

The author(s) shown below used Federal funds provided by the U.S. Department of Justice and prepared the following final report:

Document Title: Evaluation and Application of Polynomial Texture Mapping (PTM) in the area of Shoe/Tire Impression Evidence

Author(s): James S. Hamiel, John S. Yoshida

Document No.: 240591

Date Received: December 2012

Award Number: 2004-IJ-CX-K008

This report has not been published by the U.S. Department of Justice. To provide better customer service, NCJRS has made this Federally-funded grant report available electronically.

Opinions or points of view expressed are those of the author(s) and do not necessarily reflect the official position or policies of the U.S. Department of Justice.

Evaluation and Application of Polynomial Texture Mapping (PTM) in the area of Shoe/Tire Impression Evidence NIJ Grant# 2004-IJ-CX-K008

James S. Hamiel and John S. Yoshida

Senior Criminalist James Hamiel has a B.S. in Criminalistics from California State University at Sacramento and is currently a staff scientist with the Central Valley Crime Lab. He has been working in the field for 11 years. His current assignment is firearms/toolmark examinations and crime scene responses. Mr. Hamiel is one of the scientists qualified to examine shoe/tire impressions and is the lead researcher on the PTM project. He can be reached at (209) 599-1400 or by e-mail at james.hamiel@doj.ca.gov.

Laboratory Director John S. Yoshida has a B.S. in Biological Sciences from the University of California at Davis and has worked in various crime laboratories for 28 years. He has worked in multiple disciplines in the lab including trace, firearms/toolmarks, chemistry and biology. He has also been involved in many crime scene and clandestine lab investigations in the past 27 years. Currently, he is the Director of the Central Valley Crime Lab that has 30 professional scientists on staff. The services range from crime scene investigations to a full complement of forensic services. He can be reached at (209) 599-1400 or by e-mail at john.yoshida@ca.doj.gov.

Evaluation of the PTM Technique for Impression Evidence

Acknowledgements:

This research would not have been possible without the support and hard work of many people. The Central Valley Laboratory would like to thank the California Department of Justice and the Bureau of Forensic Services (BFS) for their support and encouragement. Mr. Malzbender and Mr. Gelb¹, the developers of the PTM technique, introduced this technology to the Forensic community. Their assistance with this research was indispensable. The building of the PTM dome and the electronic components of the portable dome would not have been completed without the work of Mr. Michael Cavallo². The work of Mr. Robert Kuta and Allied Engineering and Production Corporation³ with the final design and fabrication of the frame for the portable PTM unit allowed this project to be completed. Finally, the testing of this technology would not have been possible without the hard work and dedication of Bureau of Forensic Services -Central Valley Laboratory staff that put many hours into this project. The core group of testers includes Central Valley Senior Criminalists Sarah Yoshida, Elizabeth Schreiber, John Brogden and Criminalists Nicole Snodgrass and Scott Bauer. Senior Criminalist Taro Swanson provided assistance in testing the portable LED PTM unit.

¹Mr. Malzbender (Senior Research Scientist) and Mr. Gelb (Software Design Engineer) are at HP Labs and Mr. Malzbender can be reached at malzbend@hpl.hp.com

² Mr. Michael Cavallo can be reached at michael.cavallo@comcast.net

³ Mr. Robert Kuta can be reached at Allied Engineering & Production Corp. (510) 522-1500

Evaluation of the PTM Technique for Impression Evidence

Content

Acknowledgements.....2

Executive Summary.....5

 Introduction.....5

 Polynomial Texture Mapping (PTM).....5

 Hardware Considerations.....6

 Impact on Forensic Impression Evidence.....8

 Future Research.....8

Project Description.....9

 Equipment.....9

 PTM dome.....11

 Portable PTM Unit.....12

 Testing of PTM Technique.....13

 Results and Conclusions.....13

 Portable PTM Unit Testing.....18

 Results and Conclusions.....18

 Digital Camera Resolution.....19

 Results.....23

 Conclusions.....28

Additional Project – Portable LED PTM Unit.....29

References.....32

Evaluation of the PTM Technique for Impression Evidence

List of Exhibits in this report:

Exhibit 1: Oblique light PTM images of a shoe impression in soil.....	7
Exhibit 2: PTM workflow diagram.....	10
Exhibit 3: Laboratory PTM Dome.....	11
Exhibit 4: Portable PTM Unit.....	12
Exhibit 5: Traditional soil impression vs. a PTM enhanced soil impression.....	15
Exhibit 6: Traditional and two PTM enhanced images of a shoe impression in blood.....	16
Exhibit 7: Traditional soil impression and a PTM enhanced soil impression of a boot.....	17
Exhibit 8: Canon EOS 1Ds Mark 2 camera.....	19
Exhibit 9: Canon EOS 20D camera.....	20
Exhibit 10: Canon EF 24-85 mm, EFS 17-85 mm, and EF 24-105 mm lenses used for study....	20
Exhibit 11: Edmunds Scientific Resolving Power Chart.....	21
Exhibit 12: Canon EOS 1Ds Mark 2 camera at ISO 100 to 35 mm film.....	23
Exhibit 13: Canon EOS 1Ds Mark 2 camera at ISO 400 to 35 mm film.....	24
Exhibit 14: Canon EOS 1Ds Mark 2 camera at ISO 400 to 35 mm film.....	24
Exhibit 15: Canon EOS 1Ds Mark 2 camera at ISO 800 to 35 mm film.....	24
Exhibit 16: Comparison of Canon EOS 20D camera resolution to 35 mm film.....	25
Exhibit 17: Canon EOS 1Ds Mark 2 and EOS 20D cameras using EF 24-85 mm lens.....	26
Exhibit 18: Canon EOS 1Ds Mark 2 and EOS 20D cameras using EF 24-105 mm lens.....	26
Exhibit 19: EF 24-85 mm and EF 24-105 mm lens on Canon EOS 1Ds Mark 2 camera.....	27
Exhibit 20: EF24-85 mm, EF 24-105 mm, and EFS 17-85 mm lens on Canon EOS 20D.....	27
Exhibit 21: Portable LED PTM Unit.....	29
Exhibit 22: PTM image using 30° and 44° lenses with LED lights.....	31

Evaluation of the PTM Technique for Impression Evidence

Executive Summary:

Introduction:

A shoe or tire has to have some unique characteristics that are transferred to impressions for successful comparisons. These characteristics are acquired through use or abuse. Small cuts, tears, and abrasions appear on the soles of shoes or the treads of tires as they travel in different environments or situations. These unique characteristics must have significant detail and be transferred to a corresponding impression. The unique characteristics transferred to the impression must then be captured through photography and/or other collection techniques. The ability to capture this unique detail in a crime scene impression is critical to the successful comparison to a known shoe or tire. It is also important to find the responsible shoe or tire before the unique characteristics captured by the impressions have worn away or changed.

The documentation of footwear and tire impressions at crime scenes is primarily performed through the use of photography. Other than improvements in film resolution, photographic documentation techniques have remained virtually unchanged. This method of capturing the detail left by a particular shoe or tire utilizes photographs taken with oblique lights from different directions. This time-consuming process could take up to an hour for the setup and photography of multiple oblique light images of the same impression. Traditional photography of footwear and tire impressions does not always capture the unique characteristics present in an impression. When the unique characteristics in a footwear or tire impression from a crime scene are not adequately documented, comparisons to a suspect's shoe or tire will result in inconclusive findings.

Polynomial Texture Mapping (PTM):

Tom Malzbender of Hewlett Packard Laboratories developed the Polynomial Texture Mapping (PTM) software. This software was designed to improve the photorealism of texture maps. The software is able to map light values from digital images taken with multiple light sources and create a light space model in a single image. The light direction in this image can be changed in real time allowing an unlimited variation of the light angle within the hemisphere of the photographs. Additional technical information regarding the mathematics and software function of the PTM software "Polynomial Texture Maps" by Thomas Malzbender, Dan Gelb, and Hans Wolters can be viewed at: www.hpl.hp.com/personal/Tom_Malzbender/papers/PTM.pdf

PTM technology has been used in art galleries and for the display and enhancement of ancient clay tablets and fossil remains for several years. The enhancement of detail observed when applying these techniques to the fossils or clay tablets has led to better interpretations of these objects. The images are remarkable and led to our proposal to test this technique in a forensic science application. PTM has the potential of yielding much more information from impressions than the current techniques of single image oblique lighting and casting with dental stone.

The goal of this project is to determine whether the Polynomial Texture Mapping (PTM) technique would enhance the forensic impression evidence comparisons and to create a PTM unit that is portable for field use.

Evaluation of the PTM Technique for Impression Evidence

Hardware Considerations:

Cameras

The researchers started the project by evaluating different digital cameras for use with the PTM dome. The Canon EOS 1Ds Mark II 16.7 megapixels (MP) and Canon EOS 20D 8.2 MP cameras were purchased for resolution comparison to 35mm film. The Canon digital cameras were evaluated using a Canon EF 24-85 mm, Canon EFS 17-85 mm, and Canon EF 24-105 mm lenses. The digital cameras were compared to the 35 mm Canon EOS élan IIE using the same lenses. Other lenses may have better or worse resolving power.

Computer

Most modern computers are adequate for the PTM software. The minimum recommended random access memory (RAM) is one (1) gigabyte (GB) and there must be adequate storage space for the digital camera images (approximately 2.5-7 megabytes per image) and the resultant PTM file. Each PTM file is approximately 75-100 megabytes (MB). These file sizes are dependent on the size of each captured image (resolution setting). We would recommend at least 60 GB hard drive or other storage space. An increase in RAM improves the operation of the PTM software.

PTM Dome

The Laboratory PTM dome at Hewlett-Packard (H-P) Laboratories is approximately three (3) foot in diameter and contains 50 fixed lights or strobes. Mr. Malzbender indicated that additional strobe positions would provide smoother lighting transitions in the finished PTM file. We decided to use 64 different light positions on our PTM dome.

Portable Unit

The portable PTM unit was designed after the dome structure. A rotating 3-foot arc (18" radius) with eight (8) light sources (slave camera flashes) attached was fabricated. The arc can be manually stopped at eight (8) different positions to mimic the 64 different light positions on our PTM dome. The portable unit requires more human intervention than the PTM dome. Also, there is a potential weakness in capturing images with the portable unit during daylight hours. This can be overcome by the use of any opaque material for shading the impression.

