



11th **3DBODY.TECH** Conference & Expo
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Book of Abstracts

3DBODY.TECH 2020

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Introduction #00

Nicola D'APUZZO

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3DBODY.TECH 2020 - The 11th International Conference and Exhibition on 3D Body Scanning and Processing Technologies was held on November 17th to 18th 2020, online/virtually.

This event was organized by Hometrica Consulting - Dr. Nicola D'Apuzzo, Switzerland.

3DBODY.TECH Conference & Expo, the premier multidisciplinary international conference and exhibition on 3D human body scanning and processing technologies, provides a platform of eminent professionals, entrepreneurs, academicians and researchers across the globe to present, learn and discuss the latest in 3D human body scanning and processing technologies.

The multidisciplinary character of 3DBODY.TECH makes it unique and not comparable to any other meeting related to 3D body technologies.

3DBODY.TECH Conference & Expo website 3dbody.tech give all information related to this event.

These proceedings gather the papers presented during the conference by renowned experts in the field of 3D body scanning and processing. The technical papers are organized in theme sessions.

Note: not all the presentations at the conference have a correspondent abstract and/or paper.

Technical Session 1: 3D Body Scanning Systems I

Mobile Scanning of Body Parts with Calibry Mini Scanner #59

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no paper/abstract

When Standard is No Longer Enough: Developing Versatile Body Scanners and Scanning Strategies #49

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no paper/abstract

Evaluation of 3D Registration Deep Learning Methods Using Iterative Transformation Estimations #31

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3D registration is a process of aligning multiple three-dimensional (3D) data structures (such as point clouds or meshes) and merging them into one consistent and seamless 3D data structure. With the scope of 3D reconstruction, 3D human body scans from multiple views need to be registered into a single point cloud to create a seamless 3D representation.

Following current state-of-the-art deep learning approaches, we argue that an encoder-decoder approach, where the decoder part of the architecture uses a recursive layer that iteratively estimates the rigid transformation, should provide the best results. We adapt an approach created for the task of 3D segmentation called RSNet to the task of 3D registration and compare it to the current state-of-the-art algorithm PCRNet.

Practical Procedures for Breast Profiling Using Shape-from-Shading #42

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The measurement of female breast shapes appears to be a useful procedure for a number of medical purposes. Achieving this measurement by the numerical analysis of a single digital photograph of the breast, by utilising the principle known as shape-from-shading (SfS), is appealing because of its advantage of simplicity: the technique requires the analysis of only one image. However, the

advantage of simplicity can be lost if practical implementation becomes complicated. This paper examines the practical steps required to implement the SfS measurement, in order to reflect on its feasibility.

The SfS method seeks to deduce surface gradients across an object - the breast in this case - by using the reflectance levels which are apparent in the image of the breast. From the gradients, shape can be deduced. But, because it is theoretically impossible to deduce the two parameters of surface slope from the single reflectance level at individual pixels, the method followed here is restricted to obtaining profiles which pass through the breast centre, when the theory is then simple.

Practical implementation involves a number of complications: the imagery must be taken with a flash in dark conditions, in order to provide a known illumination model; the centre of the breast should be at the centre of the image; the focal length of the camera is needed for use in the mathematical model; a means of scaling the resultant breast shape is required if a single image is used; the analysis needs to be undertaken on a monochrome image, which needs in turn to be transformed into a text file for numerical analysis; the method requires that the object has smooth physical texture and light even colouring, as the breast generally does, but the irregularly textured areola region needs to be excluded from the shape analysis; the analysis also requires finding the breast's limits, defined as occurring when the breast rises from the background chest shape. If all these practical requirements tasks can be satisfied, the subsequent analysis is easy, involving little more than simply fitting a simple cubic or quadratic function to the reflectance levels across the breast cross-section.

Each of these practical steps is assessed in this paper, which reports on the feasibility and costs of procedures followed by the writer so far in attempts to achieve the measurement goals. It is shown that none of the problems is impossible to solve.

Technical Session 2: 3D Body Scanning Systems II

Computers Have Much to Learn About Humans!

