the quality and subsequently the imaging requirements before standards can be agreed. This will become increasingly important as co-operation between institutes requires the exchange of data.

Research

In the last review it was shown that digital technology has great potential in the forensic environment. It was also noted that not many law enforcement agencies had implemented digital imaging technology into routine casework. Therefore, it is not surprising that the main research activities in the forensic establishments over the last 3 years has been the evaluation of digital technology and its applicability compared to traditional photographic techniques. From the survey, it was evident that a wide range of technologies was being evaluated for use in casework. These technologies were assessed against acceptance criteria that depended on the user's requirements (i.e. note taking, comparison interpretation) which vary between different areas of law enforcement. However, individual establishments generally undertake the evaluation and implementation of digital technologies with little evidence of co-operation between establishments.

Another common research activity has been the development of image databases. There are a wide range of databases being produced (documents, drugs, firearms) some independently and some (inter)-nationally. The most common national databases are fingerprints and shoemarks.

The largest research project to involve representatives from law enforcement (FSS,UK & NICC, Belgium) and academia (Oxford University,UK; KUL, Belgium; INRIA, France; & KTH, Sweden), in the last report, was the European Esprit project IMPROOFS (IMage PROcessing Operations for Forensic Support). The IMPROOFS project aimed at helping police forces and other parties concerned (e.g. the defence) draw the maximum out of image data (mainly CCTV footage). The project finished in November 2000 and the results can be seen at www.esat.kuleuven.ac.be/~konijn/improofs.html.

In summary, the project was looking to develop tools in the following areas; image enhancement and restoration, metrology and person identification.

> **In the area of image enhancement and restoration a range of image enhancement and restoration tools which tackle the problem of restoring noisy and blurred scalar images and sequence of images. A method for removing distracting patterns from forensic evidence was also implemented to render evidence marks more visible [34].**
>
> **A successful method for obtaining height measurement from single images was aslo developed, which was based on projective geometry. This method was shown at the International Society of Optical Engineering Conference on Investigative and Trial Image Processing in Boston, 1998 [44]. In addition, to the single view metrology tool a multiple view metrology tool was produced. These prototype tools enables distances to be measured between two points and for the 3D reconstruction of scenes.**

> In the field of person identification one-shot active 3D-acquistion technology to capture facial shapes was used to produce 3D mugshots of individuals. The 3D mugshots could then be adapted for pose and illumination to conditions under which an offender has been observed by a surveillance camera. Experiments on recognition of faces based on their 3D descriptions were also carried out.
>
> The project also looked at gait analysis. Here three complementary methods were investigated. Two used purely 2D data and the third approached the problem by fitting an underlying 3D-body model. The most successful method involve the identification of working people using view consistency constraints and could identify x of 10 individuals [144]. However, more research is required to address the issue of robust determination of personal identify from gait.

In the field of human identification a lot of work is being carried out on facial identification/recognition system. The result of this research has lead over the last two years to range of commercial security systems involving facial recognition on the market. Even though these systems may not be suitable for forensic use at the present moment, the research & developments in this area are a step towards the demands of the forensic science. HISCORE is one of these projects; HISCORE, High Speed 3D Colour Interface to Real World, is a European project aiming to development and validation of a leading edge 3D and colour subsystem based on of-the-shelf CCTV camera and projects. The technology developed in HISCORE will be applied to two main application areas: face recognition (for security purposes) and gesture recognition. In the face recognition aspect they are looking to establish a more reliable method of identifying individuals by using the extra information captured in 3D compared to the standard 2D images. For more details refer to http://www.softeco.it/english/servizi/hiscore_www.html.

Another organisation that is looking at identification of Humans is the Defense Advanced Research Projects Agency (DARPA) in their project Human ID at a Distance. The objectives are to develop an automated multi-modal surveillance technology for identifying humans at distance as an enable for protection and early warning against threats. The goals of the program are to identify humans, using multiple biometrics modes. Furthermore, the system will operate at all times, day or night, during all weather conditions, with a probability of correct identification of 0.99, a probability of false alarms of 10^{-3} and a gallery size up to 10^{6}. Identification would be possible on uncooperative subjects, possibly in disguise, alone or in groups, and automatically create folders for collecting data on repeat visitors. For more details on this project refer to http://dtsn.darpa.mil/iso/

Visual surveillance research is focussed on three key applications: intelligent alarming through motion detection and event classification; smart tracking assistants for control rooms capable of target acquisition and automatic tracking; and intelligent description, storage and querying of events within monitored scenes for incident reconstruction. There are several Universities and conferences [179, 182] looking into this area Kingston University and Bristol University in the UK are just two. In addition there is a European project called PREMATICA which is also working in this field.

Intelligent Alarming : Robust real time event detection and tracking software generate events descriptions (colour, projected area, 2D and 3D trajectory) which employed to classify both event type and event behaviour in monitored domains such as car-parks. Particular emphasis is placed on learning to enable systems to automatically adapt system parameters for ease of installation and maintenance.

Smart Tracking Assistants : Development of tools that automatically detects, evaluates and prompts security staff with targets. Selected targets are automatically tracked and framed. Vehicle classification software capable of classifying vehicles into common types e.g. hatchback, transit, bus, etc.

Vigilant : Information system capable of real-time efficient storage of events occurring within a monitored scene. Scheduled classification tools process stored events to generate chromatic, event-type, and trajectory information to enable untrained security operators to generate complex human-centric queries for video-data based on content.

Other areas of research where collaboration has taken place is in the authentication or identification of images acquired from digital cameras. The Netherlands Forensic Institute and the National Research Institute of Police Science in Japan have been looking into different methods of examining a camera for determining if a specific digital image has been produced by it [143-144]. These methods include effect of CCD defects, file formats, noise introduced by the pixel arrays and watermarking in images used by the camera manufacturer.

Working Groups

Over the last few years a number of working groups have been established that are focussed on digital images, namely European Network of Forensic Institutes (ENFSI) Digital Imaging Working Group, Scientific Working Group on Imaging Technologies, FBI, USA, Digital Imaging in the Criminal Justice System – policing issues, Police Scientific Research and Development Branch, Home Office, UK, SPIE Investigative Image Processing Technical Group, USA [199-204].

In the UK there has been a response published by the Government to the House of Lords Report on Digital Images as Evidence that has been forwarded to the Home Office to lead on. This has resulted in a 3year project looking at delivering standard procedures to maximise the integrity of digital images captured within law enforcement agencies. A draft of the procedures was issued in June 2001 and is subject to revised editions.

The British Standards Institute (BSI) has published guidelines on evidence stored electronically and a sister compliance document [197].

An on-line draft set of procedures has also been published by Scientific Working Group on Imaging Technologies [198].

FUTURE REQUIREMENTS

The future is always difficult to predict and in such a fast moving technology as digital image analysis this is particularly so. Nevertheless, there are some key areas of work that will certainly progress such as establishing robust procedures for ensuring the integrity and continuity of digital images and image processing. Alongside these processes there is a need for defined competencies and quality assurance for both people and systems involved in this area of forensic science. The emergence of standard operating procedures will allow for best practice to be established.

The convergence of information and communication technologies will see an increase in digital images as a file type on mobile phones, Personal Digital Assistants, computers, and the Internet. This will see an increase in the number of images submitted as evidence for forensic analysis and will drive the requirements for more demanding signal processing methods than are currently available.

If the quality of data captured digitally is ever going to be suitable for forensic analysis then standards will need to be set for the capture of traditional evidence such as footwear, toolmarks, handwriting, etc. As more and more evidence is captured this way there will be a drive to use computers to analyse the data. This will be a major area of research in the coming years. As International Standards emerge there will be the ability for data exchange and more opportunity for rapid database growth.