PTM Advantages:

The PTM technique has several advantages for the documentation of footwear and tire impressions. The first is that multiple images of the impression are taken using a different fixed light source position for each image. This is similar to the traditional method of impression photography. However, this system is synchronized and controlled through a computer interface and allows these images to be captured in a fraction of the time required for traditional photography techniques (2-3 minutes for 64 images vs. up to an hour with traditional photography). The second is the use of the PTM software. The software creates a light space model using calculated light values from the captured images. The photographed impression can be viewed through the software with infinite light positions in a hemisphere over the impression. This software allows the examiner to fine tune the light position for any area of an impression during a comparison and gives the examiner the ability to maximize the visualization of the texture in an impression. This software also has several enhancement techniques (specular and diffuse gain) that can further improve the visualization of texture detail in an impression. The use of the PTM technique allows for better documentation and better-resolved images of impressions left at the crime scenes. The fixed lighting positions required for the PTM technique

Evaluation of the PTM Technique for Impression Evidence

improves the consistency of impression documentation. The use of the PTM technique could significantly improve the quality of comparisons to known shoe soles or tire treads.



Exhibit 1: The red arrows depict six of the infinite light positions from a PTM image. An infinite number of light positions can be viewed with this technique using the same interactive image.

Evaluation of the PTM Technique for Impression Evidence

Impact on Forensic Impression Evidence:

Various digital cameras were tested for use with the PTM technology. The evaluations compared the resolution of 35 mm photographs to the digital images. The research indicates that a minimum sensor resolution is needed. For the Canon cameras tested, this was approximately 8 megapixels. This will vary with different manufacturers and models of digital cameras and each should be evaluated prior to use for forensic work. The PTM software utilizes JPEG file format. The JPEG compression did not affect the images significantly and RAW or TIFF file formats can be saved prior to a conversion to the JPEG format.

The testing performed with the fixed dome determined the PTM software could improve the visualization of texture within a shoe or tire impression when compared to traditional photography techniques. The PTM technique offers a dramatic improvement in the documentation of footwear and tire impressions compared to traditional techniques and saves significant time in the documentation process. This technique gives the examiner the best opportunity for visualizing unique characteristics in impression evidence. The additional software enhancements (specular and diffuse gain) further assist in the texture visualization and can improve the quality of comparisons to shoes and tires.

This improvement in the visualization of detail in impressions, improvement in documentation and the reduction in collection time also apply to the portable version of the PTM dome.

When compared to traditional photography techniques, the PTM technique improved the visualization of unique characteristics in several of the impressions captured during testing. Many of the areas of unique detail improved with the PTM technique were visible in the traditional photographs, but the shape of the detail was not as well defined. The PTM technique improved the detail shape in these areas allowing the examiner to confirm the correspondence of the detail in the impression to a unique characteristic in the shoe. However, the use of the PTM technique did not improve the visualization of texture in all of the impressions captured when compared to traditional photography techniques.

Overall, the research indicates that the use of PTM technology for documentation and evaluation of impression evidence improves the quality of the analysis. The PTM technique saves a tremendous amount of time in capturing different oblique-lighted images of an impression. The analysis of different detail in an impression is much easier using one PTM file vs. multiple 35 mm impression photographs needed to capture the unique detail. Using the PTM technique, examiners have an infinite number of images from different lighting positions available for their comparisons.

Future Research

Future designs could also incorporate an automated (motorized) sweep of the light positions rather than the current manual movement through the different positions. A simplified software interface could be developed to simplify the creation of the PTM files.

Future research could also include an even smaller unit for use in latent print and questioned document examinations. The use of the PTM technique in forensic sciences can be varied and the technique should be evaluated for other types of comparative evidence.

Evaluation of the PTM Technique for Impression Evidence

Project Description:

This National Institute of Justice (NIJ) research project was awarded to evaluate the PTM imaging technique for use with forensic footwear and tire impression evidence comparisons and to develop a portable unit for use at crime scenes. The first part of the project was dedicated to construction of a laboratory-based PTM dome, purchase and testing of camera equipment, and the development of software to synchronize the digital camera control (image capture) with the flash sequence. The second part of the project consisted of testing the PTM technique with several different types of impression evidence. The impressions captured with the PTM method were compared to traditional techniques to determine any advantages or disadvantages with the PTM method. The third part of the project was designing and constructing the portable field unit including the evaluation of various flash units (strobes) for use with this device. The field unit was constructed and then tested in field conditions.

The PTM software has two main components: a fitter program and a viewer program. The PTM fitter program creates the PTM file using the biquadratic polynomial coefficients and a light position file. The fitter program recognizes image files with the JPEG (.jpg) file extension. Image files with TIFF (.tiff) and RAW (.raw) file extensions cannot be converted into PTM images. The light position file describes the vector light value and location of each strobe and matches this information to the image captured when this strobe was fired. Once the fitter program has created the PTM file, the viewer program is used to view the images and enhancement features. The light position file is specific to each dome constructed. The PTM fitter and viewer programs can be downloaded from <http://www.hpl.hp.com/research/ptm/downloads/download.html>.

Equipment

The equipment needed to utilize the PTM software can be relatively simple. The minimum requirements are a fixed camera and repeatable lighting positions (LP) with known coordinates in three-dimensional space (X, Y, and Z positions). The positions of the lights are used to create the LP file used by the fitter program that produces the PTM file. The light positions need to be repeatable or you have to create a new LP file for each set of images. The lights only need to be turned on and off in a designated sequence for each photograph. The sequencing of the lights and photographs can be accomplished manually. For example: Light 1 is turned on and a photograph (Image 1) is taken. Then Light 1 is turned off and Light 2 is turned on and a photograph (Image 2) is taken. This process continues until photographs have been taken with all of the light positions. The vector position value for Light 1 in the LP file must correspond to Image 1 and Light 2 to Image 2 etc. The PTM fitter uses the images and the corresponding vector locations from the LP file to create the PTM file.

The coordinates of the fixed lighting positions are critical in calculating the light space in between each LP. This lighting model is the basis of the PTM technique.

Evaluation of the PTM Technique for Impression Evidence

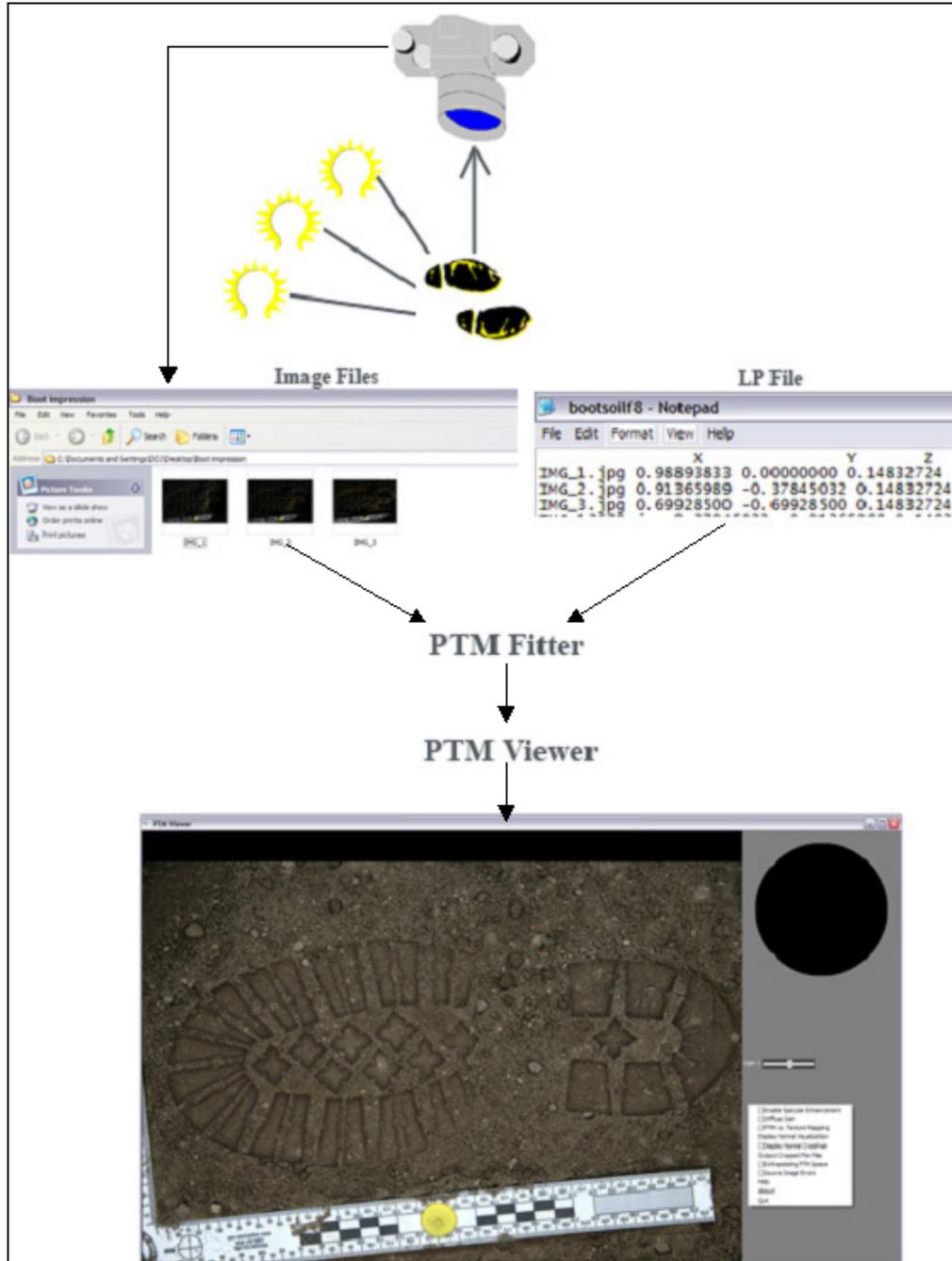


Exhibit 2

Evaluation of the PTM Technique for Impression Evidence

PTM Dome

A PTM dome was constructed based on the design utilized by Tom Malzbender of Hewlett Packard Research Laboratories. The prototype dome built by Mr. Malzbender utilized 50 strobe positions. These strobes were evenly distributed around the hemisphere and gave adequate light coverage for the object being photographed. The PTM dome was used to document various impression samples (shoe impression casts, electrostatic dust lifts, etc.) for initial viability with forensic impression evidence. Mr. Malzbender indicated that additional strobe positions would provide smoother lighting transitions in the finished PTM file. The size of the dome can vary based on the intended application. Michael Cavallo was contracted for the construction of this dome. The shell of this dome is constructed of blow-molded plastic with a diameter of approximately 27 inches. This dome was selected because it was readily available from Mr. Cavallo. The interior of the dome shell was painted flat black to reduce reflections within the hemisphere. Sixty-four (64) strobes attached to circuit boards were mounted around the hemisphere of the dome. The strobe boards were designed and custom built by the contractor. The power to the strobes and the sequence of firing are controlled through a controller box. The controller box utilizes 110-volt current. The 110-volt current is reduced through a transformer to the capacitors on the strobe boards. The capacitors on the strobe boards are charged in series through a ribbon cable attached to the controller box. Mr. Cavallo utilized software available with digital cameras (software development kits (SDK)) to synchronize the camera shutter with the firing of the strobes and the download of the images to an attached computer. The metal frame around the top of the dome has a polyacrylic plate used for mounting the camera. The lens of the camera is oriented through a hole at the top of the dome. The strobe positions in the dome were measured in three-dimensional space and the light vector values calculated to create a light position (LP) file.