.....How 4D Scanning Can Accelerate This. #01

Chris LANE

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no paper/abstract

ZOZOSUIT & ZOZOMAT: Solutions for Online Shopping in Japan #47

Bo LI

ZOZO New Zealand Ltd., Auckland, New Zealand

ZOZOSUIT & ZOZOMAT are well-known products for online shopping in Japan. This talk will introduce the team who developed ZOZOSUIT & ZOZOMAT, followed by further discussion around ZOZOSUIT & ZOZOMAT technologies and how their services are built in Japan.

FITTIN - Online 3D Shoe Try-on #58

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Description for an easy and user-friendly computerized method for the online try-on of shoes that dynamically references a three-dimensional topological model of a foot with a three-dimensional topological model of the inner surface of footwear. A comfort level is then calculated based on the matching results. With the help of these calculations, a consumer can make a conclusion about the suitability of the footwear and make a purchase decision. The topological 3D model of a foot is reconstructed by analyzing a series of foot images taken with a mobile device (smartphone or digital camera). In addition to geometric information (such as shape and size), the topological model of the footwear's inner surface also contains information about pressure forces and tensile stiffness at different points. The present article gives a critical analysis of existing virtual shoe fitting methods.

Technical Session 3: 3D Body Scanning for Medicine

Personalized 3D Breast Cancer Models with Automatic Image Segmentation and Registration #15

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Breast conservative surgery (BCS) combined with radiotherapy has become the treatment of choice for the majority of women suffering from breast cancer. Every year approximately 2.1 million new cases arise worldwide, but fortunately the 10-year survival rate now exceeds 80% mostly due to the early detection of non-palpable breast cancer. The accurate localization of the tumor is of utmost importance to decrease the re-excision rate and necessity of a second surgery, and also pivotal to the minimization of unaesthetic outcomes caused by these interventions. Nevertheless, 7 out of 10 patients will need invasive pre-operative localization and women will live long lives with the dire consequences of cancer treatments. Currently, it is up to the physicians to correlate multimodal 2-dimensional (2D) sectional images to the 3D space for surgical planning. The challenge is now focused on the technology to create an alternative non-invasive tumor location procedure that can be ethical and fit to the clinical set. This paper describes an automatic image segmentation and registration algorithm that fuses 3D optical scans of the breast surface, with interior radiological data for tumor characterization, to build a personalized digital breast model that can potentially be used as a non-invasive digital pre-operative localization technique, improving tumor visualization and surgery planning.

Post-Covid-19 Beauty Industry #43

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The coronavirus pandemic has affected many industries, including the beauty industry. Beauty services and treatments and cosmetic procedures, which are considered elective and unnecessary, have been eliminated. Many believe that even if coronavirus diminishes, this pandemic might leave a lasting mark on how cosmetic care will be provided in the future. It is predicted that the beauty-related businesses will move into providing remote and online services pursuant to the use of novel technologies such as 3D scan and extended reality. We present an overview of the beauty industry possible changes after the coronavirus pandemic using the mentioned technologies and also introduce novel 3D-printed guides for cosmetic procedures.

Investigation of Smallest Volume Difference Measurable Using 3D Imaging #26

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With the advent of three-dimensional (3D) surface imaging technology, objective measurements of breast aesthetics, such as contour, surface area, shape, size, and volume are now possible, and studies have demonstrated its utility and efficacy in clinical medicine. Moreover, several relatively low-cost portable hand-held 3D scanners are now commercially available, which has increased the likelihood of the technology finding widespread clinical adoption. An understanding of the capabilities and limitations of 3D imaging technology and corresponding measurements is essential for its successful application in pre-operative planning as well as post-operative assessments. Breast volume is a key outcome measure in aesthetic and reconstructive surgery; thus, it is critical to not only have validated algorithms for accurate measurements, but to also understand the ability of the technology to resolve and detect volume changes. Inconsistencies in volume measurement and lack of appropriate

standardization protocols can influence applications that utilize quantitative measurements. For example, changes in breast volume need to be quantified to maintain breast symmetry and any inconsistencies may impact the surgeon's ability to formalize pre-operative plans. In this study, we assessed the resolution of 3D imaging in terms of assessing breast volume change and compared volume measurements made using a non-portable 3D imaging system (3dMDTorso) and a hand-held 3D scanner (Go!SCAN 3D). Using adjustable implants with varying volumes, with the non-portable system and customized volume computation software, we could reliably detect changes in volume as low as 5.5+-2.6cc. In addition, volume measurements made using the non-portable system and the hand-held scanner were highly correlated ($R^2=0.99$), demonstrating feasibility of using the portable hand-held scanner for breast volume measurements.