REFERENCES

Interpol Symposium

[1] Klasén L, Image Analysis, Proceedings of the 12th Interpol Forensic Science Symposium, Co-ordinating Laboratory Reports on Evidence Types, Frank RS and Peel HW, pp. 261-302, 1998.

Digital Capture (forensic activities which involve digital image capture)

[2] Klasén, L, Photography and Digital Imaging, *Photography and Digital Imaging,* Encyclopaedia of Forensic Sciences, Academic Press 2000, pp1254-1264, 2000

[3] Palmer, R., Chohan, G., The use of PC Image Scanning to Enhance the Visualisation and Detection of Fibre Dye Chromatogram Components (Paper from EFG Meeting), Proceedings of European Fibres Group, Vol. 8, pp. 142-147, September 2000

[4] Nelson, L.K., Hicks, A.F., Preparation of Court Charts through Digital Imaging, J-am-soc-quest-doc-exam, Vol. 1, No 2, pp. 121-129, 1998

[5] Pirlot, M., Chabottier, A., Celens, E., De-Kinder, J., Van-Ham, P., Feature Extraction of Optical Projectiles Images, Sci-Just, Vol. 39, No 1, pp. 53-56, 1999

[6] Sweet, D., Parhar, M., Wood, R.E., Computer-Based Production of Bite Mark Comparison Overlays, Journal of Forensic Sciences, Vol. 43, No 5, pp. 1050-1055, September 1998

[7] Kurosawa, K., Kuroki, K., Saitoh, N, CCD Fingerprint Method – Identification of a Video Camera from Videotaped Images, Proceedings of the IEEE, Vol. 3, pp. 537-540, 1999

[8] Mackay, D., Digital Versus Analogue, Police-Government Security Technology, pp. 34-38, 1999

[9] Cunningham, C.C., Peloquin, T.D., Analysing Crime Scene Videos, Proceedings of SPIE, Vol. 3576, pp. 195-202, 1998

[10] Hardie, R.C., Barnard, K.J., Bognar, J.G., Armstrong, E.E., Watson, E. A., High-Resolution Image Reconstruction from a Sequence of Rotated and Translated Frames and Its Application to an Infrared Imaging System, OPT-ENG, Vol. 37, No 1, p247-260, 1998

[11] De-Kinder, J., Bonfanti, M., The State of the Art in 3D Forensic Imaging, INFO_BULL_SP_TM_EXAM, Vol. 4, No. 3, pp. 18-22, 1998

[12] Van-Beest, M., Zaal, D.E., Hardy, H.J.J., The Forensic Application of the MikroCad 3D Imaging System, Inf-Bul-Sp-Tm-Exams, Vol. 6, No 1, pp. 77-84, 2000

[13] Petrov, M., Talapov, A., Robertson, T., Lebedev, A., Zhilyaev, A., Polonskiy, L., Optical 3D Digitisers; Bringing Life to the Virtual World, J-AM-PODIAT-ASSOC, Vol. 18, No 3, pp. 28-37, May 1998

[14] Cossling, D.B., Imprint Identification System, Patent, pp. 1-14, August 1997

[15] Beer, R.C., Bassindale, C., Emberton, A., Mashiter, K., Goldthorpe, S.B., McConnell, P., A New Method of Recording Clinical Forensic Evidence, Journal of Clinical Forensic Medicine, Vol. 8, pp. 34-35, 2001

[16] Goldthorpe, S.B., McConnell, P., A New Method of Recording Clinical Forensic Evidence, Journal of Clinical Forensic Medicine, Vol. 7, No 3, pp. 127-129, 2000

[17] Horswell, J., Recording, *Crime-Scene Investigation and Examination,* Encyclopedia of Forensic Sciences, Academic Press 2000, pp443-447

[18] Gadher G, Smile, you're on 300 candid cameras, The Sunday Times, pp. 5, 14 February 1999,

[19] Russ, J, Video Digitisers – A user's prespective, Journal of Computer Assisted Microscopy, Vol.. 7, 1995.

Image Enhancement / Restoration

[20] Chellappa, R., Girod, B., Munson, D.C., Tekalp, A.M., Vetterli, M., The Past, Present and Future of Image and Multidimensional Signal Processing, IEEE Signal Processing Magazine, pp. 21-58, 1998

[21] Patti, A.J., Tekalp, A.M., Sezan, M.I., A new Motion-Compensated Reduced-Order Model Kalman Filter for Space-Varying Restoration of Progressive and Interlaced Video, IEEE Transactions of the Image Process, Vol. 7, No 4, pp. 543-554, 1998

[22] Guler, S., Advanced Digital Video Surveillance, Proceedings of SPIE, Vol. 4232, 2000

[23] Bright, D.S., LISPIX: Image Processing and Data Visualization Tool for the PC and Macintosh, *Proceedings of SCANNING*, Vol. 22, 2. (2000), pp111-112.

[24] Li, G., Tribble, J., Zwick, H., Ness, J., Reddix, M., Lund, D.J., Stuck, B., Biggerstaff, S., D'Andre, J., Study of the Retinal Image Quality in the Human Eye by Confocal Principle, *Proceedings of SCANNING*, Vol. 22, 2. (2000) pp91

[25] Brekke, R., Composite Data Structures for Video Analysis, Proceedings of SPIE, Vol.3576, Pp. 264 – 273, 1998

[26] Vorder Bruegge, R. W., Noise Reduction of Video Imagery Through Simple Averaging, Vol. 3576, Pp. 185 – 194, 1998

[27] Gee, T.F., Karnowski, T.P., Tobin, K.W., Multiframe Combination and Blur Deconvolution of Video Data, Proceedings SPIE, Vol. 3974, pp. 788-795, 2000

[28] Burgiss, S. G., and Goodridge, S. G., Multiframe Averaging and Homomorphic Filtering for Clarification of Dark and Shadowed Video Scenes, Proceedings of SPIE, Vol. 4232, 2000

[29] Geradts, Z.J., Bijhold, J., Forensic Video Investigation with Real Time Digitised Uncompressed Video Imaging Sequences, Proceedings SPIE, Vol.3576, pp. 154-164, 1998

[30] Huynh-Thu, T.Q., Lardinois, Y., FIPE: A Forensic Image Processing Environment, Proceedings SPIE, Vol. 3576, pp. 176-184, 1998

[31] Klasén, L. M., Li, H., and Forchheimer, R., Evaluation of a Method for Invariant and Automated Detection and Tracking of Objects from Video, Proceedings of SPIE, Vol. 4232, Pp. 455 – 463, 2000

[32] Romeo, K., Schwering, P. B., and Kemp, R. A., Evaluation of Tracking in Video Sequences, Proceedings of SPIE, Vol. 4232, Pp. 464 – 471, 2000

[33] Hardie, R.C., Barnard, K.J., Bognar, J.G., Armstrong E.E., Watson, E.A., High Resolution Image Reconstruction from a Sequence of Rotated and Translated Frames and its Application to a Infrared Imaging System, OPT_ENG, Vol. 37, No1, pp. 247, 260, 1998

[34] Capel, D, Zisserman A, Bramble S, Compton D, Automated method for the removal of unwanted nonperiodic patterns from forensic images, Proceedings of SPIE, Vol. 3576, Pp. 274 – 284, 2000

[35] Linke, M.J., Deinet, W., Image Processing of Luminescent Fingermarks, Journal of Forensic Science, Vol. 43, No 1, pp. 363-365, 1998

