

# MEASUREMENT OF HUMAN SKIN COMPRESSION DYNAMICALLY USING AN AUTOMATED PHOTOGRAMMETRIC TECHNIQUE

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## KEY WORDS:

Automatic target reading, stereo matching, dot target projection, synchronized digital cameras, digital image matching, real time measurement, dynamic measurement, human skin, human tissue compression, peripheral vascular disease.

## ABSTRACT:

This paper describes the procedure used to measure human tissue compression and distortion at a dynamic rate. This is part of an ongoing research program on skin tissue and is set up to monitor capillary occlusion especially over areas of bony prominences. The monitoring of the skin surfaces allows us to measure the swelling as to the shape of the object applying the pressure. Eventually the tissue recovers, and normal capillary flow is restored, the pattern of least pressure recovers first and the most pressure recovering last. This whole response is affected by multiple factors, including illness, peripheral vascular disease, and heart disease to name a few. This research is also applied to monitor the lapse rate of human skin indentation. To meet the demand for near real time measurement of this magnitude requires special hardware configurations and software integration and solutions in hardware as to provide near real time throughput. The system utilizes multiple synchronized digital cameras with a precision pattern projector. The projection system projects a fine mesh of dots on the skin surface and auto point measurement and stereo matching are also utilized to measure the surface at near real time rates.

## 1. INTRODUCTION

### 1.1 Background:

The following describes the historical research we have undertaken over the years regarding skin imprint analysis mainly in regard to forensic applications. It also describes the expanded areas where this research is applied.

Initially, the work led to procedures used to locate and measure imprint or impact marks on skin. This forensic analysis covered imprints found on suspects and murder victims. The key to impact or imprint mark analysis is the ability to locate the mark that in most cases might not be visible to the human eye. Several detailed analyses were made including, image acquisition techniques utilizing laser or ALS (Alternate Light Source) with the digital images. In addition, we implemented a procedure using target or pattern generation and automated target reading of the imprint to generate a 3D model and x,y,z, coordinate data. Also, in this study is digital image matching and measurement of the object that made the mark. One of the major areas of this study was using pigskin in a comparison for developing a database for ante mortem and post-mortem marks. This research developed the procedures used to precisely (positional accuracy in the micron range) model the same imprints on pig and human skin and how close the actual relationship is.

The second phase of the research involved more analysis of ante, and post mortem skin imprints including lab controlled studies of imprints at the instant of death with sub micron accuracy. At this point, we discovered that the lapse rate of

skin or its dispersion rate back to normality stops at the moment of death. We also worked on the characteristics at time of death including the analysis of the frozen state of skin utilizing pigs.

We now have a system to measure human tissue compression and distortion at a dynamic rate. This is part of our ongoing research program on skin tissue and is set up to monitor capillary occlusion especially over areas of bony prominences. The monitoring of the skin surfaces allows us to measure the swelling as to the shape of the object applying the pressure. This research follows earlier testing to calculate the elasticity and coefficients of human and pig skin, in addition to the property analysis of ante-mortem and post mortem imprint marks on human and pig skin. This precise modelling of skin has opened a new area of research since the ante mortem marks can be used to determine time of death calculations from the time the imprint was made.

### 1.2 Current:

We are now looking at various responses that would affect the lapse rate of skin including drugs, illness, peripheral vascular disease, heart disease and also the characteristics of frozen skin. The testing of these various conditions gives us a comparison of skin lapse rates from normal, that is skin imprints from individuals with no medical condition or situations where the use of drugs would affect the lapse rate of skin. For the first part of the testing we looked at conditions that would relate directly to circulation. In this case we studied individuals with conditions of CREST and Raynaud's.