Application of Multiple Views and Stereo-3D Imaging Technology to Burn Care #16

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Objectives: This study is concerned with the geometrical part of the vision, or more specifically with the 3D aspects. The ability of humans to perceive the 3D world from the two-dimensional (2D) projections on the retinae is fascinating. How some of the basic sub-problems of geometric vision can be solved, but the overall aim was to reconstruct a scene from several images. So how do we combine the basic solvers to handle multiple images?

Methods: We studied the multiple views and stereo-3D imaging technology to burn injury of stereo 3D vision and 3D studied visual issues related to it, including visual discomfort, binocular disparities, veingance-accommodation mismatch, and visual fatigue. We also studied the burn care of medical applications of stereo-3D imaging techniques, and application trends as pertain to imaging medical devices. A new camera having many correspondences among the estimated 3D points is added to the model by computing its camera pose. To stabilize the estimation bundle adjustment is normally performed several times, sometimes for every new camera that is added. The Face & Future SID device is a mobile 3D wound measurement device attached to an App It has a friendly user interface and a LED assisted multiple views 3D camera that can assess both wound area and volume. In this study, we compare three modalities in wound area measurements: The Face & Future SID device, the device, and standard hand measurements.

Results: The multiple views 3D face imaging technology, we are providing the convenience and widespread use for 3 main groups in the catastrophe inclusive of patients, emergency medical technicians (EMTs), and ambulance technicians and doctors. For patients who could be civilians or our soldiers who participate in the rescue mission, the 3D face imaging device could lead to developing new dressing for the wound on the face. The new dressing could fully cover the wound and prevent the production of dead space in order to fix the structure of the wound and provide good hygiene. For the EMTs, in the scene of the catastrophe, the 3D face imaging device provides them a good way to take care of the wound and may transfer the information to the doctors in the hospital. For example, the depth of the wound is useful information for a plastic surgery doctor to guide the EMTs to perform different types of wound dressing.

Conclusions: The application of multiple views 3D stereo-imaging technology to the medical and burn care field will help improve surgically and burn care accuracy, reduce operation times, and enhance patient safety. Therefore, this device has been applied to a variety of fields such as burn care and the plastic surgical or cosmetic medical fields. Particularly, in the medical and burn care field, various medical imaging devices have adopted the stereo-imaging technique, such as the stereo 3D camera and multiple views 3D camera, and have been developed and utilized clinically to improve surgical and burn care accuracy and patient safety.

Technical Session 4: 3D Body Scanning for Apparel I

Development of an Automated Product Development Process for Tailored Bras Using Breast-Specific Measurements from 3D Body Scans in Conjunction with an Interactive Pattern Construction #55

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The process for the production of customized bras is really challenging. Although the need is very clear, the lingerie industry is currently facing a lack of data, knowledge and expertise for the realization of an automated process chain. Different studies and surveys have shown, that the majority of women wear the incorrect bra size. In addition to aesthetic problems, health risks such as headaches, back problems or digestive problems of the wearers can result from this. An important prerequisite for improvements is the basic knowledge about the female breast, both in terms of body measurements and different breast shapes. The current size systematic for bras only defines a bra size by the relation between bust girth and underbust girth and standardized cup forms do not justice to the high variability of the human body. As the bra type shapes the female breast, basic knowledge about the relation of measurements and shapes from the clothed and the unclothed breast is missing.

In the present project, studies are conducted to explore the female breast and to derive new breast-specific body measurements, different breast shapes and deformation knowledge using existing bras.

Furthermore, an innovative process is being developed that leads from 3D scanning to individual and interactive pattern construction, which allows an automatic pattern creation based on individual body measurements and the influence of different material parameters.

In the course of the presentation, the current project status will be shown and the future developments and project steps will be introduced.

Virtual Fit vs. Physical Fit - How Well Does 3D Simulation Represent the Physical Reality #21

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The popularization of new technologies, such as 3D Simulation programs is an important factor to help speed up the development chain and save resources within the clothing industry. Proper fit to help size conformity, company loyalty and to decrease return rates is becoming an increasing requirement. This study aimed to investigate the effectiveness of 3D virtual fitting technologies of garments and analyzing the similarities as well as differences between real and virtual fit.

