3D Anthropometric Scanning based on Pattern Projection

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Abstract *– In the current global fashion marketplace taking body measurements using scanner technologies is increasingly gaining popularity. This is mainly due to the majority of transactions are now being done online and almost 50% of such purchases are returned annually due to mismatches in size. The time and effort requirement for taking manual measurements is also a contributing factor.*

Several studies have been carried out in this regard, particularly in the Bio Medical field where anthropometry is an integral part in diagnostics. Several companies are also providing 3D scanning solutions for the fashion industry with various attributes. However the majority of such scanners are based on Laser Triangulation System which is not the most economical in a competitive environment. This study focuses on the feasibility of incorporating a scanner based on pattern projection for the same purpose.

The main aspects this study will be covering are achieving a low scanning time and a significant reduction in cost against the conventional method. The Laser Triangulation Scanners that are currently in the market take up to 33 seconds in scanning time while ranging between $25 000 - $85 000 in cost. This study will discuss the possibilities of achieving a scanning time under 5 seconds and designing the physical scanner under $10 000.

In the Pattern Technique, a series of stripes/patterns were projected simultaneously on to the object. This contrasts with the Laser technique where scanning is done on a single line of point where independent range profiles are processed. Patterns ranging from simple stripes of white light to complex Moiré patterns were tested out on a Mannequin with a standard erect pose. A camera was used to view the projected pattern from an angle complimenting the projection angle which generated straight equally spaced fringes incident on the surface, producing equally spaced contour intervals.

The study indicated that using Moiré pattern projection wasn't the optimal solution in body scanning, given the constrains. The complex mathematics involved in demodulating the viewed pattern to create fringes required extensive processing. Binary coded pattern was generating the best results as it required a simple low cost projector and simple processing. However the use of incoherent light resulted in a compromise of the depth of view and the resolution of the image compared with its laser technique counterparts, a drawback which can be mitigated during programming.

Keywords: **Anthropometry, Triangulation, Pattern Projection, Structured Light**

Introduction

Today, with the advancements of technology, fashion industry has taken many forward leaps where it is no longer necessary to step in to a tailors shop or a clothing store to browse for clothes. The trends are changing day by day and there are a myriad of options to choose from. Online stores such as eBay, Amazon, Shopify and Tobi are increasingly gaining popularity while many others are popping up in the Internet. Garment manufacturers and Retailers are connected with a global marketplace with an ever increasing demand for their products. But one of the major challenges encountered in this global fashion market place is the lack of a standard procedure to get the dimensions correct. It is estimated that almost 50% of all the online clothing purchases are returned back to the sellers due to mismatches in size.

Anthropometrics, simply known as taking body dimensions has taken a novel approach in order to meet the demands of the expanding fashion industry. Body Scanning has been cited as the go to solution in this regard. While body scanning has been prevalent in the Medical Field for several years, it is a relatively novel subject in the context of fashion. The industry demands for a highly efficient, low cost device with a relatively simple setup.

However most of the current solutions in the market have fallen short of addressing the key requirements of the industry although they might be incorporating very sophisticated technologies. Almost all the existing solutions fall under the price range of $25 000 - $85 000 which seems obsolete in the perspective of Small and Medium scale fashion designers and retailers. Moreover the space requirement of around 50-100 sqft and the long scanning time haven't been addressed by most of the developers.

Due to the above mentioned predicaments the fashion industry is yet to embrace body scanning with both hands. It is still confined to a few high end apparel designers and manufacturers many of whom went back to the conventional method of manual body measurement citing the complex operation of scanners as extra effort.

It is a fact that the global fashion industry's major players are small and medium scale designers who operate under limited budget and restricted spaces. Therefore body scanning technology is still out of league for the majority involved in the fashion business.

Emerging markets especially in countries such as Sri Lanka, Bangladesh, Kenya and Vietnam could see long term growth in their operations and increase

their competitiveness in the global market if this technology was within assess for them.

Hence this study is an attempt to discuss the viability of pattern projection techniques in scanners used for body measurement.