[36] Moler, E., Ballarin, V., Pessana, F., Torres, S., Olmo, D., Fingerprint Identification Using Image Enhancement Techniques, Journal of Forensic Science, Vol. 43, No 3, pp. 689-692, May 1998

[37] Bakowski, P, Walencik, R., Method for Reconstruction of Illegible Markings of Vehicles, Problemy – Kryminalistiki, Vol. 225, pp. 50-53, 1999

[38] Kurosawa, K., Kuroki, K., and Saitoh, N., Recognition of Degraded Characters on License Plates, Proceedings of SPIE, Vol. 3576, Pp. 247 – 252, 1998

[39] Geradts, Z., Super Resolution. http://forensic.to/superresolution.htm

[40] Goodridge, S. G., Content-Based Software Demultiplexing of Surveillance Video, Proceedings of SPIE, Vol. 4232, 2000

[41] Guichard, F., Litz, A., Rudin, L. I., and Yu, P., Software-Based Universal Demultiplexing: Threshold-Free Energy Minimization Approach, Proceedings of SPIE, Vol. 4232, Pp. 513 – 520, 2000

[41a] F. Guichard and Rudin L, Velocity Estimation from images sequences and application to super-resolution, ICIP 99, Kobe, Japan, 1999

[41b] Rudin L and Guichard F, Multi-channel Mosaic formation for registered terrain database, Cognitech Inc, Technical report, March 2000.

Metrology

[41] Reis, I., Zisserman, A., Goal-directed Video Metrology, *Dept of Engineering Science, University of Oxford, Oxford, OX1 3PJ,* pp647-658

[42] Klasén, L., Fahlander, O., Using Videogrammetry and 3D Image Reconstruction to Identify Crime Suspects, Proceedings SPIE, Vol. 2942, pp. 161-169, 1997

[43] Bijhold, J., Geradts, Z., Forensic Photo/Videogrammetry; Monte Carlo Simulation of Pixel and Measurement Errors, Proceedings SPIE, Vol. 3576, pp. 239-246, 1998

[44] Criminisi, A., Zisserman, A., Van-Gool, L. Bramble, S., Compton, D., A New Approach to Obtain Height Measurements from Video, Proceedings SPIE, Vol. 3576, pp. 227-238, 1998

[45] Rothwell, C., Faugeras, O., Csurka, G., A Comparison of Projective Reconstruction Methods for Pairs of Views, Computer Vision Image Understanding, Vol. 68, No 1, pp. 37-58, 1997

[46] Klasén, L. Li, H., Faceless Identification: A Model for Person Identification Using the 3D-Shape and 3D-Motion as Cues, Proceedings SPIE, Vol. 3576, pp. 216-226, 1998

[47] Compton, D. Prance, C., Shears, M., and Champod, C., Systematic Approach to Height Interpretation from Images, Proceedings of SPIE, Vol. 4232, Pp. 521 – 532, 2000

[48] Maas, H.G., Concepts of Real Time Photogrammetry, Human Movement Science, Vol. 16, pp. 189-199, 1997

[49] Thali, M.J., Braun, M., Bruschweiler, W, Dirnhofer, R., Matching Tyre Tracks on the Head Using Forensic Photogrammetry, Forensic Science International, Vol. 113, No 1-3, pp. 281-287, September 2000

[50] Steffan, Accident Investigation, *Determination of cause: reconstruction,* Encyclopedia of Forensic Sciences, Academic Press 2000, pp16-24

[51] Lambourn, R, Accident Investigation, *Tachograph,* Encyclopedia of Forensic Sciences, Academic Press 2000, pp48-58.

[52] Digital Imaging Software for Bloodstain Pattern Analysis at Crime Scenes, BackTrack™ Software, www.physics.carleton.ca/~carter/index.html

3D Reconstruction

[53] The Reality of 28 Years Ago, Government Computing, May 2000

[54] Postlethwaite, A., Virtual Investigations, Fire Preview, Vol. 311, pp. 28-29, 1998

[55] Schofield, D., Noond, J., Doyle, M., Goodwin, L., and Fowle, K., The use of Forensic Animations in the Courtroom, Road Safety-Crash Conference, Australia, February 2000

[56] Example of Computer Reconstruction of shooting incident used in Trial in Oregon, http://www.applied-kinematics.com/SERT.htm

[57] Contact Litigation Services – Engineering Animation Inc, Reconstruction of Princess Diana Crash, http://www.eai.com/corporate/newsroom/1999/princessdiana.html

[58] The Courtroom of the Present, Courtroom 21 Project, LawOnLine: Courtroom of the Future, Williamsburg Virginia, http://www.west-knights.com/williams.htm

[59] On the Job: The Digital Courtroom, Engineering Animation Inc, Cadalyst, Vol. 16, No 12, Pp. 20, December 1999

[60] Thomas, R. D., Computer Reenactment a New Form of Investigation Using Virtual Reality Computer Technology, http://www.pimall.com/nais/n.reenact.html

[61] Borsook, P., Guilty! Digital Animations Shake Up the Courtroom: Discord Within the Magic Kingdom, http://coverage.cnet.com/Content/Features/Techno/Digital/digital2.html

[62] Working Model: Helping the Police with Their Enquiries, CAD User, Pp. 62 – 63, October 1997

[63] Courtroom Presentation Technologies – Better, Faster, Cheaper, National Lawyers Association Review Winter 1996, http://www.nla.org/library/winter96/pg24.html

[64] Templeman, M., Virtual Reality for Major Incidents at Strathclyde Fire Brigade, Industry Emerging Journal, Vol. 13, No 2, pp. 6-8, 1998

[65] Spearpoint, M., Shipp, M., Virtual Reality for the Channel Tunnel Fire Investigation, FIRE_SAF_ENG, Vol. 4, No 6, pp. 6-7, 1997

[66] Doyle, M., Forensic Animations in Criminal Cases, Proceedings from the First Digital Conference on Authenticity and Admissibility of Digital Data, pp. 1-18, October 1999

[67] Schofield, D., Noond, J., Accident Reconstruction: Possible Features, Proceedings from Senior Accident Investigations Conference, April 1999

[68] Howard, T.L.J., Murta, A.D., Gibson, S., Virtual Environments for Scene of Crime Reconstruction And Analysis, Proceedings SPIE, Vol. 3960, pp. 41-48, 2000

[69] Little, C.Q., Small, D.E., Peters, R.R., Rigdon, J.B., Forensic 3D Scene Reconstruction, Proceedings SPIE, Vol. 3905, pp. 67-73, 2000

[70] Neis, P., Fink, T., Dilger, M., Rittner, C., Use of the Software 'Poser4' in Reconstruction of Accident and Crime Scenes, Forensic Science International, Vol. 113, No's 1-3, pp. 277-280, September 2000

[71] Bijhold J, Geradts Z and Huyben E, Investigation of Surveillance Video-Tapes at the Netherlands Forensic Institute. Identification of Persons and Cars by Visual Comparison, Second European Academy of Forensic Science Meeting, Cracow, September, 2000.