Within this study different garments on the upper and lower body were analyzed and compared, by evaluating the whole development chain. The first step was to scan different test subjects with individual body shapes and figure types in the Vitus Smart XXL 3D Scanner and to generate according avatars for each size analyzed (a small, middle and large size). Then patterns were created for each garment and simulated virtually on the according avatar within three different 3D Simulation programs: CLO 3D, Vidya Assyst, and V-Stitcher Browzwear. These same garments were also sewn physically and fitted on the same test subjects to evaluate the similarities and differences between the virtual fit and physical fit.

The analysis showed that for both the virtual fit testing and physical fit testing in-depth fit knowledge was essential to evaluate the results properly. Sufficient ease and proper fit was given virtually in the example of this male jacket German size 50, which was simulated in CLO 3D. However, the ease was not sufficient enough when creating the physical garment and could not be closed, or small movements such as lifting arms could not be made, resulting in a too tight real jacket. Folds and tension will show on the physical garment, but not within the 3D software. An important insight was to simulate with base layers, as it would be worn in real life, since without base layers the fit was not shown accurately within the 3D system.

The investigations revealed that there are various factors that affect the success of virtual fit testing, This is an important research effort for the clothing industry, as it demonstrates which parameters need to be taken into consideration for a realistic and accurate virtual fit testing with the help of 3D technologies.

Scan to Knit - From Body Scan Directly to the Knitting Machine #30

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In this work, we describe an integrated solution to manufacture individualized made-to-measure (MtM) garments based on 3D body scanning by means of automatic data transmission from scanner to the flat knitting machine. The underlying process automatization reduces the complexity of the production of individualized lot-size-one garments.

The process consists of two main steps: from scan to garment order files and from garment order files to Jacquard patterns and subsequent knitting process.

Initially, a person is scanned with a 3D body scanner and body measures are extracted by the scanning software. After uploading the obtained body measures, the best fitting size is automatically suggested from size charts and corresponding fit rules for the selected garment type. The MtM Plugin of the scanning software is responsible for evaluating individual alteration rules of selected measures for the best fit. The resulting order file thus contains references to the garment piece file in the size chart database, the basic size and the alteration values. The second step comprises the algorithmic interpretation of 2D garment pieces and subsequent generation of Jacquard patterns. In addition to the piece file, information such as the material parameters is provided to the algorithm. The procedure starts with sampling of the garment piece according to the stitch construction, followed by piece manipulation to insure knitability. The resulting Jacquard pattern can be produced immediately by an appropriately configured flat knitting machine.

3D Body Scanning with Mobile Application: An Introduction to Globalise Mass-Customisation with Pakistani Fashion E-Commerce Unstitched Apparel Industry #12

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The study aims to explore the 3D Body scanning mobile application Nettelto to determine mechanism, precision and level of acceptance of application for mass-customisation of garments. The mix-methods (Quantitative and Qualitative both) approach has been conducted to determine the responses of Pakistani consumers. Participants' responses have been analysed with try-on bespoke garments constructed by digital measurements extracted from 3D body scanning mobile application. Bespoke garments are well established and commonly utilised by consumers of Pakistan. Additionally, Pakistani fashion brands are famous for selling and designing unstitched apparel products which are economical and sustainable, to be used as a personalised tailored garment. However, traditional body measurement technique has been used to construct garments, which is a major obstacle to establish globalise mass-customised garments business using e-commerce fashion platforms. To extract digital human measurements for garments customisation, high and low-tech 3D body scanning mobile applications are available to both IOS and Android users. In addition, these web 3.0 technologies virtual size and fit tools and 3D body scanning technology have the potential to enhance the fashion e-commerce environment for online bespoke apparel shopping. The reliability of 3D body scanning technologies has been evidenced in various studies. The unstitched apparel product is famous in South-Asian countries, especially Pakistan has one of the biggest unstitched apparel industries with diversity in style, designs, and price range. The growth of 3D body scanning technology and virtual size and fit to enhance the consumer satisfaction level with sustainability in terms of bespoke garment construction is the most promising e-commerce fashion business model under development presently. 3D body scanning mobile applications have the potential to initiate globalise mass-customisation in fashion e-commerce Industry.