Methodology/Experimental Design

The approach for the development of the prototype was based on several key steps;

1) Determining the Fringe Projection Technique
2) Development of a Mathematical model for Phase Evaluation of the Projection
3) Simulation on basic 3D shapes
4) Simulation on a Mannequin
5) Calibration and code modifications

Preceding the Prototyping phase, developing a working model for live samples is currently under way. There the complexities that arise due to clothing, minor body movements and other variables have to be accounted for during coding and calibration, which will not be discussed in this paper.

a) Determining the Fringe Projection Technique

The principle used in developing the scanner is measuring the three dimensional shape of an object using projected patterns of light on the surface of the object. Projecting narrow stripes (binary coded) of lines on to a three dimensionally shaped surface produces a distorted array of form when it is viewed from different perspectives than that of the projector. This form can be used to generate an exact replication of the surface's geometric shape.

With two main methods of stripe pattern generation available; laser inference and projection, the latter was selected for the purpose of this study considering the cost and complexity of implementing the laser inference method.

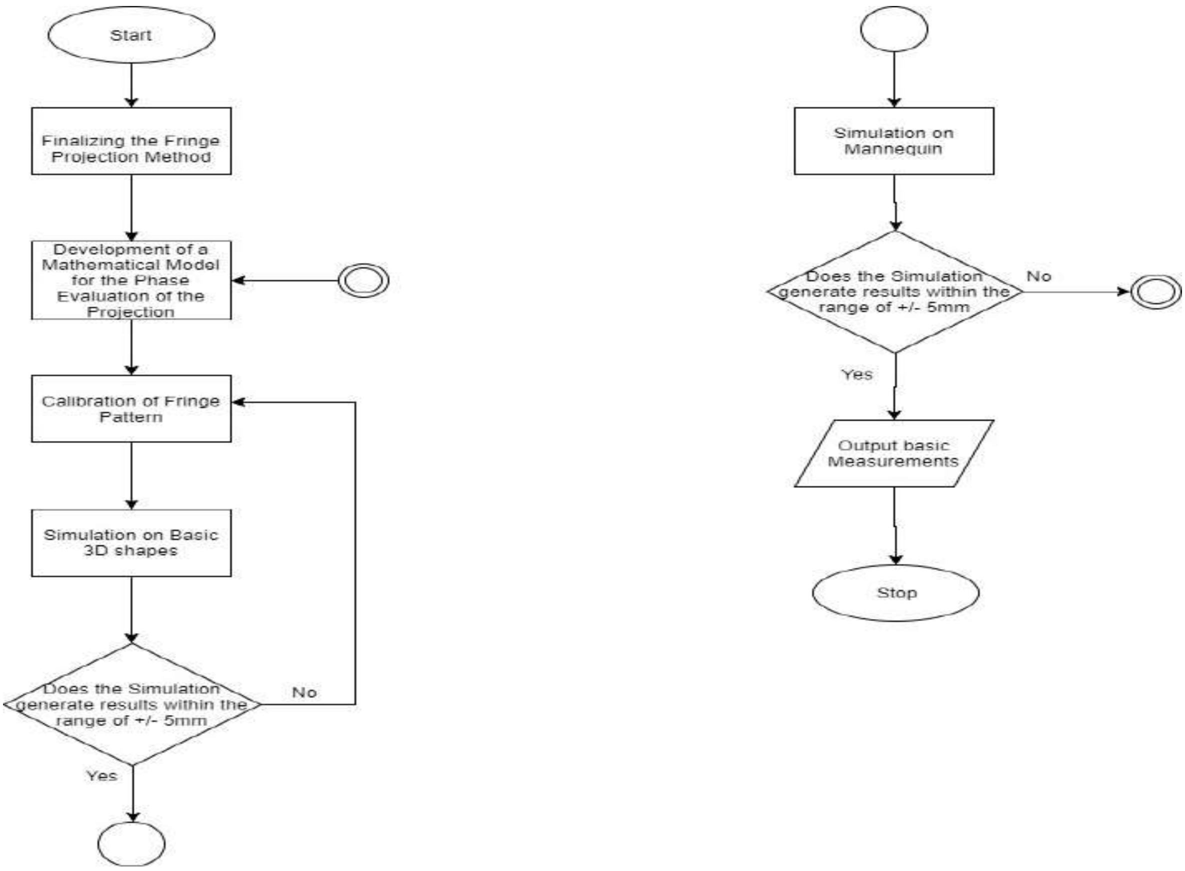

Figure 1: Prototyping Process Flowchart

Projection of incoherent light involved selecting a spatial light modulator for the projector, which were available in several different technologies. The following table discusses the characteristics and applicability of three such methods namely; Transmissive Liquid Crystal, Reflective Liquid Crystal on Silicon (LCOS) and Digital Light Processing (DLP).