The object to be photographed is placed in the center of the lighting hemisphere. A single photograph is taken for each strobe position. The dome constructed for this project uses 64 strobes. This results in 64 separate digital photographs. Except for the angle of oblique light, each photograph is identical. Each photograph corresponds to the vector light direction of the strobe that was fired when the image was captured. With this information, the software applies biquadratic polynomial coefficients to determine light values for each pixel of each image. These values are combined to create the PTM file, which is a model of the lighting hemisphere. The original 64 images are retained separately.

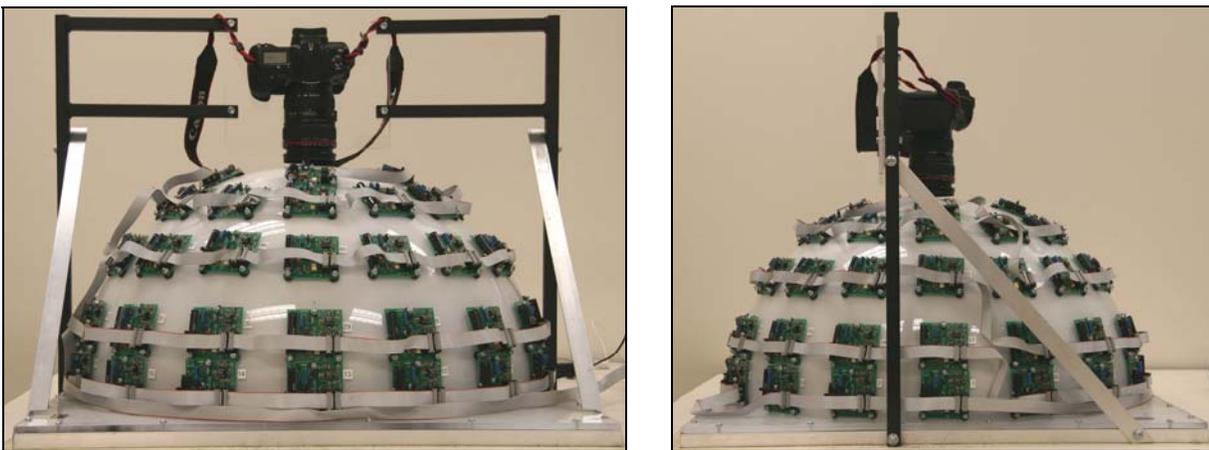


Exhibit 3

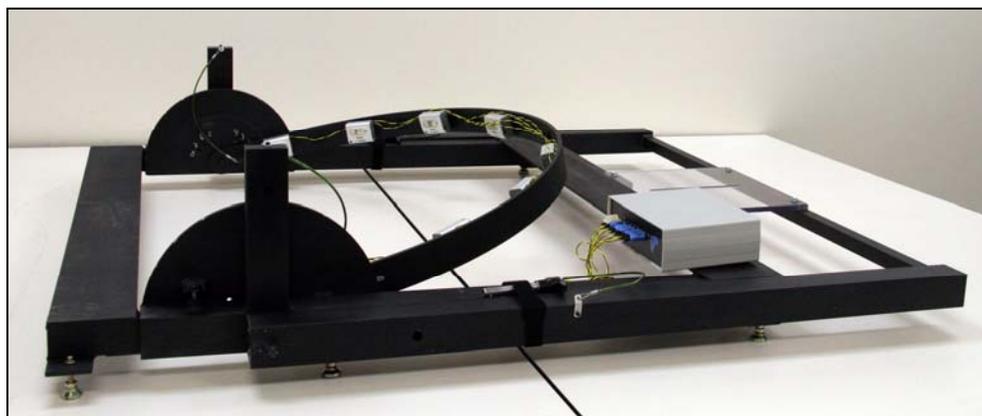
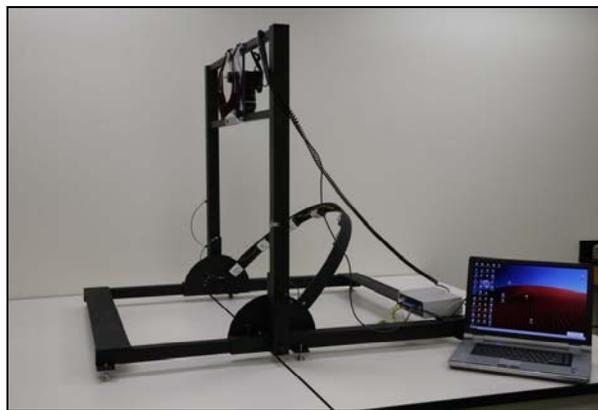
Initial testing of the PTM technique was performed using this laboratory dome. The design for the prototype portable dome was built utilizing the features of the laboratory-based dome.

Evaluation of the PTM Technique for Impression Evidence

Portable PTM Unit

The portable dome frame was modeled using PVC pipe to determine whether the design is adequate for construction. The final design was developed with input from Robert Kuta of Allied Production and Engineering Corporation (APEC) located in Alameda CA. He recommended the engineering specifications required for the unit based on the weight of the components. The frame was constructed of square, tubular aluminum. The flash arc was constructed of 1/4" sheet aluminum with an 18" radius. The flashes used on this dome are modified Vivitar DF120 digital slave flashes with a guide number of 40' at 35 mm. These flashes were selected due to their compact size and because the light output worked well with the radius of the flash arc. Michael Cavallo was again contracted to develop the software, controller box, and modify the flashes. The controller box for this dome utilizes a USB connection and is powered through the attached computer. Two AAA batteries power each of the flashes. Eight flashes are attached to the rotating strobe arc. The strobe arc has eight rotation positions giving a total of 64 flash locations. The flash locations were measured and the light vector values calculated to create a Light Position (LP) file. The camera mount is a polyacrylic plate mounted on square tubular cross members.

The portable PTM unit is 45" W x 53" L x 42" H in the open position. The camera mount frame and the swing arm fold flat and one set of legs telescope inward for transport and storage. In this position the unit is 45" x 50" x 11". There are six adjustable legs, which assist in leveling the unit over the impression and limit the unit's contact with the ground/impressions. The unit weighs approximately 50 pounds.



Evaluation of the PTM Technique for Impression Evidence

Testing of PTM technique:

Purpose:

To compare the detail visualized in footwear impressions using traditional lighting techniques and the PTM process.

Procedure:

Test footwear impressions were produced using several different substrate materials and types of footwear. Test impressions were made in soil, mud, and blood with the three types of footwear (an athletic type shoe, a work boot, and a dress type shoe). One shoe from each pair was used to make all of the impressions for evaluation. Additional impressions were made on cardboard and a dust impression was created for collection with an electrostatic lifter.

These impressions were photographed using the PTM dome system with the Canon EOS 1Ds Mark II camera. Casts were made of the three dimensional impressions in soil and mud, these casts were photographed with the PTM system for evaluation.

Four of the 64 images captured using the dome were selected for use as the traditional type impression photographs. These photographs were evaluated and compared to the test shoes using normal comparison techniques to document the unique detail that was visible using the traditional lighting methods. Using the PTM software, images were printed with light positions similar to the light positions used for the traditional images. These images were evaluated and compared to the test shoes using normal comparison techniques to document the unique detail visible using the PTM software to mimic traditional lighting. Finally, the traditional images were compared to the PTM images. The amount and quality of detail correspondence were recorded between the traditional and interactive PTM images.

Results and Conclusions:

The PTM files assisted in the comparisons of the footwear impressions. When using the PTM file for comparisons the adjustable light position was very useful for highlighting texture information in an area of interest. In some comparisons, the enhancement features in the software (specular and diffuse gain) improved the visibility of unique detail in an area of interest. The PTM image and enhancements improved the visibility of detail in some of the impressions photographed. When compared to traditional oblique light images the shadows of the PTM file were slightly soft compared to the hard-edged shadows in the traditional photographs. Mr. Malzbender indicated this effect is caused by the simplicity of the polynomial equation used to map the light values. He also indicated a more complete equation could be developed. However, the size of the PTM files would become prohibitively large. The PTM files utilized during this study were approximately 75 MB. PTM file sizes in the 400-500 MB range were estimated if a more complete equation were developed. The soft shadows did not significantly affect the quality of the comparisons performed during this study. Additionally, 64 traditionally lighted images with the hard-edged shadows are captured during this process and are available for use in comparisons. For these reasons the development of a more complete equation is not warranted.

Evaluation of the PTM Technique for Impression Evidence

Athletic shoe:

The traditional photographs, the printed PTM images, and the interactive PTM file for the impressions made with blood were compared to the athletic shoe sole using normal comparison procedures. There was sufficient correspondence of unique detail in all of these images to identify the athletic shoe to the impressions in blood. Some improvement in the visibility of the impression detail was observed with the specular enhancement feature of the PTM software.