Technical Session 5: Digital Anthropometry & Ergonomics

Allometry Between Measures of Body Size and Shape in a Large Population-Based Cohort #10

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Traditional manual anthropometrics have been used extensively in practice to derive indicators of health risk, such as growth disorders or obesity; however, these approaches typically reduce the complex shape of human bodies to a series of simple size measures. Three-dimensional (3D) imaging systems capture detailed and accurate images of human morphology which have the potential for use within health applications. However, previous studies utilising 3D imaging have only assessed body shape based on combinations and relative proportions of large numbers of size measures. Geometric morphometrics - established mathematical methods within the fields of anthropology and evolutionary biology - analyse morphological variation and allometric relationships between the size and shape of organisms. The aim of this study was to investigate allometry between traditional measures of body size and novel measures of body shape. Developed analytical procedures were utilised to extract scale-invariant features of torso shape from 3D imaging data of 4,405 male participants in the LIFE-Adult cohort, obtained using a Vitus Smart XXL laser scanner. Partial least squares regression (PLSR) models were created to determine how human body shape changes with increases in body size. This study demonstrated that linear combinations of size measures can explain between 3.2 - 84.4 % of the variation in individual body shape features. These results indicate that measures of human body shape show a complex dependence on body size, providing complementary anthropometric features of the human body. The aim of future studies will be to investigate the efficacy of these measures in clinical epidemiology.

Modification of the Female Figure Identification Technique (FFIT) Formulas to Include Plus Size Bodies #22

Susan L. SOKOLOWSKI , Chrissy BETTENCOURT

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With new 3D plus size body scan data available through surveys like Size North America and manufacturers investing in their own data, there was an opportunity to study the shape of modern female plus sized bodies to inform the fit of products for this emerging business demographic. The researchers partnered with a leading apparel company to analyze 3D plus size body scans with the Female Figure Identification Technique (FFIT) for apparel developed by Simmons, Istook, and Devarajan (2004), using mathematical representations of the FFIT body shapes created by Lee, Istook, Nam, and Park (2007). However, during the project, it was discovered through visual inspections there were opportunities to modify the FFIT mathematical formulas to be more inclusive of plus size women. The inspections indicated that some scans were inaccurately classified or not sorted into any shape category. Since plus size women often have larger abdomens than bust or hips, the formulas were modified to include a check for that condition. By understanding shape, manufacturers can have a better idea of how to design, fit and grade products for this market throughout a size range, as opposed to relying on only 2D measurements or linear grading rules from a sample size.

Comparison and Validation of Traditional and 3D Scanning Anthropometric Methods to Measure the Hand #41

Emily SEIFERT, Linsey GRIFFIN

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Using full-color hand-held three-dimensional scanners allows researchers to gather anthropometric data outside of a lab setting. The ability to gather a broader and more diverse database is essential to the fit and sizing of products. However, full-color hand-held three-dimensional scanning has not been fully validated as a methodology to take accurate measurements for the hand. This study aimed to

examine three different tools for collecting anthropometric data for the hand by their precision. The anthropometric methods compared include tools used in traditional anthropometry, such as a small-bone caliper and tape measure and two (2) full-color hand-held three-dimensional scanners (Occipital Structure Sensor and Artec Leo). Twelve (12) three-dimensional hand scans were 3D printed with a Creality CR-10 three-dimensional printer using PLA materials. The three-dimensional scans were a part of a more extensive database, and the chosen scans represented a range of handbreadth measurements. Eight traditional anthropometric measurements, including length, breadth, and circumference, were collected to assess the precision of manual anthropometric measurements compared to digital measurements from the Occipital Structure Sensor and the Artec Leo. The results from this study showed no statistically significant differences between the manual anthropometric measurements and the digital measurements from the Artec Leo. There were limited statistical differences between the manual anthropometric measurements and the digital measurements from the Occipital Structure Sensor. There were limited statistical differences between the digital measurements from the Occipital Structure Sensor and the digital measurements from the Artec Leo. The information provided in this study will benefit the collection of anthropometric data for the hand by researchers. Three-dimensional technology and processes offer more opportunities to collect data for the hand, which will help improve the design of products that interact with the hand.