Table 1: Spatial Light Modulator Technologies

Feature	Liquid Crystal	Liquid Crystal on Silicon	Digital Light Projection
Contrast Ratio	Good	Best	Worst
Light Output (Brightness)	Good	Worst	Best
Color Accuracy	Good	Good	Good
Motion Blur	Worst	Worst	Best

Out of these technologies which suited mostly with the study requirement was Digital Light Projection (DLP), since the main objective was to achieve a higher brightness for the light pattern rather than a higher contrast. Moreover the pixel boundaries that appear due to the lower contrast can be negated due to the superior motion blur of DLPs.

The DLP used in this study was a low cost general purpose projector obtained from a local camera equipment shop. It was then disassembled and the in built spatial light modulator was replaced with a custom build one. This module was used to project the fringe pattern on to the Mannequin. See Figure 1.

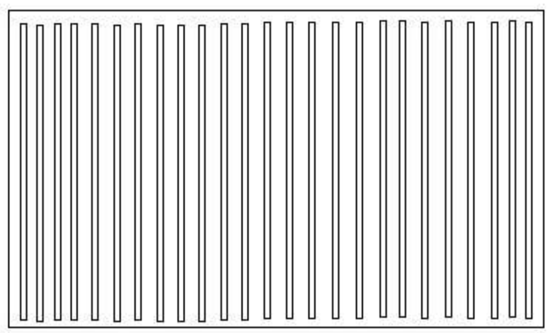

Figure 2: Spatial Light Modulator with Fringe Pattern

b) Camera and Projector Calibration

Although the camera used in the initial phases of the research was a DSLR, it proved to be ill suited for this application due to a variety of different reasons. The main reason being the overheating issues of the sensor when remaining in operation for substantial periods of time. Moreover the imagery generated by the camera used was not a supported format by the MATLAB Image Acquisition Toolbox. Since MATLAB was used as the main tool in demodulating the images, it proved to be convenient to use a compatible device. According to MathWorks, following are the supported devices by the Image Acquisition Toolbox;

- Scientific video cameras
- USB and FireWire (IEEE-1394, i.LINK) Web cameras
- Video capture boards
- DV camcorders

It has also provided a list of Manufacturers as a guideline and it was incorporated in the process of narrowing down the options under criteria such as Image Quality, Cost and Interface. For the purpose of this study Point Grey Grasshopper GS3-U3-14S5M-C was used, which provided a rate of 30 fps.

As a standard practice, camera calibration required recording a sequence of Images of a calibration object, essentially a simple 3D shape, comprised of a unique set of distinguishable features with known 3D displacements. Thus, each image of the calibration object provides a set of 2D to 3D correspondences, mapping image coordinates to field points.
Projector calibration is also a paramount factor when perusing to achieve a high quality scan. It is supplemented by the fact that implementing lower cost digital projectors could essentially compromise the quality. The projector is ideally the "inverse" of a camera, wherein points on an image plane are mapped to outgoing light rays passing through the centre of projection.

c) Developing a Mathematical Model for the Phase Evaluation of the Projection

The observed stripe patterns on the surface contain several depth cues. The displacement of an individual stripe can be converted to three dimensional coordinates. For the identification of individual stripes, a stripe counting technique was incorporated. These fringe patterns were then used to reconstruct the 3d shape of the mannequin.