CREST syndrome is one form of scleroderma, a progressive disease that leads to hardening and scarring of the skin and connective tissues. The acronym CREST stands for the manifestations of this syndrome, which are: The “C” stands for calcinosis, where calcium deposits form under the skin on the fingers or other areas of the body. The “R”, stands for Raynaud’s phenomenon, spasm of blood vessels in the fingers or toes in response to cold or stress. The “E” represents esophageal dysmotility, which can cause difficulty in swallowing. The “S” is for sclerodactyly, tightening of the skin causing the fingers to bend. Finally, the letter “T” is for telangiectasia, dilated vessels on the skin of the fingers, face, or inside of the mouth

Raynaud's is a condition that causes some areas of your body — such as your fingers, toes, tip of your nose and your ears — to feel numb and cool in response to cold temperatures or stress. It's a disorder of the blood vessels that supply blood to your skin. During a Raynaud's attack, these arteries narrow, limiting blood circulation to affected areas. Spasms of the small blood vessels (capillaries) cause color changes varying from white to blue to red. Example of this would be when fingers become white due to lack of blood flow, then blue as vessels dilate to keep blood in tissues, finally red as blood flow returns. Exposure to cold or emotional stress can intensify the problem and there may be pain, tingling, numbness or a burning sensation.

## 2.0 MEASUREMENT SYSTEM

The measurement system itself comprises both software and hardware components to allow measurement either in static or dynamic modes. The system utilizes dual CCD cameras linked and synchronized by computer and software. The system is designed to allow for multi-processor, multi disk system that will support multiple camera units that are interfaced to a custom projection system. The system was designed for real-time measurement, but will also work in offline batch processing of data.

The dot projection process excels in areas of dynamic measurement especially in areas of human skin and thin skin membranes.



Figure 1. Dot pattern projector

Several combinations of synchronized digital cameras have been tested from 1 to 2 mega pixel size although larger pixel sizes are available for special applications. The cameras used can operate up to 15 and 30 frames per second, higher frame

rates are also available for specialized applications. (See Figure 2 and 3 for example camera systems)



Figure 2.



Figure 3.

## 2.1 Automated Measurement

The stereo matching principal used in ShapeCapture and ShapeMonitor software is based on epipolar geometry as shown in Figure 6.

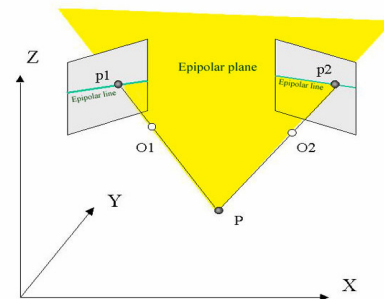


Figure 4. Epipolar Model

The object point P, the two projection centers of the two images, O1 and O2, form a plane (the epipolar plane) that intersects the two image planes. As a result, two epipolar lines are created. The matched points fall on these lines. Once the camera positions and orientations at the two image locations are known, the equations of the epipolar lines become known. We will now start by taking the coordinate p1 in the left image and look for point p2 on the epipolar line in the right image. Since there could be other points falling on the same line, we need additional constraint to make sure we select the appropriate point.

The projector can be configured with several dot pattern sizes, down to 154 micron spacing, this, along with motorized projector movement over the object can provide point cloud data equal to laser range data. The system can be configured in

several ways real time or buffered frame store then read. The buffer frame/disk store method can be configured for this system due to the 15 frame per second or higher data acquisition from the two cameras. The points on the left and right image are automatically windowed and read. The software utilizes a multi target extraction tool for measurement. Prior to automated measurement the registration of the two cameras must be made to determine camera position and orientation. One method is to use our target template providing automated calibration and camera registration with the target extraction tool. (Example of the sequence of the skin measurement can be seen in Figures 5 thru 10)



Figure 5.



Figure 6.



Figure 7.

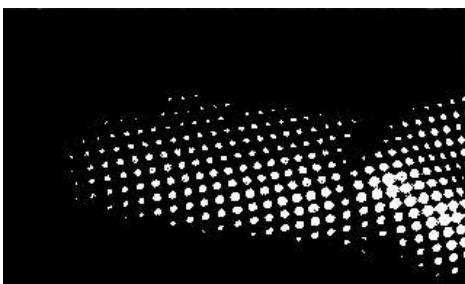


Figure 8.