Improving the Fit of Respiratory Face Masks through 3D Scanning, Finite Elements Analysis and Additive Manufacturing #33

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The 2020 COVID-19 pandemic sheds a new light on the importance of wearing a mask to prevent virus propagation. A respiratory mask's efficiency is highly dependent on its adjustment with the face. With traditional face masks, achieving a perfect seal with the face proves to be challenging, even impossible without the aggressive tightening of its straps. Healthcare workers typically wear protective face masks for several consecutive hours, leading to discomfort, inflammation, or more serious injuries.

This paper highlights how the combination of current technologies such as 3D scanning, Finite Element simulation, machine learning, and additive manufacturing offers a seamless workflow to generate a sterilizable, reusable and validated custom-fit mask.

The process starts with a 3D face scan acquired from a mobile 3D scanning device. From this scan, the software Shapeshift3D automatically repairs the 3D scan and fits the mask to the facial features. A custom Finite Element model is created by morphing the mesh of a generic face model and its corresponding mask onto the person's face. The fit, achieved through customization, is then assessed via biomechanically simulating the mask's tightening while accounting for the face-mask interface and the facial tissue's behavior. A real time assessment of the mask's sealing properties and the pressure on the skin is made possible by a machine learning algorithm that was trained on a database of face mask tightening simulations (ANSYS software). This approach allows to quantify in real-time the level of fit achieved through customization. The custom mask is then 3D printed and assembled before being shipped to the end-user.

Technical Session 6: 3D Body Scanning Systems III

**Research Applications of 3D Body Shapes Capture in Movement. MOVE4D
A New Innovative Solution for 4D Full Body Digitization #39**

Sandra ALEMANY

Instituto de Biomecanica, Universitat Politècnica de València, València, Spain

no paper/abstract

Medical-Grade Smartphone 3D Body Scanning Technology in Consumer-Facing Applications #60

Jeff CHEN

NetVirta, Boston MA, USA

Smartphone-based 3D body scanning technology has been playing a key role in medical orthotics applications since early 2013, however, it only started to attract more attention from apparel & footwear industries in the recent several years, especially in consumer-facing applications. Part of this delay was due to the significant amount of undertaking needed for researchers to convert a clinician-facing medical-grade 3D scanning technology into a consumer-facing application. We would like to share our experience in our journey of converting a medical-grade clinician-facing technology into a consumer-facing application. Our presentation will cover considerations of 3D scanning accuracies, difference in user-experience between professional users and consumers, product designs ideology transformations. We hope that this report will contribute to the community and help more technology providers effectively pivot their products towards the apparel & footwear industries.

MeThreeSixty Improvements from Size Stream #27

Warren WRIGHT

Size Stream LLC, Cary NC, USA

Size Stream's me-three-sixty app brings the power of 3D body scanning to the mobile phone. This app enables users to track measurements and weight-loss goals from the comfort of their homes. The development of our measurement technology is always evolving. This presentation is about showing some of these evolutions and sharing our current measurement performance. This will be demonstrated using data from internal product testing and the public IEEE 3DBP Comparative Analysis scan survey. The discussion of measurement performance will be in the context of accuracy and precision. For the bulk of users, their measurement expectation is set by the quality of manual measurements. From this expectation, we will discuss aspects of the paradigm shift needed to embrace scan-based measurements. Additionally, the aesthetic quality of the 3D models is a large factor in user satisfaction. We are continually improving our aesthetic quality and this presentation will discuss some of the difficulties and our solutions.

IO Industries' Volucam - Simplified Multi-Camera Video Recording Solutions #61

Andrew SEARLE

IO Industries Inc., London ON, Canada

IO Industries recently announced the world premiere of our new Volucam™ camera series, designed for integration into volumetric video capture systems, 4D body scanners, and other synchronized multi-camera recording systems. This presentation will review the innovative Volucam video camera family and explain its capabilities in comparison to other solutions IO Industries and other camera system designers have provided the market thus far.

The Volucam is the first camera of its kind, combining capabilities and features normally found in industrial machine vision style cameras with internal RAW recording to a high-capacity solid-state drive (SSD). Precise synchronization features ensure microsecond-level accuracy between many cameras (as many can be connected to an Ethernet network), making the Volucam series ideal for synchronized multi-camera video recording applications. Easy-to-use operator software allows control and management of many cameras from a single interface, and a high-speed 10GigE connection ensures recordings are downloaded quickly, so the data may then be promptly processed by 3rd party tools such as 3D reconstruction software for volumetric video content creation.