[72] Hug, C., Wehr, A., Applications of Imaging Laser Sensors in Close-Range Metrology and Remote Sensing, Proceedings from Optical 3D Measurement Techniques, pp. 141-148, 1997

[73] El-Hakim, S.F., Boulanger, P., Blais, F., Beraldin, J.A., A System for Indoor 3-D Mapping and Virtual Environments, Proceedings SPIE, Vol. 3174, pp. 21-35, 1997

[74] Borghese, N.A., Ferrigno, G., Baroni, G., Pedotti, A., Ferrari, A., Savare, R., Autoscan; A Flexible and Portable 3D Scanner, IEEE_COM_GRAPHICS_APPL, pp.38-41, May 1998

[75] Petrov, M., Talapov, A., Robertson, T., Lebedev, A., Zhilyaev, A., Polonskiy, L., Optical 3D Digitisers; Bringing Life to the Virtual World, J_AM_PODIT_ASSOC, Vol. 18, No3, pp. 28-37, May 1998

[76] Fischer, D., Kohlhepp, P., Bulling, F., An Evolutionary Algorithm for the Registration of 3D Surface Representations, Pattern Recognition, Vol. 32, No 1, pp. 53-69, 1999

[77] Beraldin, J.A., Blais, F., Cournoyer, L., Rioux, M., El-Hakim, S.H., Rodella, R., Bernier, F., Harrison, N., Digital 3D Imaging System for Rapid Response on Remote Sites, Proceedings from the Second International Conference on 3D Digital Imaging and Modelling, pp. 34-43, October 1999

[78] Altschuler, B. R. and Monson, K. L., Initial Progress in the Recording of Crime Scene Simulations using 3-D Laser Structured Light Imagery Techniques for Law Enforcement and Forensic Applications, SPIE, Vol. 3240, Pp. 230 – 241, 1998

[79] High Speed 3D- and Colour Interface to the Real World, Information Society Technologies Project Website, The European Commission, http://www.cordis.lu/ist/projects/99-10087.htm

[80] Batterman, S. C., and Batterman, S. D., Motor Vehicle, Accident Investigation, *Encyclopedia of Forensic Sciences*, Academic Press 2000, pp. 33 – 42.

[81] Rudram, D., Engineering, *Encyclopedia of Forensic Sciences*, Academic Press 2000, pp. 691 – 699, 2000

[81a] Robey, D., Palmer I., Chilton, N., Dabeedin, J. Ingham, P. and Bramble, S.K., From Crime Scene to Computer Screen: the use of Virtual Reality in Crime Scene Investigation, UK VR SIG 2000 Conference Proceedings, pp. 21-32, 19th September 2000

**[81b] Robey, D., Palmer I., Chilton, N., Dabeedin, J. Ingham, P. and Bramble, S.K., The Development of an Intelligent Virtual Environment for Training, 6th International Digital Media Symposium,
25th April 2001**

3D Comparison

[82] Thali, M.J., Braun, M., et al, Improved Vision in Forensic Documentation: Forensic, 3-D/CAD-Supported Photogrammetry of Bodily Injury External Surfaces, Combined with Volumetric Radiologic Scanning of Bodily Injury Internal Structures, Provides More Investigative Leads and Stronger Forensic evidence, Proceedings of SPIE, Vol. 3905, pp.213-221, 2000

[83] De-Kinder, J., Nys, B., Recording Fingerprints on Cartridge Cases by 3D Laser Topography, Journal of Forensic Identification, Vol. 50, No 3, pp. 271-275, 2000

[84] De-Kinder, J., Bonfanti, M., Automated Comparisons of Bullet Striations Based on 3D Topography, Forensic Science International, Vol. 101, No 2, pp. 85-93, 1999

[85] Laturnus, P., Computerised Analysis of Bloodstain Patterns, Ident Canada, Volume 21, No1, pp. 13, 1998

[86] Subke, J., Wehner, H.D., Wehner, F., Szczepaniak, S., Streifenlichttopmetrie (SLT) – A new Method for the Three-Dimensional Photorealistic Forensic Documentation in Colour, Forensic Science International, Vol. 2113, No's 1-3, pp. 289-295, 2000

[87] Weiss, I., Ray, M., Model-Based Recognition of 3D Objects From Single Images, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 23, No 2, pp. 116-128, February 2001

[88] Sharman, K.J., Nixon, M.S., Carter, J.N., Non-Invasive 3D Dynamic Object Analysis, Proceedings from the IEEE, Vol. 4, pp. 214-218, April 2000

[89] Miller, J., Criteria for Identification of Toolmarks Part 2: Single Land Impression Comparisons, Journal for the Association of Firearms and Toolmarks, Vol. 32, no 2, pp. 116-131, 2000

[90] Bodziak, W.J., Some Excellent Methods for Making Three-Dimensional Known Impressions of Footwear, INF_BUL_SP_TM_EXAMS, Vol. 6, No 1, pp. 73-75, 2000

[91] Bunch, S.J., Some Proposals for Standardising Trajectory Analysis and Reporting, Journal for the Association of Firearms and Toolmarks, Vol. 30, No 3, pp. 482-491, 1998

[92] Koch, K.H., Koerschgen, A., Radke, A., Case Report; Ecstasy Tablets and Toolmark Identification Techniques, INF_BULL_SHOEPRINT<TOOLMARK_Exam, Vol. 4, No 1, pp. 25-35, 1998

[93] Tam, C., K., Use of Comparison Microscope – Pseudo- 3D Approach, Journal of the Association of Firearms and Toolmarks, Vol. 29, No 4, pp. 470-471, 1997 Weiss, I., Model-Based Recognition of 3D Objects from Single Images, *IEEE Trans. on Pattern Analysis and Machine Intelligence*, Vol. 23, No.2, pp116-128, 2001.

[94] Thali, M.J., Braun, M., Bruschweiler, W., Dirnhofer, R., Matching tire tracks on the head using forensic photogrammetry, *Forensic Science International*, 113 (2000), pp281-287.

Image Comparison/Interpretation

[95] Klasén L Madsen S, Waco Investigation: Image Analysis and Video Authentication, www.osc-waco.org/finalreport

[96] Vector Data System, Imagery Analysis Report: The events at Waco, Texas 19April 1993, www.osc-waco.org/finalreport

[97] Vorder Bruegge, Photographic Identification of Denim Trousers from Bank Surveillance Film, J. Forensic Sci., 1999, 44 (3), pp. 613-622.

Person Identification

[98] Bramble S. K., Lecture 'Bertillion Revisited' Forensic Science Society Meeting, Birmingham, UK, 2000.

[99] Phillips, P, Martin A, Wilson C and Przybocki M, An introduction to evaluting biometric systems, IEEE Computer, Vol. 33, No. 2, Feb 2000, pp 56-63.

[100] Jain, A, Bolle R, and Pankanti (eds), Biometrics Personal Identification in Networked Society, 1999, Kluwer Academic Publishers.

Facial Recognition / Identification

[101] Bruce, V., Henderson, Z., Greenwood, K., Hancock, P., Burton, M., and Miller, P., Verification of Face Identities from Images Captured on Video, JEP: Applied 1999

[102] Burton, A.M., Wilson, S., Cowan, M., Bruce, V., Face Recognition in Poor Quality Video: Evidence from Security Surveillance, Psychology-Science, Vol. 10, No. 3, pp. 243-248, 1999

[103] Cohn, J.F., Zlochower, A.J., Lien, J., Kanade, T., Automated Face Analysis by Feature Point Tracking has High Concurrent Validity with Manual FACS Coding, Psychophysiology, Vol.36, pp. 35-43, 1999

[104] Evison, M.P., Computerised 3D Facial Mapping, Proceedings from First International Conference on Forensics of Human Identity, pp. 1-9, October 1999

[105] Tian, Y-L., Kanade, T., and Cohn, J., Recognizing Action Units for Facial Expression Analysis, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 23, No 2, pp. 97 – 115, February 2001

[106] Donato, G., Bartlett, M. S., Hager, J. C., Ekman, P., and Sejnowski, T. J., Classifying Facial Actions, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 21, No 10, Pp. 974 – 989, October 1999

[107] Ravela, S. C., Multiscale Representations for Face Recognition, Proceedings of SPIE, Vol. 4232, Pp. 19 – 28, 2000