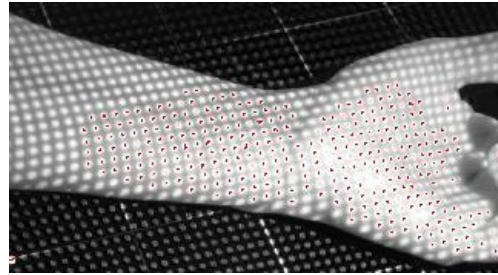


Figure 9.

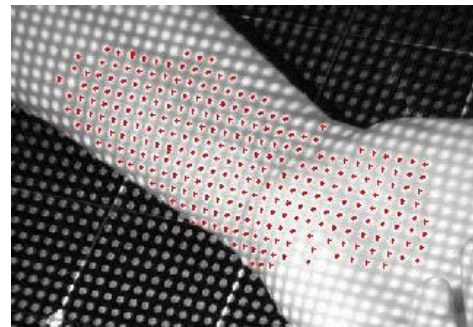


Figure 10.

### 3.0 IMPRINT ANALYSIS

#### 3.1 Pig and Human Skin Imprint Analysis

The use of pigs for forensic analysis is not new. Pigs are used in various studies and training such as forensic entomology. We can use pigskin for a comparison of human skin, there are a lot of similarities, you can accurately model the skin parameters. This comparison had to be made before any type of database could be developed for post mortem imprint or indentation marks.

To begin the comparison pigs are chosen at the same weight of a human model. For this test the pig is sedated and objects are placed under the pig for a predetermined time. For the following examples a hammer and nylon rope were used for both the pig and human model for exactly the same amount of time. Utilizing the ShapeCapture system and the hardware described we were able to measure the skin surfaces in 3D to an accuracy of between 160 to 200 microns. The following Figures 12, 13, 14 are examples of the comparison test.

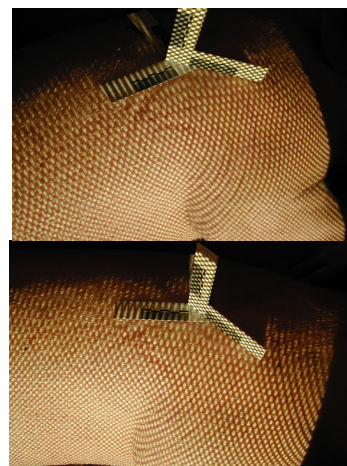


Figure 12.



Figure 13. Imprint on pig skin



Figure 14. Imprint on human skin

Using this analysis we are able to determine the coefficients of human and pig skin and precisely model the two. The characteristics of the imprint or indentations were the same in all testing. The mechanics of this can be best described by the following.

For the cycle of indentations from pressure: External pressure on the skin causes tissue compression and distortion. If the external pressure is greater than the capillary pressure keeping the capillaries open, then capillary occlusion occurs. Susceptible areas are over bony prominences.

Occlusion of capillaries leads to the secretion of endogenous chemicals that have multiple effects. One is to signal all the capillaries in the area to "open up". Another set of chemicals is secreted to attract the immune system to send cells to "clean up" any damaged tissue. Yet another set of chemicals cause the capillaries to become "leaky" to allow the cells attracted to get to the tissue affected.

Initially, the area of capillary occlusion will have no blood flow and appear white in color. If the circulation is interrupted by death, then the area of pressure will never receive any further blood flow and remain permanently white. As tissue re-expansion requires blood flow, the tissue will remain permanently indented.

If blood flow is restored, blood resumes flowing to an area that has capillaries that are "wide open" and "leaky". The net result is a red discoloration of the area, and the area begins to swell. The swelling follows a pattern similar to the shape of the pressure applied; the areas with less pressure will swell first, followed by the areas of greater pressure. This will give palpable ridges in the area in the shape of the object applying the pressure.

Eventually the tissue recovers, and normal capillary flow is restored, again following the pattern of least pressure recovering first and most pressure recovering last.

### 3.2 Ante and post mortem imprint marks

This study covered areas of ante and post mortem marks related to forensic applications. We all know that when pressure is applied to skin, an imprint mark will be made. We also know that over a period of time this mark will dissipate and the skin will return to normal. There are distinct differences between ante and post mortem imprint marks. To model these differences we had to model the characteristics at time of death. We obviously used pigs for this phase. Figure 15. illustrates the procedure. We placed objects on the skin to produce indentation or imprints on the pig. A lethal injection is made in the heart. Using our targeting and imaging as described we monitor the reaction to the imprints in addition to imprints made prior to death. The test provided very interesting results.