The traditional photographs, the printed PTM images, and the interactive PTM file for the impression made in soil were compared to the athletic shoe sole using normal comparison procedures. In the traditional photographs and the printed PTM images sufficient correspondence of unique detail was observed to conclude the athletic shoe most likely made the impression in soil. However, the quality of the correspondence was insufficient for identification. When the soil impression was viewed using the interactive PTM file additional clarity of unique detail was observed using the specular enhancement feature of the software. The additional clarity of the detail observed was sufficient to identify the athletic shoe to the impression in the soil.

The traditional photographs, the printed PTM images, and the interactive PTM file for the impression made in mud were compared to the athletic shoe sole using normal comparison procedures. In all of the images some unique detail was observed. However, the correspondence of unique detail in this impression was insufficient for identification. Some additional clarity of detail was observed using the interactive PTM file and enhancement features. However, the additional clarity was not sufficient to change the examiner's conclusion.

Work boot:

The traditional photographs, the printed PTM images, and the interactive PTM file for the impressions made with blood were compared to the work boot soles using normal comparison procedures. There was sufficient correspondence of unique detail in all of these images to identify the work boot to the impressions in blood. Some improvement in the visibility of the impression detail was observed with the specular enhancement feature of the PTM software.

The traditional photographs, the printed PTM images, and the interactive PTM file for the impressions made in soil were compared to the work boot soles using normal comparison procedures. There was sufficient correspondence of unique detail in all of these images to identify the work boot to the impression in soil. Several additional areas of correspondence were observed in this soil impression using the specular enhancement feature of the PTM software. The defects were observed in the traditional impression, but appeared to be soil artifacts, not unique detail transferred from the boot sole. The specular enhancement improved visualization of these features and allowed a clear correspondence to defects in the boot sole to be observed.

Evaluation of the PTM Technique for Impression Evidence



Exhibit 5

The traditional photographs, the printed PTM images, and the interactive PTM file for the impression made in mud were compared to the work boot soles using normal comparison procedures. In all of the images sufficient correspondence of unique detail was observed to conclude the work boot most likely made the impressions in mud. However the quality of the correspondence was insufficient for identification. Improvements in the clarity of some impression features were observed with the specular enhancement and diffuse gain features of the PTM software.

Dress shoe:

The traditional photographs, the printed PTM images, and the interactive PTM file for the impressions made with blood were compared to the dress shoe sole using normal comparison procedures. There was sufficient correspondence of unique detail in all of these images to identify the dress shoe to the impressions in blood. Additional clarity of the unique detail was visualized in the interactive PTM file using the diffuse gain and specular enhancement features.

Evaluation of the PTM Technique for Impression Evidence

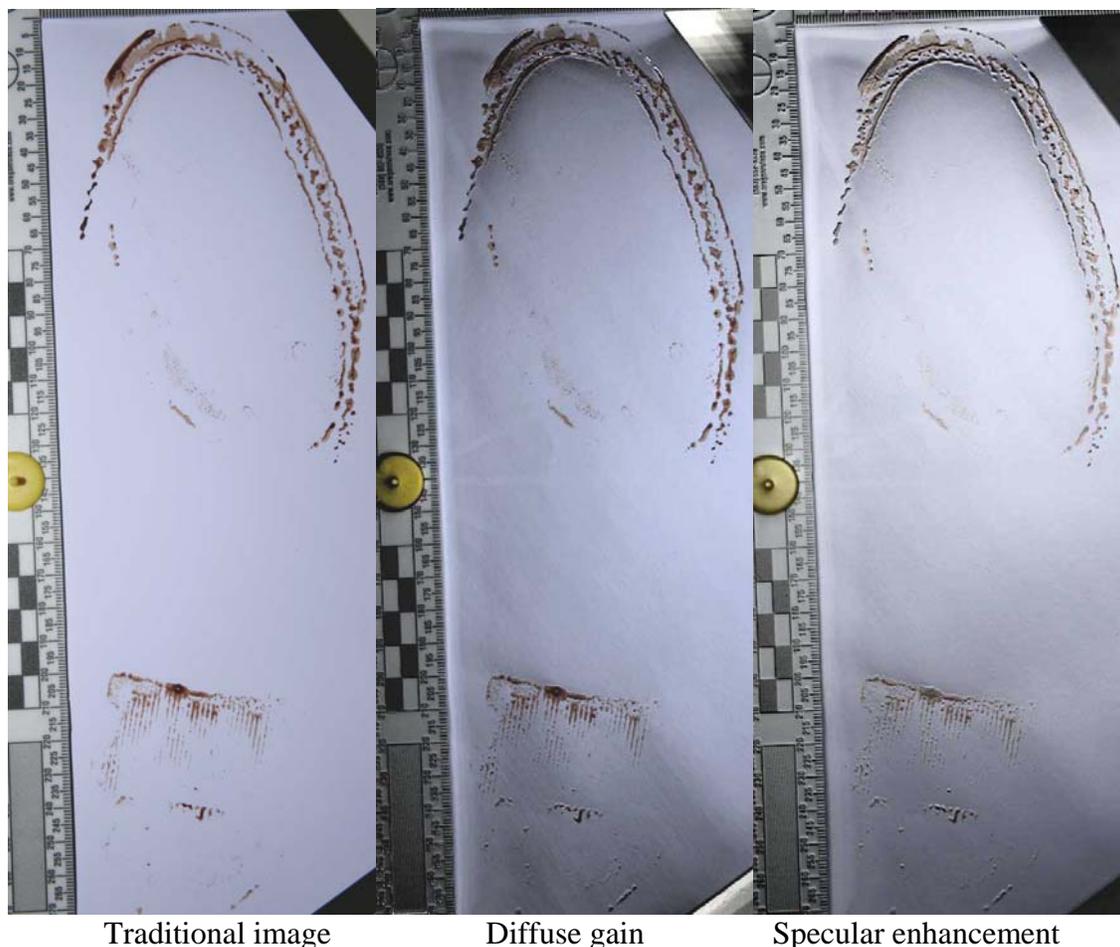


Exhibit 6

The traditional photographs, the printed PTM images, and the interactive PTM file for the impression made in soil were compared to the dress shoe sole using normal comparison procedures. There was sufficient correspondence of unique detail in all of these images to identify the dress shoe to the impression in soil. Additional clarity of the unique detail was visualized in the interactive PTM file using the specular enhancement feature.

The traditional photographs, the printed PTM images, and the interactive PTM file for the impression made in mud were compared to the dress shoe sole using normal comparison procedures. In all of the images sufficient correspondence of unique detail was observed to conclude the dress shoe most likely made the impression in mud. However, the quality of the correspondence was insufficient for identification. Some additional clarity of detail was observed using the interactive PTM file and enhancement features. However, the additional clarity was not sufficient to change the examiners' conclusion.

Evaluation of the PTM Technique for Impression Evidence



Exhibit 7

Casts:

The casts produced from the mud and soil impressions were photographed using the PTM technique. The interactive PTM file of these casts was evaluated. The clarity of the detail in the interactive PTM file for some of the casts was slightly improved using the diffuse gain and specular enhancement features of the software. The improved visibility of texture within the casts collected for this study was not significant. However, in a situation where poor photographs are received with a quality cast, the PTM technique may be beneficial.

Electrostatic lift:

An electrostatic lift of a positive dust impression was collected for photography using the PTM technique. The interactive PTM file of this lift was unsuitable for use. The highly reflective surface of the Mylar sheet used for collection of the dust impression prevented the visualization of the impression on this lift. The PTM technique did not improve the visualization of impression characteristics on the electrostatic lift.

Evaluation of the PTM Technique for Impression Evidence

Cardboard:

An impression was made on cardboard using the work boot and photographed using the PTM technique. The cardboard was not expected to capture unique detail. This impression was evaluated for the class characteristics of the boot sole. Using the interactive PTM file the general class characteristics of the boot sole were visible. The ability to freely move the light position allowed the examiner to quickly discern the shapes and general characteristics of the boot sole in the cardboard.

Testing of the Portable PTM Unit

Purpose:

To document tire impression evidence and test the prototype portable PTM unit in a field environment.

Procedure:

The Canon EOS 20D camera with the EFS 17-85 mm lens was used for the portable PTM unit. A tire impression in soil was produced outdoors using one of the Laboratory vehicles. A section of this impression was documented with the PTM technique during daylight and at night for comparison to the responsible tire. Daylight documentation was performed with the impression in full light and in shade. The set of images with the best quality was selected for final comparison to the responsible tire. The same comparisons performed for the testing of the laboratory-based dome were performed for the comparison of this tire impression.

Results and Conclusions:

The images of the tire impression taken during daylight showed reduced contrast and weak shadows. This effect is typical of impression photography using oblique light during daylight. The image quality was improved when the impression was shaded prior to taking the images.

The images captured at night had the best contrast and visibility for comparison and were used for the comparison to the tire. Comparisons were performed in the same manner as the comparisons for the footwear impressions tested with the laboratory PTM dome.

The traditional photographs, the printed PTM images, and the interactive PTM file for the impression made in soil were compared to the tire tread section using normal comparison procedures. There was sufficient correspondence of unique detail in all of these images to identify the tire tread section to the impression in soil. Some improvement in the clarity of the detail in the tire impression was observed. However, additional areas of unique correspondence were not observed.

Evaluation of the PTM Technique for Impression Evidence

Digital Camera resolution:

Canon EOS 1Ds Mark II (16.7 MP) and Canon EOS 20D (8.2 MP) cameras were purchased for resolution comparison to 35mm film. This study determined the minimum resolution settings for these cameras when compared to 35mm film using a standard resolving power chart.

This study is applicable to the Canon EOS 1Ds Mark II and Canon EOS 20D digital cameras with the Canon EF 24-85 mm, Canon EFS 17-85 mm, and Canon EF 24-105 mm lenses. Other lenses may have better or worse resolving power.