The algorithms used to decode the structured light sequences are relatively straightforward with a reasonable level of literature availability. For the camera, it required to be inferred whether a given pixel is directly illuminated by the projector in each displayed image. If it is illuminated in any given frame, then the corresponding code bit was set as high, otherwise it was set to be low. The decimal integer index of the corresponding projector

column was then recovered by decoding the received bit sequences for each camera pixel. A manually selected intensity threshold was incorporated to determine whether a given pixel is illuminated.
The following Pseudocode proposed by Douglas Lanman and Gabriel Taubin was used as the basis for developing the demodulating program used in this research.

```
BIN2GRAY(B)
n   length[B]
G[1]   B[1]
for i   2 to n
do G[i]   B[i   1] xor B[i]
return G
GRAY2BIN(G)
n   length[G]
B[1]   G[1]
for i   2 to n
do B[i]   B[i   1] xor G[i]
return
```

Results and Discussion

The demodulated 3d structure was harbouring an error of 1.4cm after calibration. This condition was due to a resolution drop in the fringe projection which was later overcome by applying new spatial light modulators with reduced stripe width and conditioning the backlight. But further decreasing the width of the stripes gave inconsistent results, which was partly due to the limited depth of field of the camera that was used and the poor optical quality of the stripes.

Given the inconsistencies, the generated three dimensional structure was an improvement over the image generated by a standard Kinect sensor. The resolution was higher and the form was smoother. However, it wasn't adequate for the expected level of accuracy for the measurements. Apart from opting for a better camera with a higher depth of field, it was decided to use phase shifted projections.

Alternating stripes were projected on to the surface while 3 to 8 exposures were taken each with a slightly shifted phase. This approach proved to be more effective in resolving the surface errors of the image. It also allowed the image resolution to increase approximately up to 1/10 the of the stripe width which was initially set to 3mm.

The outcome could be further enhanced if Grey-Code binary images were used in the process. Binary grey code sequences identify the number of each individual stripe hitting the object. This is the same principle used in some position encoders and can be readily implemented for optical encoding.

Several other measures that could be embodied to obtain further enhanced results are using stripe frequency and phase in a Fourier Transform and using Wavelet Transform techniques. A combination of these methods could achieve an escalation in the resolution up to 1/50 the stripe width. However, the defocus of the projected pattern cannot be addressed by any of these measures. It is a phenomenon that arises due to the requirement to use a large projector lens in order to cover the entire body surface of an average person.

Improvements done in the Image sensing segment (i.e.: camera) is an integral part in enhancing the quality of the 3d image. Here in the study, the camera used was a standard DSLR camera positioned 45˚ to the line of projection. But in ideal conditions at least two cameras positioned at complimenting angles should be used. This method also known as stereoscopic vision requires more complex programming which was one reason for excluding it in this particular study. However combining it with "structure from motion" techniques, the visual accuracy of the image can be vastly improved.

The size of the CMOS sensor is also a contributing factor for the quality of the 3d image. The camera used in the study comprised a sensor with APS size range (14mm by 21mm to 16mm by 24mm). Using a camera with a full frame sensor (i.e.; allowing for the use of the lens without the complication of focal length magnification factors) can generate the highest quality images.

Conclusion

Pattern Projection in 3d Anthropometry is not a widely discussed concept when it comes to body scanning technologies. This is partly due to the widespread use of Laser Triangulation systems and the rise of IR scanners such as the Microsoft Kinect and ASUS Xiton. However the currently available scanning solutions used for the purpose of taking body measurements haven't been successful in reaching the wide spectrum of the fashion industry. The exorbitant cost of the setup, restricted manuverability and the unimpressive scanning times can be identified as the cause.

The structured light pattern projection method presented in this study has addressed some of those pressing issues with impressive results. Especially the cost can be reduced by more than tenfold of the existing solutions. Moreover the minimal setup is easy to manuver and requires less floor space. However there are several issues to be addressed before the system being commercialized. The constrains in achieving superior resolutions compared to its Laser triangulation counterparts is a major drawback of this system. Moreover, the pattern blur is an inherent undesirable to this system which had to be tolerated at this level.

Taking the overall understanding in to perspective, it can be established that Pattern Projection techniques in 3d Anthropometry is an apt solution for the fashion industry. Most drawbacks encountered in this study can be mitigated with superior processing and device upgrades still maintaining the cost threshold.

Therefore it is strongly recommended that new light be shed on the subject in order to come up with a system that will replace manual body measuring with 3d anthropometry.