[108] Dubois, S., Rossion, B., Bodart, J.M., Michel, C., Bruyer, R., Crommelinck, M., Effect of Familiarity on the Processing of Human Faces, Neuroimage, Vol. 9, pp. 278-289, 1999

[109] Oh, H.S., Park, J.S., Chang, D.H., Oh, G.R., Content-Based Retrieval System for Image Using Human Face Information, Proceedings from SPIE, Vol. 3972, pp.12-20, January 2000

[110] Grudin, M. A., On Internal Representations in Face Recognition Systems, Pattern Recognition 33, pp. 1161 – 1177, 2000

[111] Phillips, P. J., and Rauss, P. J., The Face Recognition Technology (FERET) Program, Proceedings SPIE, Vol. 2962, pp. 253 – 262, 1997

[112] Phillips, P. J., and Rauss, P. J., The FERET Evaluation Methodology for Face-Recognition Algorithms, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 22, No 10, pp. 1090 – 1104, October 2000

[113] Jayaprakash, P.T., Srinivasan, G.J., Amravaneswaran, M.G., Cranio-Facial Morphanalysis: A New Method for Enhancing Reliability While Identifying Skulls by Photo Superimposition, Forensic Science International, Vol. 117, pp. 121-143, 2001

[114] Van Den Heuvel, H., Positioning of Persons or Skulls for Photo Comparisons Using Three-Point Analyses and One-Shot 3D Photographs, Proceedings of SPIE, Vol. 3576, Pp. 203 – 215, 1998

[115] Yoshino, M., Matsuda, H., Kubota, S., Imaizumi, K., Miyasaka, S., Computer Assisted Facial Image Identification System using a 3D Physiognomic Range Finder, Forensic Science International, Vol. 109, No. 3, pp. 225-237, April 2000

Facial Reconstruction

[116] Miyasaka, S., Progress in Facial Reconstruction Technology, Forensic Science Review, Vol. 11, No 1, pp. 51-90, 1999

[117] Stoney, M.B., Koelmeyer, T.D., Facial Reconstruction: A Case Report and Review of Development of Techniques, MED_SCI_LAW, Vol. 39, No 1, pp. 49-60, 1999

[118] Michael, S. Volumetric Facial Reconstruction, PhD Thesis, University of Wales, Swansea, Sept 1999.

[119] Vanezis, M., Vanezis, P., Cranio-Facial Reconstruction in Forensic Identification – Historical Development and a Review of Current Practice, MED_SCI_LAW, Vol. 40, No 3, pp. 197-205, 2000

[120] Quatrehomme G, Iscan M., Computerized Facial Reconstruction, Encyclopedia of Forensic Sciences, Academic Press 2000, pp.. 773-779

[121] Evison, M.P., Forensic Facial Reconstruction, Fingerprint World, Vol. 24, No93, pp. 96-98, July 1998

[122] Vanezis, P., Vanezis, M., Mccombe, G., Niblett, T., Facial Reconstruction Using 3D Computer Graphics, Forensic Science International, Vol. 108, No 2, pp. 81-95, 2000

[123] Archer, K., Coughlan, K., Forsey, D., Struben, S, Software Tools for Craniofacial Growth and Reconstruction, Proceedings from Graphic Interface, pp. 73-81, June 1998

[124] Ho S.Y., Huang, H.L., Facial Modelling from an Uncallibrated Face Image Using a Coarse-to Fine Genetic Algorithm, Pattern Recognition, Vol. 34, pp. 1015-1031, 2001

[125] Coy, A., Ohlson, J.W., Special Case in Three-Dimensional Bone Reconstruction of the Human Skull, Journal of Forensic Identities, Vol. 50, No 6, pp. 549-562, 2000

[126] Green, M.A., Evison, M.P., Interpolating Between Computerised Three-Dimensional Forensic Facial Simulations, Journal of Forensic Sciences, Vol. 44, no 6, pp. 1224-1228, 1999

[126a] Facing the Millennium: Advances in Craniofacial Comparisons (9th Biennial Scientific Meeting of International Association for Craniofacial Identification, Washington, DC, July 24-28th, 2000, www.fbi/gov/hq/lab/fsc/backissu/oct2000/Crani01.htm

Other Biometrics

[127] McDowall, R, Biometrics: The password you'll never forget, LC-GC Europe, 2000.

[128] Harrris G. F and Wertsch J. J, Procedures for gait analysis, Arch Phys Med Rehabil, Vol. 75, 1994, pp 216-225.

[129] Nixon, M. S, Carter J. N. et al, Chapter 11 Automatic gait recognition, Biometric Personal Identification in Networked Society, 1999, Kluwer Academic Publishers.

[130] Ricquebourg, Y., Bouthemy, P., Real-Time Tracking of Moving Persons by Exploiting Spatio-Temporal Image Slices, IEEE Transactions of Pattern Analysis and Machine Intelligence, pp. 797-808, August 2000

[131] Collins, R.T., Lipton, A.J., Kanade, T., Introduction to the Special Section on Video Surveillance, IEEE Transactions of Pattern Analysis and Machine Intelligence, pp. 745-746, August 2000

[132] Shutler, J.D., Nixon, M.S., Harris, C. J., Statistical Gait Recognition Via Velocity Moments, Proceedings from IEEE Colloquim Visual Biometrics, pp. 1-5, March 2000

[133] Sharman, K.J., Nixon, M.S, Carter, J.N., Non-Invasive 3D Dynamic Object Analysis, Proceedings from IEEE Southwest Image Analysis and Interpretation, Vol. 4, pp. 214-218, April 2000

[134] Chang, R., Guan, L., Burne, J.A., An Automated Form of Video Image Analysis Applied to Classification of Movement Disorders, Disability Rehabilitation, Vol. 22, No 1-2, pp. 97-108, 200

[135] Schutte, L.M., Narayanan, U., Stout, J.L., Selber, P., Gage, J.R., Schwartz, M.H., An Index for Quantifying Deviations from Normal gait, Gait Posture, Vol. 11, pp. 25-31, 2000

[136] Macelleri, V., Giacomozzi, C., Saggini, R., Spatial-Temporal Parameters of Gait: Reference Data and a Statistical Method for Normality Assessment, Gait Posture, Vol. 10, pp. 171-181, 1999

[137] Hausdorff, J.M., Zemany, L., Peng, C.K., Goldberger, A.L., Maturation of Gait Dynamics: Stride-to Stride- Variability and Its Temporal Organisation in Children, Applied Physiology, Vol. 86, No3, pp. 1040-1047, 1999

[138] Huang P.S., Harris, C.J., Nixon, M.S, Recognising Humans by Gait Via Parametric Canonical Space, Artificial Intelligence England, Vol. 13, pp. 359-366, 1999

[139] Bobick, A.F., Davis, J.W., The Recognition of Human Movement Using Temporal Templates, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 23, No3, pp. 257-267, March 2001

[140] Canal-Lugne, P., Alizon, J., Collange, F., Van-Praagh, E., Motion Analysis of an Articulated Locomotive by Video and Telemetric Data, Journal of Biomechanics, Vol. 32, pp. 977-981, 1999

[141] Klasén, L., Li, H., Person Identification by Using 3D Deformable Wireframe Models, Paper From First International Conference on Forensics of Human Identity, pp. 1-5, October 1999

[142] Human Identification at a Distance, Defence Advanced Research Projects Agency (DARPA) Information Systems Office Website, http://dtsn.darpa.mil/iso/programtemp.asp?mode=349

[143] Merlijn, M., Gait Parameters for Identification Purposes, http://zeno.simplenet.com/gait.html

[144] Carlsson S, Recognising walking people, In Proc 6th ECCV, Dublin, July 2000, Springer LNCS, 2000.