Equipment

- Edmund Scientific resolving power chart
- Tripod
- Canon EOS élan 35mm camera body
- Canon EOS 1Ds Mark II digital camera body
- Canon EOS 20D digital camera body
- Canon EF 24-85 mm lens
- Canon EFS 17-85 mm lens
- Canon EF 24-105 lens
- Tape measure
- ISO 200 and 400 35mm Film
- Computer with Adobe PhotoShop

Cameras

The Canon EOS 1Ds Mark II is a single lens reflex (SLR) style digital camera with a full frame (36 mm x 24 mm) single plate CMOS sensor. The sensor has 16.7 effective megapixels with an RGB primary color filter and a low-pass filter located in front of the sensor. Images can be recorded on Type 1 or 2 CF cards or an SD card. Images can also be recorded directly to a computer using a FireWire® connection. The camera body is compatible with all Canon EF series lenses and EX series flashes.



Exhibit 8

Evaluation of the PTM Technique for Impression Evidence

The Canon EOS 20D is an SLR style digital camera with a single plate CMOS sensor. The sensor of this camera uses the same technology as the Canon 1Ds Mark II, but has a smaller physical size (22.5 mm x 15 mm) than 35mm film resulting in a magnification change of 1.6x for lenses attached to this camera. The sensor has 8.2 effective megapixels with an RGB primary color filter and a low-pass filter located in front of the sensor. Images can be recorded on a Type 1 or 2 CF card or recorded directly to a computer using a USB connection. This camera body is compatible with all ES and EFS series lenses and EX series flashes. This camera was selected because it has a physically smaller sensor and lower price.



Exhibit 9

The EFS 17-85 mm and EF 24-105 mm lens have an image stabilization feature within the lens to minimize the effect of camera vibration on captured images. The EF 24-85mm lens does not have this feature and is a representative medium quality lens. The zoom ranges of the two EF lenses are unchanged on the Canon EOS 1Ds. The EFS series lens is not compatible with the Canon EOS 1Ds Mark II camera body. Because the EOS 20D camera uses a smaller sensor size than the EOS 1Ds, the effective zoom range of lenses on this camera are 1.6 times greater. For example, a 50 mm focal length is actually 80 mm with the EOS 20D body. The EF 24-85 mm lens and the EF 24-105 mm lens were tested on the EOS 1Ds Mark II and all three lenses were tested on the EOS 20D.



Exhibit 10

Evaluation of the PTM Technique for Impression Evidence

Resolving Power Chart

The Edmund Scientific resolving power chart is a 36 inch x 24 inch poster with reproductions of 25 USAF 1951 test patterns printed in several orientations across the poster. The USAF test pattern consists of a stepped series of three bar patterns (elements) in both horizontal and vertical orientation. The coarsest element printed on the poster has a center-to-center line spacing of 4 mm, which represents 0.25 line pairs per millimeter (LPM). A photograph of the chart is taken with the camera system being tested to determine the limiting group/element that can be resolved when examined. The relationship between the line pairs per millimeter on the chart (LPM chart) and the line pairs per millimeter on the photograph (LPM photo) is:

$$\text{LPM photo} = 1.41 \times (D - f_0) / f_0$$

Where f_0 is the focal length of the lens taking the image and D is the distance to the middle of the lens when the image was taken.

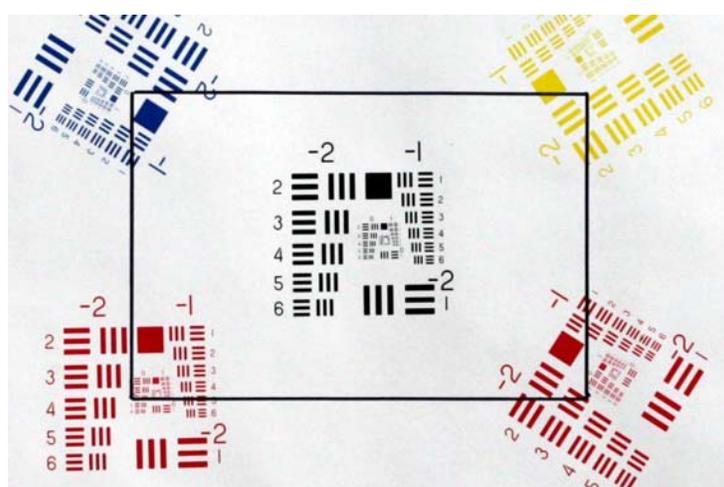
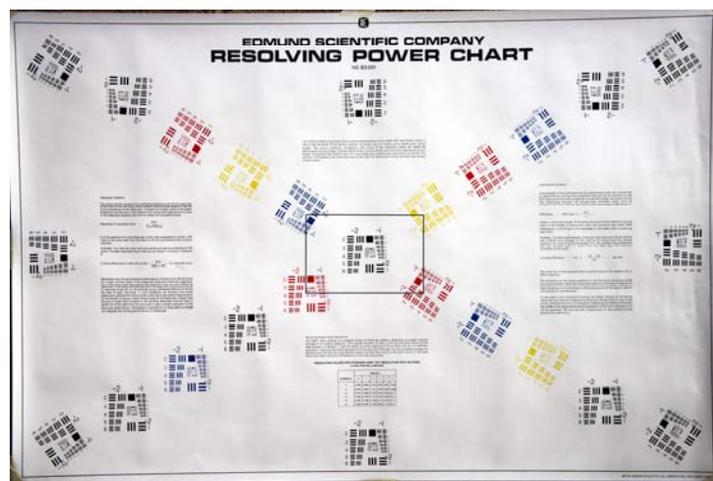


Exhibit 11

Evaluation of the PTM Technique for Impression Evidence

Canon EOS 1Ds Mark II

Experimental

The Edmund Scientific Resolving Power chart was used to determine the resolution of digital images to 35 mm film. Prior to photographing the resolution chart, a 4 x 6 inch border was placed around the USAF resolution target at the center of the resolution chart. This border was used for cropping purposes to print the enlargements at natural size. The center target was utilized to maximize the available resolution and minimize any potential lens effects.

The Canon EF 24-85 mm lens was used for the initial comparison of the digital cameras to film. Lens comparisons were performed using the two digital camera bodies.

The film and digital photographs were taken with natural daylight under similar lighting conditions. The digital photographs were printed at the same processing lab as the film prints to minimize paper and printing effects on the resolution. The 35mm photographs could not be cropped to the 4" x 6" border placed around the center resolution target due to enlargement limitations of the processing lab. The digital photographs were cropped and enlarged to the same size as the prints received from the processing lab using Adobe PhotoShop prior to having the images printed. The final prints were 65% of natural size for all digital and film photographs.

Film

The edges of the resolution chart filled the frame of the viewfinder for each photograph. The 35mm photographs were taken with Fuji brand ISO 200 and 400 films used at the Laboratory (ISO 200 speed film is the slowest film currently utilized at crime scenes). The EF 24-85 mm lens was used for the film images and was set at a 50mm focal length. The distance from the approximate center of the lens to the resolution poster was measured for the line resolution calculations. The lens aperture was set at f16, using an aperture priority, to ensure the poster was in focus.

Canon EOS 1Ds Mark II

The poster was then photographed with the Canon EOS 1Ds Mark II digital camera using the same lens, ISO setting, and focal length as the film camera. The edges of the poster filled the frame of the camera viewfinder. Four ISO settings (100, 200, 400, and 800), three image sizes (small, medium, and large), and three compression settings (1, 5, and 10) were selected for the digital photographs. The small image size is approximately 4.1 MP, the medium image size is approximately 8.6 MP, and the large file size is approximately 16.7 MP. The compression settings on the camera range from 1-10, with 1 having the most compression and 10 having the least. All of the images were captured as .jpg images since this is the only format the PTM software will recognize.

Line resolutions for the prints were determined and the results compared.

Evaluation of the PTM Technique for Impression Evidence

Canon EOS 20D

Resolving power chart images were captured with a Canon EOS 20D and compared in the same manner as the images for the EOS 1Ds Mark II using the EF 24-85 mm lens. The file sizes for these images ranged from 0.9 MB to 3.2 MB. The results of these photographs indicated that this camera and lens combination was not equivalent to film when the 24" x 36" poster filled the frame of the viewfinder. Based on these results, a modified procedure was used to test this camera body. A target area on the resolving power chart with a similar size to footwear and tire photographs taken at crime scenes was selected. An 11" x 17" border was placed around the center USAF target of the resolving power chart. The area in this border filled the frame of the viewfinder for all-subsequent testing with the three lenses. Images were also taken with the EOS 1Ds Mark II camera using the same 11" x 17" border with image size setting at small, medium and large with a compression setting of 10. As in the prior procedure, the lenses were set to an equivalent 50mm setting and images were cropped to the 4" x 6" border for printing at the same processing lab.

The line resolutions for these prints were determined and the results compared. The absolute value of the lines per millimeter calculated for the 11" x 17" border images may not be accurate due to the effect of the reduced distance used for these images. This reduced distance directly affects the calculated lines per millimeter value in the resolution formula for the resolving power chart. However, the results of the comparison between these cameras and lenses are valid.

Results

Canon EOS 1Ds Mark II compared to film.