Figure 15. Lethal Injection to the Heart

The test provided precise method of monitoring the major differences between ante and post mortem marks. As stated earlier, when pressure is applied to skin, an imprint mark will be made. We also know that over a period of time this mark will dissipate and the skin will return to normal. It was discovered that at the instant of death the dispersion rate of the indentation stops. It is also noted that the amount of pressure and length of time the object that causes the indentation does not affect the overall depth of the imprint in most cases. This opens a new area for forensic study. By modelling the elasticity of skin we can calculate the dispersion or lapse rate of the skin returning to normal. This can provide the ability to determine the time of death after the wound or imprint is made on the skin. This observation and characteristics were duplicated in subsequent testing. The following Figures 16. and 17. illustrate the indentations on the skin.

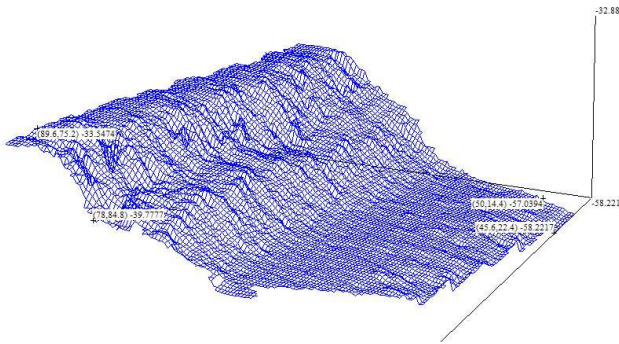


Figure 16.

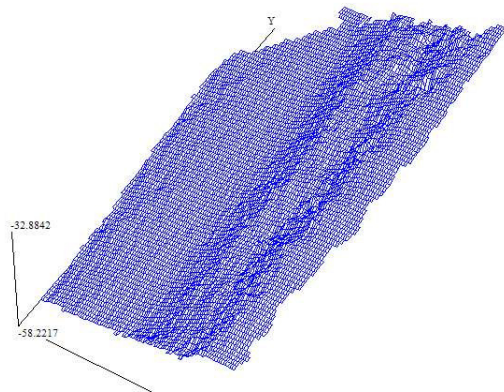


Figure 17.

#### 4.0 DISCUSSION OF RESULTS:

There appears to be limited amount of data regarding imprint marks and an imagery database of ante mortem and post mortem skin imprints. We have used past and present homicide case files to draw from including, our detailed skin imprint analysis of ante and post mortem imprints. Our further study of conditions that effect the circulation and directly affect the dispersion lapse rate has provided promising results. Of course, this whole response is affected by multiple factors, including illness, peripheral vascular disease, and heart disease to name a few.

During one phase of the study we detected a slower lapse rate of the skin. We found that the subject was displaying slight edema due to the medication. It is known as "pitting edema" which occurs when fluid collects in the tissue. By pressing a thumb or finger firmly against the tissue for a few seconds, a dent can be produced. When the finger is withdrawn, the dent may persist for several minutes. Pitting edema also refers to the failure of the skin and soft tissue to immediately resume its normal contour upon release of pressure. This procedure would be used in areas with visible swelling, since the Photogrammetric procedure is determining the skin surface and lapse rate at the micron level, it would have to be quite pronounced to be seen during visible examination.

Presently, many decision's regarding imprint marks are very subjective and most pathologist do not have a good imagery database regarding imprint marks. In fact, some believe there

are no differences between ante and post mortem marks, there are in fact major difference between the two. Imprint marks are always made with a major impact to the skin, even for ante mortem marks that dissipate and are not visible to the human eye can be viewed and measured by imaging and image processing.

Ante mortem imprint marks, dispersion or lapse rate stops at the time of death and post mortem and ante imprint marks remain on the body after death, even after subsequent processes completed on the body including embalming.

#### ACKNOWLEDGMENTS

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