Pathology

[145] Oliver, W.R., Image Processing in Forensic Pathology, Forensic Pathology, Vol. 18, No 1, pp. 151-180, March 1998

[146] Subke, J., Wehner, H.D., Szczepaniak, S. Streifenlichttopometrie (SLT) – A new Method for Three Dimensional Photorealistic Forensic Documentation in Colour, Forensic Science International, Vol. 113, No 1-3, pp. 289-295, September 2000

[147] Myers, J.C., Okoye, M.I., Kiple, D., Kimmerle, E.H., Reinhard, K.J., Three Dimensional (3D) Imaging in Post Mortem Examinations: Elucidation and Identification of Cranial and Facial Fractures in Victims of Homicide Utilising 3D Computerised Imaging Reconstruction Techniques, International Journal of Legal Medicine, Vol. 113, pp. 33-37, 1999

[148] Ackermann, R.R., Three-Dimensional Imaging in Forensic Anthropology; A Test Study Using the Macintosh, Journal of Forensic Science, Vol. 42, No 1, pp. 93-99, January 1997

[149] Myers, J. C., Okoye, M. I., Kiple, D., Kimmerle, E. H., and Reinhard, K. J., Three-Dimensional (3-D) Imaging in Post-Mortem Examinations: Elucidation and Identification of Cranial and Facial Fractures in Victims of Homicide Utilizing 3-D

Computerized Imaging Reconstruction Techniques, International Journal of Legal Medicine 113, pp .33 – 37, 1999

Dental

[150] Funayama, M., Kanetake, J., Ohara, H., Nakayama, Y., Aoki, Y., Suzuki, T., Nata, M., Mimasaka, S., and Takahashi, K., Dental Identification Using Digital Images via Computer Network, The American Journal of Forensic Medicine and Pathology, Vol.21, No 2, Pp. 178 – 183, 2000

[151] Sweet, D., Parhar, M., and Wood, R. E., Computer-Based Production of Bite Mark Comparison Overlays, Journal of Forensic Science, Vol. 43, No 5, Pp. 1050 – 1055, 1998

[152] McKenna, C. J., Radiography in Forensic Dental Identification – A Review, The Journal of Forensic Odonto-Stomatology, Vol. 17, No 2, Pp. 47 – 53, December 1999

Data Basing

[153] Deng, Y., Manjunath, M., Content-Based Search of Video Using Colour, Texture, and Motion, Proceedings of the International Conference on Image Processing, pp. 534-537, October 1997

[154] Shearer, K., Bunke, H., Venkatesh, S., Video Indexing and Similarity Retrieval by Largest Common Subgraph Detection Using Decision Trees, Pattern Recognition, Vol. 34, pp. 1075-1091, 2001

[155] Idris, F., Panchanathan, S., Review of Image and Video Indexing Techniques, Journal of Visual Communication Image Representatives, Vol. 8, No 2, pp. 146-166, 1997

[156] Smeulders, A. W. M., Worring, M., Santini, S., Gupta, A., and Jain, R., Content-Based Image Retrieval at the end of the Early Years, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 22, No 12, December 2000

[157] Geradts, Z. J., Hardy, H., Poortman, A., and Bijhold, J., Evaluation of Contents-Based Image Retrieval Methods for a Database of Logos on Drug Tablets, Proceedings of SPIE, Vol. 4232, Pp. 553 – 562, 2000

Documents

[158] Wu, V., Manmatha, R., Riseman, E.M., Textfinder: An Automatic System to Detect and Recognise Text in Images, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 21, No. 11, pp. 1224-1229, November 1999

[159] Morris, R.N., Embosser Type; A Three-Dimensional Type Examination, International Journal for Forensic Documents, Vol. 4, No 2, pp. 218-133, April 1998

[160] Will, E.J., Ink Differentiation using a Digital Camera, International Journal for Forensic Documents, Vol. 5, pp. 392-393, January 1999

[161] Horton, R. A., Identifiability of the Flatbed Scanner and its Products (Graphics Files and Printed Results), ASQDE Newsletter, pp. 41-46, 2000

Handwriting

[162] Josuja, O.P., Garg, V.K., Deciphering Obliterated Writings: A Computer – Based Simple Method, International Forensic Document Exam, Vol. 5, pp. 270-279, January 1999

[163] Kato, Y., Yasuhara, M., Recovery of Drawing Order from Single-Stroke Handwriting Images, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 22, No 9, pp. 938-949, September 2000

[164] Ionescu, L., Deciphering Illegible Handwriting, International Journal for Forensic Documents, Vol. 5, ph 405-410, January 1999

[165] Solihin, Y., Leedham, C.G., Noise and Background removal from Handwriting Images, Proceedings of SPIE, pp. 366-370, 1997

[166] Shaw, G., Digital Document Integrity, (Paper from Secure Images and Image Authentication), Proceedings from IEEE, pp. 12/1-12/4, 2000

Firearms

[167] Geradts, Z. J., Bijhold, J., Hermsen, R., and Murtagh, F. D., Image Matching Algorithms for Breech Face Marks and Firing Pins in a Database of Spent Cartridge Cases of Firearms, Proceedings of SPIE, Vol. 4232, Pp. 545 – 552, 2000

[168] Tontarski, R. E., Thompson, R. M., Automated Firearms Evidence Comparison: A Forensic Tool for Firearms Identification – An Update, Journal of Forensic Science, Vol. 43, No 3, 1998

[169] Puente Leon, F., and Beyerer, J., Automatic Comparison of Striation Information on Firearm Bullets, Proceedings of SPIE, Vol. 3837, Pp. 266 – 277, 1999

[170] Geradts, Z. J., Bijhold, J., and Hermsen, R., Pattern Recognition in a Database of Cartridge Cases, Proceedings of SPIE, Vol. 4232, Pp. 104 – 115, 2000

Authentication

[171] Read, M. E., Schwarz, W. G., Malsawma, L., Wallace, R. B., and Ryan, J., Magnetic Scanner for Forensic Examination of Audiotapes, Proceedings of SPIE, Vol. 3576, Pp. 144 – 153, 1998

[172] Pappas, D. P., Arnold, C. S., Shalev, G., Eunice, C., Stevenson, D., Voran, S. D., Read, M. E., Gormley, E. M., Cash, J., Marr, K., and Ryan, J. J., Second-Harmonic Magnetoresistive Imaging to Authenticate and Recover Data from Magnetic Storage Media, Proceedings of SPIE, Vol. 4232, pp. 11 – 18, 2000

[173] Kurosawa, K., Kuroki, K., and Saitoh, N., CCD Fingerprint Method – Identification of a Video Camera from Videotaped Images, IEEE ICIP'99, Vol.3, pp. 537 – 540, 1999

[174] Geradts, Z. J., Bijhold, J., Kieft, M., Kurosawa, K., Kuroki, K., and Saitoh, N., Methods for Identification of Images Acquired with Digital Cameras, Proceedings of SPIE, Vol. 4232, Pp. 505 – 512, 2000

Conferences

[175] Investigation and Forensic Science Technologies, Proceedings of SPIE, Vol. 4232, 3-4 November 1998, Boston.

[176] Enabling Technologies for Law Enforcement and Security, Proceedings of SPIE, Vol. 4232, Boston

[177] First International Exhibition and Conference on Forensic Human Identification in the Millennium, Queen Elizabeth II Conference Centre, London, 25-26 October 1999.