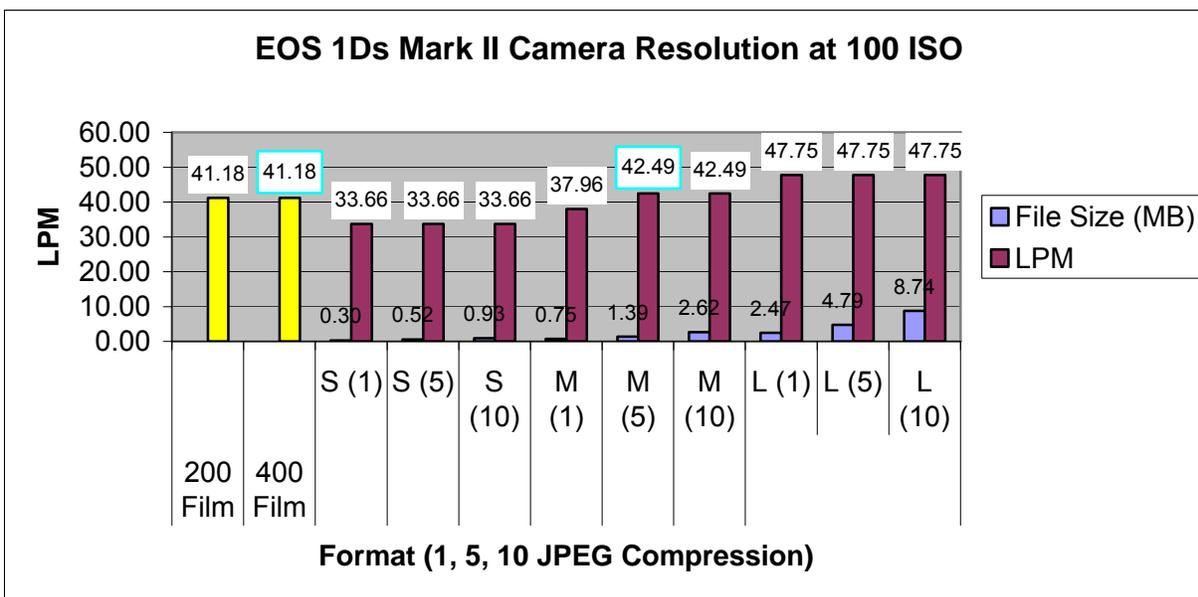


Exhibit 12

Evaluation of the PTM Technique for Impression Evidence

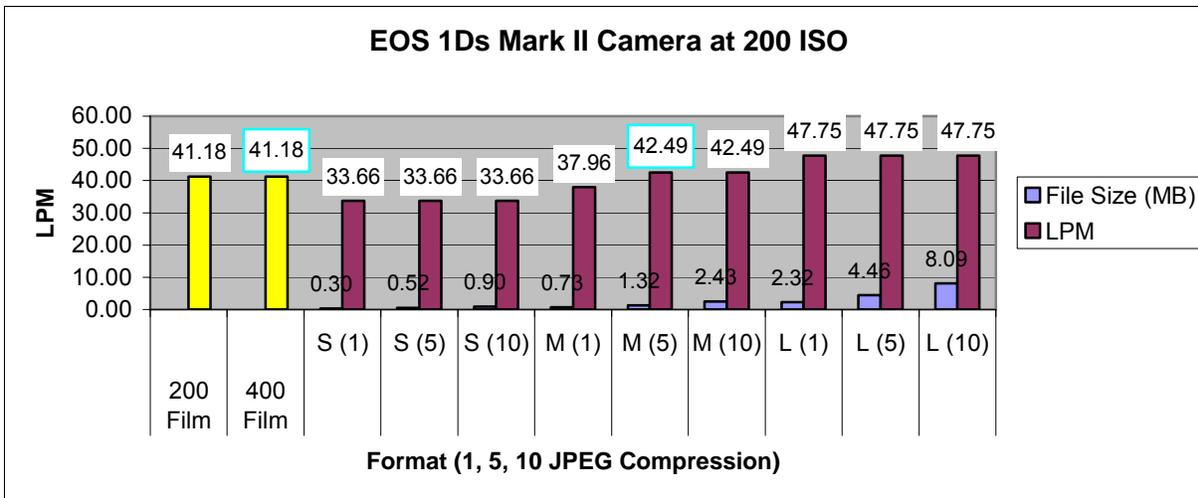


Exhibit 13

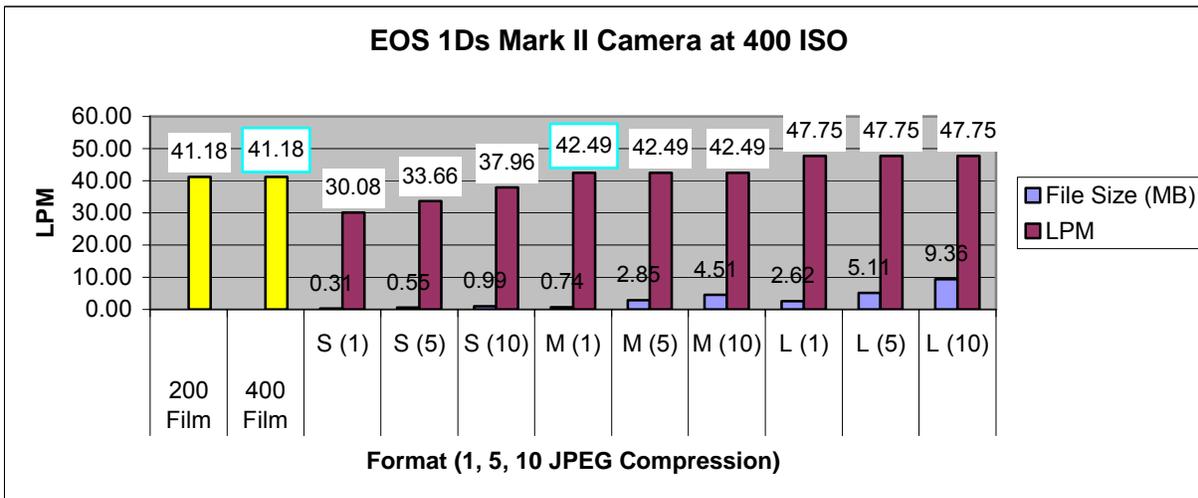


Exhibit 14

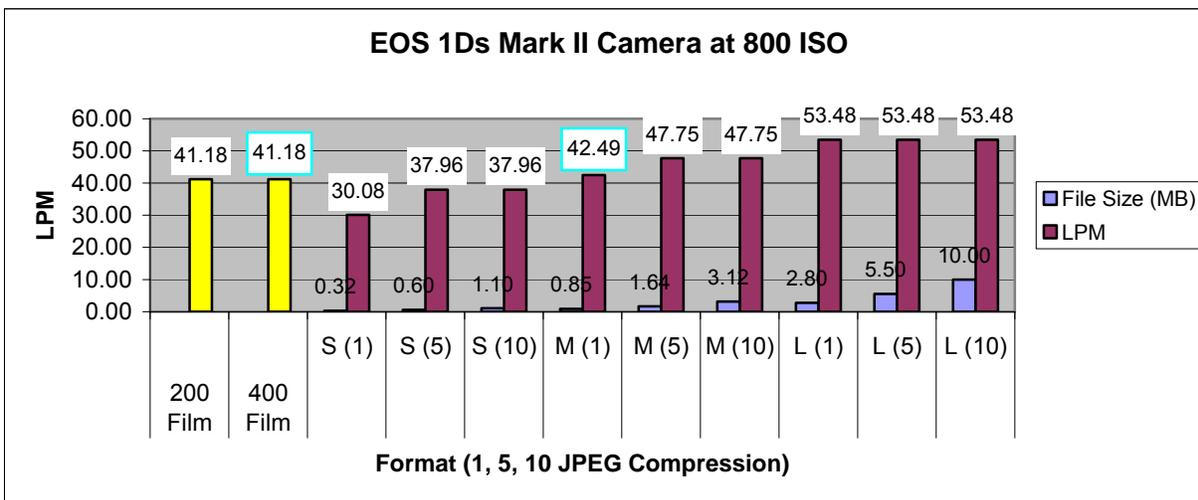


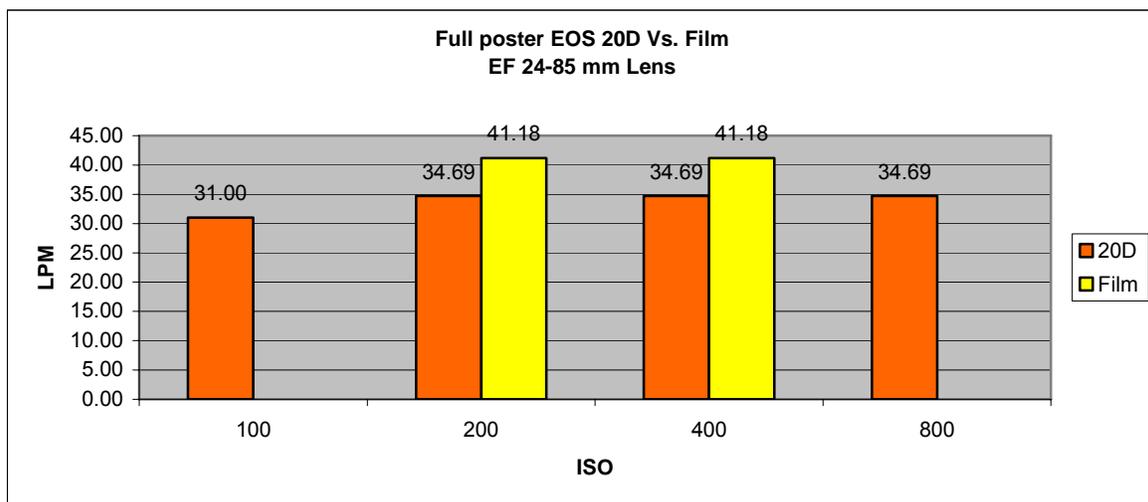
Exhibit 15

Evaluation of the PTM Technique for Impression Evidence

The graphs on the previous pages illustrate the lines per millimeter (LPM) resolved for each of the printed film and EOS 1Ds Mark II full poster images. The yellow bars are images taken with the 35 mm camera. The uncropped file size of the photographs range from approximately 0.3 MB to 10.3 MB depending on the ISO setting, image size, and compression level selected.

The two film images (200 ISO and 400 ISO) both resolved approximately 41 lines per millimeter. This was set as the minimum acceptable resolution for selecting the camera settings. The digital images captured at the ISO 800 setting appeared to be slightly sharper and the resolution slightly favored this setting. The ISO 800 setting was also selected since the PTM images would be taken in darkness with flash and this ISO setting is more sensitive to shadow information per the manufacturer. With the exception of the ISO 400 small (4.1 MP) images, the resolution of the images captured with compression levels of 5 and 10 were the same for a given ISO setting. The resolution of the images captured at a compression level of 1 was significantly lower. A compression level of 10 was selected to minimize loss of information in the photographs. All of the images taken at the medium or large image size with compressions of 5 or 10 had calculated resolutions exceeding the film images. All of the images taken with the small image setting had calculated resolutions below the film images. The medium format images taken at ISO 400 and 800 with a compression level of 1 had better resolutions than the film images. All of the large images at a compression level of 1 had better resolution than the film images. Test PTM images were captured with the camera set at ISO 800, large image, and compressions of 1, 5, and 10. The file size of these photographs range from approximately 1.1 MB to 10.3 MB. The PTM file created from these images were approximately 140 MB. The size of these files significantly slowed the speed of the PTM file creation and viewing. The size of the PTM images created from these files also prevented them from being opened on computers with less than 500 megabytes of random access memory (RAM). The large file sizes of these images made computing power a premium. Due to the problems associated with this file size, camera settings of ISO 800, medium image, and compression 10 were selected. The single image size of these photographs was approximately 5 MB. The PTM file created from these images had a file size of approximately 75 MB. PTM files were created significantly faster and could be viewed on computers with minimal amount of RAM.

Canon EOS 20D compared to film



Evaluation of the PTM Technique for Impression Evidence

The large JPEG file setting (8.2 MP) of the EOS 20D was utilized for the full poster images based on the previous results with the 1Ds Mark II camera. The this setting resolved approximately 35 lines per millimeter at ISO settings of 200, 400, and 800 when the full poster area was photographed with the EF 24-85 mm lens. The ISO 100 setting resolved approximately 31 lines per millimeter. Based on these results, the ISO 800 setting was selected for the images captured using the 11" x 17" border.

Canon EOS 20D compared to Canon EOS 1Ds Mark II

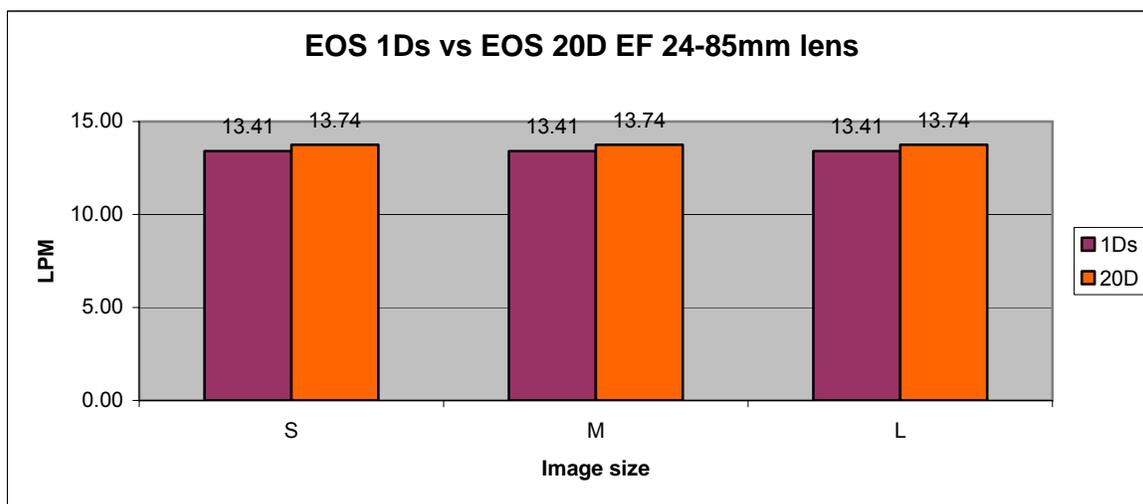


Exhibit 17

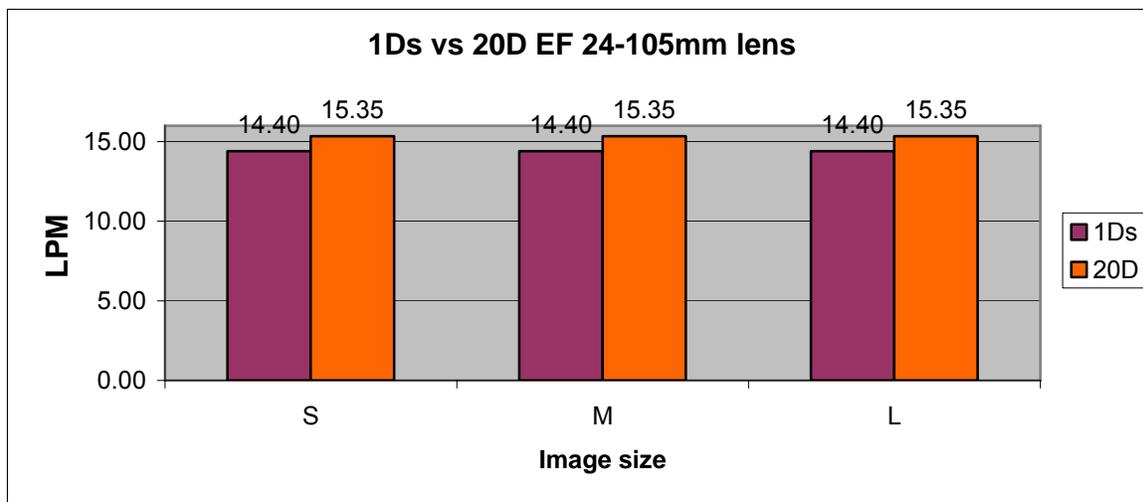


Exhibit 18

Images of the 11" x 17" border placed on the resolving power chart were captured using the small, medium, and large file size and ISO 800 settings with both the EOS 1Ds Mark II and EOS 20D cameras. Images were captured with the EF 24-85 mm lens and the EF 24-105 mm lens for both cameras. Additional images were captured with these settings using the EFS 17-85 mm lens on the EOS 20D camera.

Evaluation of the PTM Technique for Impression Evidence

The graphs on the previous page illustrate the results of the calculated resolutions for the reduced target area for the EOS 1Ds Mark II and EOS 20D cameras using the EF 24-85 mm and EF 24-105 mm lenses. Using the EF 24-85 mm lens, the EOS 20D camera slightly exceeded the resolution of the EOS 1Ds Mark II camera for all file size settings. However, the difference between the resolution numbers is minimal. Similar results were obtained with the EF 24-105 mm lens. For the 11' x 17" target area these cameras have essentially equivalent resolving powers.

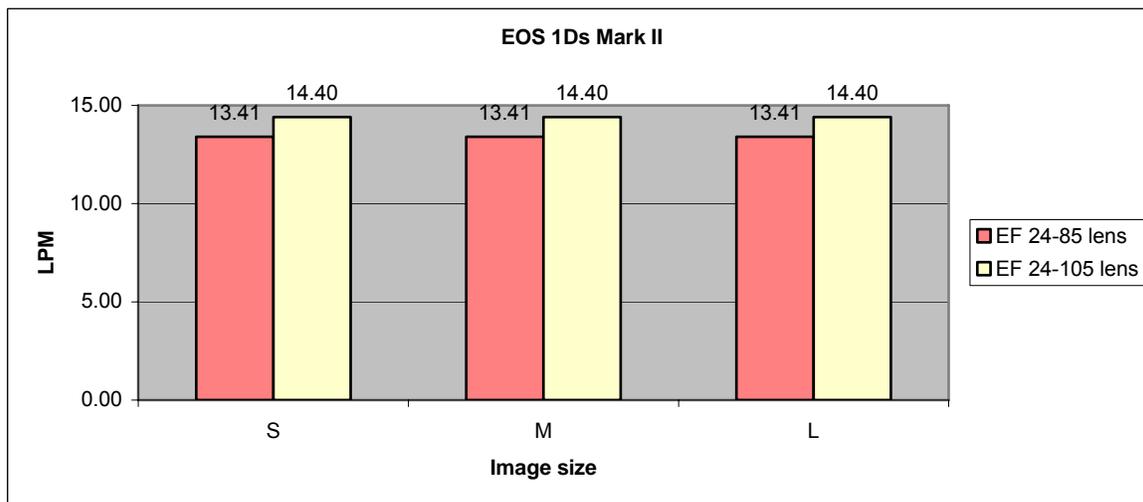


Exhibit 19

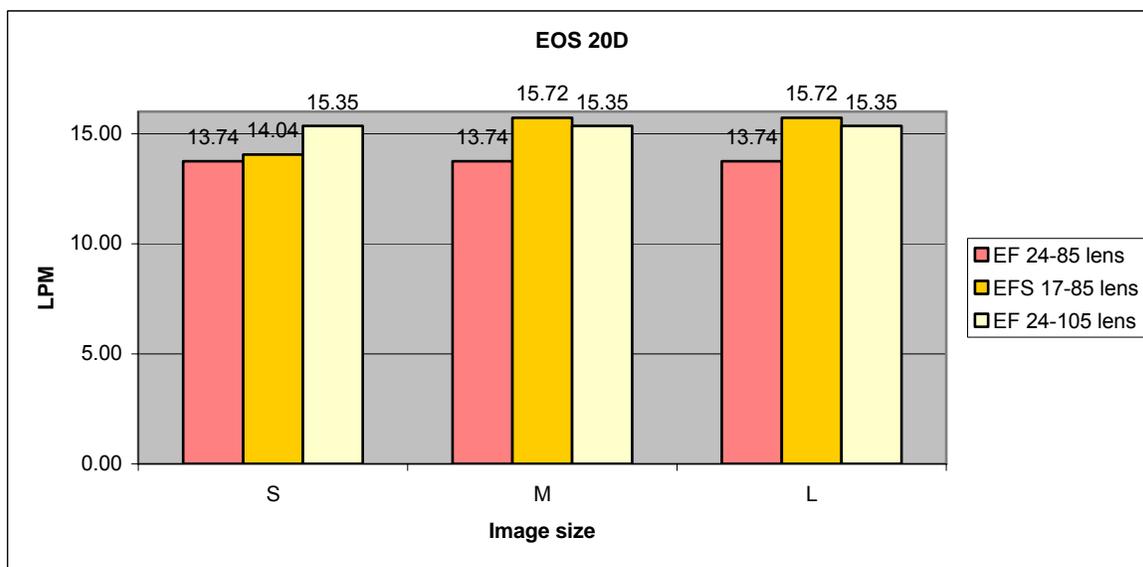


Exhibit 20

The above graphs illustrate the reduced target size images captured with the EOS 1Ds Mark II camera using the EF 24-85 mm EF 24-105 mm lenses and the EOS 20D camera using the EF 24-85 mm, EFS 17-85 mm, and EF 24-105 mm lenses. The EF 24-85 mm lens showed the least resolving power of the three lenses used for this study. The EF 24-105 mm lens showed the best resolving power of the lenses tested on the EOS 1Ds Mark II camera and for the small image file setting on the EOS 20D camera. The EFS 17-85 mm lens showed the best resolving power of the three lenses at the medium and large

Evaluation of the PTM Technique for Impression Evidence

image size settings when tested on the EOS 20D camera. However, the difference between the resolution numbers is minimal. The EF 24-105 mm and EFS 17-85 mm lenses showed essentially equivalent resolving powers on the EOS 20D camera for the medium and large image size settings.