[178] Conference Abstract, Forensic Science challenges for the New Millennium, Second European Academy of Forensic Science Meeting, Cracow, September, 2000

[179] 2nd European Workshop on Advanced Video-Based Surveillance Systems, September 4, 2001, Kingston Upon Thames, London, http://techweb.king.ac.uk/DIRC/AVBS2001/CALL.htm

[180] Fire Dynamics and Modelling, 22-26th January 2001, University of Leeds, UK, cpd@speme.leeds.ac.uk

[181] Computer Forensic Investigation Skills Focus, 12-13th June 2001, Derbyshire, victoria.simmer@cmgplc.com

[182] 20001 Internatioanl Conference on Imaging Science, Systems and Technology (CISST 2001), 25-28th June 2001, Las Vegas, USA. www.ashland.edu/~iajwa/conferences.

[183] The International Identification Conference Joint Conference the Fingerprint Society and the Fingerprint Branch. Queen Elizabeth Conference centre, London, mojan@supanet.com

Security

[184] Oh, H.S., Chang, D.H., Lee, C.H., Lee, H.K., Digital Image Watermarking on the Special Object – Human Face, Proceedings SPIE, Vol. 3971, pp. 536-544, 2000

[185] Lowe, P., Security Holograms and Counterfeiting, Intersec, Vol. 10, No 1, pp. 20-22, January 2000

[186] Huggett, A. Stubbings, C., Invisible Watermarking for Digital Video – Applications and Challenges, Proceedings from Paper on Secure Images and Image Authentication, pp. 9/1-9/6, April 2000

[187] Silvestre, G.C.M., Dowling, W.J., A Data-Embedding Technique for Digital Images, Proceedings from Paper on Secure Images and Image Authentication, pp.8/1-8/6, April 2000

[188] Green, R., User Requirements of Image Security Systems, Proceedings form Paper on Secure Images and Image Authentication, pp. 2/1-2/12, April 2000

[189] Fridrich, J., A Hybrid Watermark for Tamper Detection in Digital Images, Fifth International Symposium on Signal Processing and its Applications, ISSPA '99, Brisbane, Australia, 22-25 August1999, pp301-304

Digital Image Evidence

[190] Oxlee, G., Evidence in Imagery, Public Security, No 5, pp. 13-15, 1999

[191] Mackay, D., Digital – Where's the Evidence?, CCTV Today, Vol. 7, No 1, pp. 15-17, January 2000

[192] Imaging Standards, NIST, http://www.dynamicimaging.com/standard.com

[193] The FBI Fingerprint Image Compression Standard, http://www.c3.lanl.gov/~brislawn/FBI/FBI.html

[194] Office of Law Enforcement Standards, NIST, http://www.eeel.nist.gov/810.02/detection.html

[195] House of Lords 5th Report, Digital images as evidence, Feb 1998, www.parliament.the-stationery-office.co.uk/pa/ld/199798/ldselect/ldsctech.htm.

[196] House of Lords 8th Report, Digital images as evidence – Government's response, June 1998, www.parliament.the-stationery-office.co.uk/pa/ld/199798/ldselect/ldsctech.htm.

[197] Code of Practice for Legal Admissibility and Evidential Weight of Information Stored Electronically, DISC PD 0008:1999, British standards Institution, ISBN 0 580 33006 0

[198] Definitions and Guidelines for the use of Imaging Technologies in the Criminal Justice System (Version 2.2 Dec 7th, 2000), Forensic Science Communications, Vol. 3, No. 3, July 2001, www.FBI.Gov/hq/Lab/FSC/Current/swgit.htm

Working Groups

[199] Scientific Working Group Imaging Technologies, www.FBI.Gov/HQ/Lab/FSC/current/swigit1tr.HTM or www.theiai.org/swigit/index.HTML

[200] Investigative Image Processing Technical Group, www.spie.org

[201] ENFSI Digital Imaging Working Group, www.Forensic.to/Webhome/enfsidiwg/index.htm

[202] Corriveau, P., Webster, A., Rohaly, A.M., Libert, J., Video Quality Experts Group: The Quest For Valid Objective Methods, Proceedings SPIE, Vol. 3959, pp. 129-139, 2000

[203] Phelan, M.J., The Scientific Working Group on Digital Evidence, Microgram, Vol. 33, No. 3, pp. 48-49, March 2000

[204] Robinson, M., Petty, R., Evans, J.P.O., 3D Imaging Group, IEEE 1998, pp181-183

Appendix A – Questionnaire Search of Information

In order to determine the advances in image analysis since 1998 a request was made to 246 law enforcement agencies requesting information on the following:

4# **Technologies and Activities**

4# **Please provide a summary on any casework activities that have progressed from traditional photographic to digital imaging e.g. crime scenes, footwear, fingerprints, etc. We also require a brief description on casework activities where images constitute the primary evidence e.g. Video, Image authentication, pornography, etc. For all of the activities please include details on any image processing applied to image data, technical equipment, and software used.**

4# **Images as Evidence in the Criminal Justice System**

Could you provide a brief description of any issues images have presented to your criminal justice system, such as authentication of digital images, presenting evidence in courts. We would also be interested to know if your government is taking any steps to legislate or review the use of new imaging technologies in law enforcement?
Could you also give details of any protocols you may have implemented to ensure the admissibility or maximise the value of images as evidence in court.

4# **Research Activities**

We are interested in any research projects that your organisation is involved in that relate to imaging technologies.

4# **Issues**

Please provide details of outstanding issues relating to imaging technology that you feel still need to be resolved.

In order to capture the above information, we supplied a Questionnaire (Questionnaire A) for guidance. A second questionnaire was also supplied (Questionnaire B) to capture an overview of the prominence of digital imaging technologies in forensic activities.

Distributions of Questionnaire

The questionnaires were sent to 246 law enforcement institutions with 30 replies. A breakdown of the distribution of questionnaire and replies can be seen in Table A.1

Regions	Sent	Replies
Europe	75	19
USA	128	6
Other Americas	18	0
Asia	14	1
Australasia	11	4
Africa	0	0

Table A1 : A breakdown of the distribution and responses of questionnaires sent to law enforcement institutions.

Summary of Responses

Laboratory or Institution	Casework Methods, Activities.	Research Activities
Forensic Imaging Unit Western Australia Police Service, East Perth AUSTRALIA	Digital Identity fits Digital Identification boards Photographic Database 3D reconstruction (RTA) Transmission of images	
Fingerprint Bureau Western Australia Police Service, East Perth AUSTRALIA	Digital capture of fingerprints Digital image enhancement, Transmission of images	
Ballistics Section Western Australia Police Service, East Perth AUSTRALIA	Digital Photography Digital Image Capture. Transmission of images	
Forensic Science Service Tasmania Newtown Tasmania AUSTRALIA	Digital Photography (note keeping)	
National Institut voor Criminalistiek en Criminolgie, Brussel, BELGIUM	Digital capture (video) Image enhancement	IMPROOFS, 3D comparison
Criminal Technique Department Forensic Institute Zagreb CROATIA	Digital capture (note keeping) Video processing Comparison (docs)	
Institute of Criminalistics Prague CZECH REPULBIC	Digital Photography Digital image enhancement Photogrammetry	Digital image enhancement
Forensic Division International Relations Copenhagen DENMARK	Digital Capture (Fingermark, shoemarks) Digital Comparison	
Gendarmerie National Insitut de Recherche Criminelle, Cedex FRANCE0	Video and Image Processing Image Enhancement Photogrammety Object Recognition Comparison Image Databases	