Conclusions

The digital Canon EOS 1Ds Mark II camera meets or exceeds the resolution of 35 mm film in the medium (8.6 megapixels) and large (16.7 megapixels) formats using JPEG compression of 5 or 10.

The EOS 20D camera does not meet the resolution of 35 mm film at its highest quality JPEG image setting when photographing a 24" x 36" area. This camera meets the resolution of 35 mm film at its highest quality JPEG image setting when photographing an 11" x 17" area of the resolution chart.

The quality of the lens used on a camera will affect the final resolution of the captured images.

The PTM program uses the JPEG file format but the user can save the RAW or TIFF files from the camera prior to a conversion to JPEG if they are worried about issues with file compression. Based upon the testing above, these researchers have not observed any loss of fine detail and in some cases the JPEG images had better resolution than the 35 mm photographs.

Evaluation of the PTM Technique for Impression Evidence

Additional Evaluation - Portable LED PTM Unit

After completing the initial requirements of the NIJ grant, the authors have continued this project using the remaining NIJ funds. The goal of the additional project is to build a smaller, more portable PTM unit utilizing Light Emitting Diode (LED) technology. A portable LED PTM unit was designed after the previously discussed portable PTM unit. The goal is to build PTM field unit that is more portable (smaller and lighter).

The design uses eight (8) LED lights evenly distributed along a rotating two-foot arc. The arc was designed with eight rotational stops giving a total of 64 light positions. However, due to the smaller size of this unit, the edges of the flash arc partially blocked some of the images captured in the two most vertical rotation positions. The PTM images created with these images were of poor quality. The two most vertical arc stops were eliminated leaving six rotational stops for a total of 48 light positions. The LED PTM unit was constructed using square tubular aluminum and 1/8" aluminum sheet. Consultant Michael Cavallo was contracted to produce a controller box and the LED light string. The controller box uses eight (8) AA batteries to power the controller box and the LED lights. The controller box synchronizes the camera shutter through the remote shutter release cable port on the camera. The controller box can be used with most cameras having a remote shutter release cable port. The exposure is controlled with the camera settings and the images are written to the camera card. The portable LED PTM unit is 24" W x 30" L x 6" H with the arc in the lowest rotational position. Four adjustable feet are at the corners to reduce the unit's contact with the scene and provide basic leveling adjustment. This dome unit does not have an attached camera mount, the camera is held over the impression using a standard tripod. This unit weighs approximately 3½ pounds.

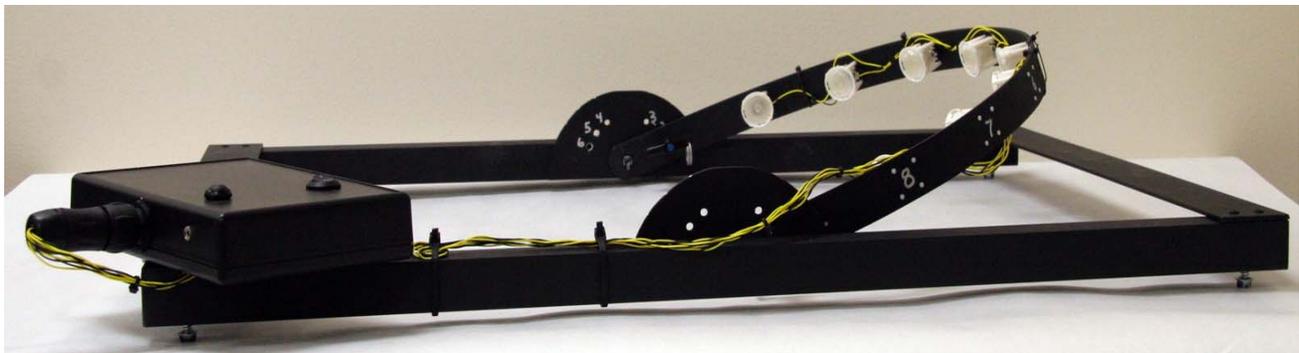


Exhibit 21

Testing of the Portable LED PTM Unit

Various LED light sources and lenses were tested to determine the optimal combination for the LED PTM unit. Static images were captured using three different white light (5500K temperature) LED stars and four different lenses. The LEDs used were a 45 lumen Luxeon with a batwing light pattern, a 45 lumen Luxeon with a lambertain light pattern, and an 80 lumen Luxeon 3 with a lambertain light pattern. The lenses used were a 15° L2 brand, 25° L2 brand, a 30° Fraen brand and a 44° Fraen brand. Images were also captured without a lens on the LEDs. The images captured with the two 45 lumen LEDs were dark and had limited shadow information, but the lambertain pattern LED provided a better distribution of light than the batwing pattern LED. The 80 Lumen LED with the Fraen lenses provided the best combination of light intensity and distribution over the surface being photographed. Therefore, the 80 lumen LED and the Fraen lenses were chosen for this PTM unit.

Evaluation of the PTM Technique for Impression Evidence

Using a test impression produced in soil, PTM files were created using the 30° and 44° Fraen brand lenses with current settings of 500 – 900mA in 100mA increments. PTM files were then created with 48 of the images taken with the 700 – 900mA settings. Additional PTM files were also created without lenses and with the 44° Fraen brand lens using the 800 and 900mA settings with several different camera settings. A total of approximately 85 PTM files were created and evaluated.

The PTM files created using the 30° and 44° lenses with 500 to 700mA current settings were unsatisfactory due to the darkness of the image and the lack of shadow information. The 800 and 900mA settings gave the best illumination of the impression. The 30° lenses concentrated the light towards the center of the image causing a loss of detail visibility at the edges of the impression. This was observed with all of the PTM images created with this lens. The 44° lenses gave a more even coverage of light over the surface of the impression and improved the visibility of detail at the edges of the impression. The PTM files created without a lens had very diffuse lighting. The diffuse lighting produced few shadows in the PTM files, which reduced the visibility of detail in the impression. This testing determined that the 80 Lumen LED with the lambertain pattern using the 44° Fraen lenses is the best combination for this PTM unit.



Exhibit 22

Evaluation of the PTM Technique for Impression Evidence

Two different cameras were used in evaluating the controller of the LED PTM unit. The Canon EOS 20D camera with the EFS 17-85 mm lens was used for the primary testing of LEDs, lenses, and current settings. A Nikon D200 with a 24–120 mm Nikkor lens was also used to test the functioning of the unit. The controller box functioned with both cameras.

Conclusions:

The PTM files created using the LED PTM unit are comparable to the portable PTM unit discussed previously in this paper. There appears to be very minimal loss of resolution when collecting 48 vs. 64 images for the PTM files.

The LED PTM unit is fully functional, considerably cheaper to build, lightweight, and smaller. This unit also allows more brands of digital SLR cameras with a remote shutter release port to be used without having to write a software program for each camera interface.

Evaluation of the PTM Technique for Impression Evidence

References

“Footwear Impression Evidence: Detection, Recovery and Examination, Second Edition,” William J. Bodziak, CRC Press 1999

“Footwear Identification,” Michael J. Cassidy, Canadian Government Publishing Centre, Ottawa 1980

“Polynomial Texture Map (.ptm) File Format,” Tom Malzbender, Hans Wolters and Dan Gelb, Hewlett-Packard Laboratories, Palo Alto, California 2001, <http://www.hpl.hp.com/techreports/2001/HPL-2001-104.pdf>

“Compression of Polynomial Texture Maps,” Giovanni Motta, Marcelo J. Weinberger, Hewlett-Packard Laboratories, Palo Alto, California 2000, <http://www.hpl.hp.com/techreports/2000/HPL-2000-143R2.pdf>

“Polynomial Texture Maps,” Thomas Malzbender, Dan Gelb, and Hans Wolters, Computer Graphics, Proceedings of ACM Siggraph 2001, http://www.hpl.hp.com/personal/Tom_Malzbender/papers/PTM.pdf

“Enhancement of Shape Perception by Surface Reflectance Transformation,” Thomas Malzbender, Dan Gelb, Hans Wolters, Bruce Zuckerman, Hewlett-Packard Laboratories, Palo Alto, California 2000, <http://www.hpl.hp.com/techreports/2000/HPL-2000-38R1.pdf>

“Maximum entropy lighting for physical objects,” Tom Malzbender, Erik Ordentlich, SPIE Visualization and Data Analysis 2006 paper 6060-10. Hewlett-Packard Laboratories, Palo Alto, California · April 21, 2005, <http://www.hpl.hp.com/techreports/2005/HPL-2005-68.pdf>

“Maximum entropy lighting for physical objects,” Tom Malzbender, Erik Ordentlich, SPIE Visualization and Data Analysis 2006 paper 6060-10. Hewlett-Packard Laboratories, Palo Alto, California · April 21, 2005, <http://www.hpl.hp.com/techreports/2005/HPL-2005-68.pdf>

“Surface enhancement using real-time photometric stereo and reflectance transformation”, Tom Malzbender, Bennett Wilburn, Dan Gelb and Bill Ambrisco, Eurographics Symposium on Rendering 2006, Nicosia, Cyprus, June 26-28, 2006, http://www.hpl.hp.com/personal/Tom_Malzbender/papers/egrw2006.pdf

Polynomial Texture Mapping: a New Tool for Examining the Surface of Paintings”, Joseph Padfield, David Saunders, Tom Malzbender, ICOM Committee for Conservation, 2005, Vol. I, pp.504-510. http://www.hpl.hp.com/personal/Tom_Malzbender/papers/icom14_079.pdf

“Imaging Fossils Using Reflectance Transformation and Interactive Manipulation of Virtual Light Sources,” Oyvind Hammer, Stefan Bengtson, Tom Malzbender and Dan Gelb: *Palaeontologica Electronica* 5 (1); http://palaeo-electronica.org/2002_1/fossils/issue1_02.htm