	Transmission of fingerprints	
Laboratoire d'Analyse et de Traitement de Signal Ministry of Interieur Cedex FRANCE	Video Processing Video & Image Enhancement Facial Comparison Video authentication	3D Facial Comparison
Department of Forensic Medicine Szeged HUNGARY	Digital Photography, Video capture Facial Comparison	Road Traffic Accident reconstruction
Division of Identification and Forensic Science, Israel Police, ISRAEL	Digital Capture (Fngermarks, shoemarks, firearms, RTA) Image Enhancement Image Comparison Image Databases	
National Research Institute of Police Science Chiba JAPAN	Digital capture/photography Image analysis, Image enhancement Pattern recognition facial comparison Firearm landmark database	CCD fingerprint of digital cameras
Netherlands Forensic Institute, Rijswijk NETHERLANDS	Digital capture Video and image enhancement Photogrammetry 3D reconstruction image databases image comparison Camera identification	3D reconstruction gait analysis Visual comparison Camera identification Image databases (drugs, firarmes/shoeprints)
National Criminal Investigation Service, Oslo NORWAY	Digital photography Digital capture (fingerprints) Image enhancement Image Comparison Transmission of images	
Forensic Science Laboratory Ministry of the Interior Ljubljana Slovenia	Digital capture (documents and ballistics)	
Comisaria General de Policia Departamento de Audiovisuales SPAIN	Digital Capture (crime scenes) Digital Video Processing Image Enhancement	

Comisaria General de Policia Cientifica SPAIN	**Digital Photography Identification**	**Facial Reconstruction**
Comisaria General de Policia Cientifica, Seccion de Fotografia Madrid SPAIN	**Digital Capture (Fingerprints, crime scenes) Image Enhancement Image database (offenders)**	
The National Laboratory of Forensic Science, Linkoping SWEDEN	**Digital capture (video) Video and image enhancement, Photogrammetry**	**Digital capture Image compression and security Image enhancement and restoration Photogrammetry**
Zurich Canton Police Zurich SWITZERLAND	**Digital Capture/Photography (scene and lab) Image Databases Video Processing Scene Reconstruction**	
Digital Image Research Centre Kingston University Kingston UNITED KINGDOM		**Image Processing Visual Surveillance Intelligent Alarming 2D/3D tracking**
Forensic Science Service London UNTED KINGDOM	**Digital Capture (note keeping, record photography, video), Video processing Video & Image Enhancement Photogrammetry Video Comparison 3D reconstruction**	**IMPROOFS (photogrammetry, enhancement and identification), Digital capture/ transmission and processing at crime scenes Image databases (shoeprints, firearms, drugs) Image comparison (shoeprints) Human Identification (heights, gait and faces)**

US Postal inspection Service Dulles USA	**Digital Photography – record, note taking Digital Capture (video and documents) Image Enhancement Image Measurements Comparison Image Database Image Transmission**	
NCIS Regional Forensic Laboratory Norfolk USA	**Digital capture (fingerprints)**	
Forensic Consultant Services Fort Worth USA	**Digital Capture (fingermarks and video) Image databases Transmission of images**	**Comparison of photography and digital data**
Division of Forensic Sciences DECATUR USA	**Digital Photography Digital capture (documents, shoemarks, firearms and drugs) Databases Image Transmission**	
Jo Co Criminalistics Lab Mission USA	**Digital Photography (Lab and crime scene) Facial Identification/comparis on**	

Table A2 : A summary of the image analysis activities in law enforcement institution that replied to questionnaire.

Questionnaire A

Exchange of General Information on Forensic Imaging Technologies.

Institution, name and address	**Contact Person :** **Phone number :** **Fax Number :** **Email :** **Web Site Address:**
Casework Activities, a brief description of all activities involving imaging technologies :	
Planned Development for casework, a brief description of activities currently under development:	
Research activities, a brief description of each activities :	
Special cases, if possible brief description of any special/first time cases :	
Experience in giving evidence in court (especially digital), if possible brief description of questions asked :	
Training, a brief description of any associated technical/forensic training programmes for people working with imaging technology:	
Issues, what is your most important unresolved issue relating to Forensic Imaging Technology.	

Details of specific Forensic Activities using Imaging Technologies.
(one form per method)

Forensic Laboratory or Forensic research Institution, name and address	**Contact Person :** **Phone number :** **Fax Number :** **Email :**
Casework activity, a brief description of activity:	
Activity Output, a brief description of what is delivered and to whom.	
Laboratory equipment, a brief description of systems and software used :	
Quality, a description of any associated quality controls, protocols, assurance etc. with the above activity	
Reports / Publications, any (un)published papers related to the above method :	
Validation and Competency, a brief description of validation and any standards employed. In additions any competency criteria adopted for operators.	
Value, please give a short description of numbers of cases, workload, general advantages, time saving, improved value of forensic evidence etc :	
Court experiences, please indicate number times this methods evidence has been given in court and any relevant experiences :	

Details of any relevant Research projects
(one form per project)

Forensic Laboratory or Forensic research Institution, name and address	Contact Person : Phone number : Fax Number : Email :
Forensic research project, a brief description of project :	
Laboratory equipment, a brief description of systems and software used :	
Publications related to the above method :	
Expected Implementation, please indicate expected implementation into casework together with any critical factors.	

Collaboration and funding, please given details of any partners involved and source of funding :

Information on Issues concerning the Criminal Justice System

Forensic Laboratory or Forensic research Institution, name and address	**Contact Person :** **Phone number :** **Fax Number :** **Email :**
Government Legislation, a brief description of any legislation:	
Guidelines, a brief description of any known working groups or organisation that are producing guidelines :	

Admissibility, a brief description of any protocols used to ensure admissibility of evidence in your CJS :
CJS Experiences, a brief description of any unusual experiences giving evidence in your CJS :

Digital Imaging Technologies (DIT) Contributions to Forensic or Law Enforcement Activities

Graph

Forensic or Law Enforcement Activities	DIT involvement (Please tick)	Digital Imaging Technologies (DIT)																		
		Digital Camera <3 Mega Pixels	Digital Camera >3 Mega pixels	2D Scanners	3D Scanners	Video Frame	Microscopy Frame Grabbers	Enhancement - Linear	Enhancement - Non Linear	Measurement - Ratios	Measurement - Absolutes	3D Reconstruction Software	Panoramic/Mosaic Software	Visual Comparison Software	Computer aided Comparison	Pattern Recognition	Image Databases	Transmission of Images -	Transmission of Images -	Other - Brief description of any other technology
Scientific Photography																				
General Photography for casenotes																				
CCTV (video)																				
Surveillance																				
Authentication																				
Computer Crime																				
Finger marks - Lab																				
Finger marks - Scene																				
Footwear marks - Lab																				
Footwear marks - scene																				
Personal Identification – Facial																				
Personal Identification –																				

Anthropometry																				
Road Traffic Accidents																				
Fire Investigation																				
Documents																				
Firearms																				
Drugs																				
Crime Scenes																				
Training																				
Court Room																				

Forensic or Law Enforcement Activities	DIT involvement (Please tick)	DIT Output				Quality of DIT Output			Validation			Operator Competency		Crimin Justice System
		Who interprets the output		Analytical method										
		Imaging Expert	Forensic Expert	Objective Analysis	Subjective Analysis	Quality Assurance	Standard Operating Procedures	Quality	International Standards	Inter-Laboratory	In house	Training Programmes	Competency Testing	Protocol for ensure admissibility
Scientific Photography														
General Photography														
CCTV (video)														
Surveillance														
Authentication														
Computer Crime														
Finger marks - Lab														
Finger marks - Scene														
Footwear marks - Lab														
Footwear marks - scene														
Personal Identification - Facial														
Personal Identification - Anthropology														
Road Traffic Accidents														
Fire Investigation														
Documents														
Firearms														
Drugs														
Crime Scenes														