IO Industries specializes in high-performance video cameras, focusing on providing robust equipment that ensures high-bandwidth video data can be collected reliably. IO Industries delivers solutions to researchers, corporations and creative studios working to push the limits of their image and video processing tools, providing confidence that a video capture system with IO Industries cameras will provide the data needed for them to deliver their best results.

Technical Session 7: 3D Body Technology for Sport & Fitness

Development of an Articulating Cycling Mannequin for Wind Tunnel Testing #11

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Toon HUYSMANS 3, Koen BEYERS 2, Stijn VERWULGEN 1

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Gaining aerodynamic advantage is crucial in cycling, wherein drag force can account for 90% of resistance to a cyclist. The interaction of wind with the moving human and cycling equipment also contributes to drag. Testing equipment for aerodynamic properties in a wind tunnel is of interest to manufacturers in the sports industry. However, a protocol that needs to depend on the ability of a human to accurately recreate desired poses and movements multiple times may be cumbersome during testing. Additionally, a stationary mannequin does not accurately represent real-life cycling, where pedaling is a constant. Hence, a moving mannequin is suited for such applications. In this contribution, we demonstrate the development of a 3D printed articulating cycling mannequin. A cyclist was scanned using a structured light 3D scanner. Our goal was to develop an articulating mannequin with pedalling legs and a detachable upper-body to recreate two common cycling poses - time-trial and regular. In this contribution, we describe the full development of the mannequin in time trial pose. This approach outlines a low-cost method to developing mannequins for testing applications in sports.

An Indoor Training Bike to Provide Real-Time Feedback on the Aerodynamic Cycling Position Using Frontal Area Calculations #24

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An incorrect position or movement or slight alteration in position during cycling can induce an increase of aerodynamic resistance, which has an immense influence on the performance. However, when defining an optimal aerodynamic position as in wind tunnel experiments, there is no control over the maintaining of this position during training or races. Furthermore, during well-defined training methods on indoor smart trainers, the aerodynamic effect has not been taken into account in determining the imposed resistance.

Therefore, an indoor training bike was developed to continuously calculate the projected frontal area of the cyclist and the bike as an indicator of aerodynamic drag to estimate the wind resistance the cyclist experience in that position. The power a cyclist in that pose must push is calculated and automatically loaded to a smart trainer. Additionally, real-time feedback on the most efficient and aerodynamic position is provided. Therefore, vibrotactile instructions are provided when cyclists exceed a certain calibrated projected frontal area value, corresponding to the most aerodynamic position.

In this study, an intervention with only changing resistance based on the aerodynamics was compared with interventions with additionally vibrotactile feedback. The addition of vibrotactile signals provides significantly higher accuracy in recapturing the most optimal aerodynamic position ($p < 0.001$) including both competitive cyclists and amateur cyclists, as well as experiments with a time trial bike and a road bike. The results in this study show that the system with variation of resistance depending on the aerodynamic position, in combination with vibrotactile feedback for alerting cyclists when deviating from their optimal aerodynamic position can be an interesting tool to use during training sessions on a smart trainer.

Half-Scale Body Forms in Active Poses for Design Development: Use of Pressure Data for Bicycle Clothing Design #19

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Considering the importance of 3D body shapes and designing with 3D bodies directly, new tools of fit evaluation and garment design are investigated. In this research, we explore half scale body forms in the cycling pose as a tool for pressure measurement for tight fitting bicycle wear. Comparison of pressure values were conducted, which were obtained from participants and their half scale forms

produced by 3D body scanning in the active pose. As a subsequent research phase, production and material alternatives for half scale body forms were investigated. Even though the correlation between the pressure values from half scale forms and human participants is not strong enough to replace participant testing, tests with alternative forms indicated reliability in pressure measuring for each of the suggested half scale forms in this research.

3D Body Scanning for Weight Loss Motivation #57

David BRUNER

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no paper/abstract

Technical Session 8: Body Modeling & Avatars

An Open-Source Articulated Multi-Person Shape Model Training and Inference Pipeline #17

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We propose an open source markerless articulated multi-person shape model training and inference pipeline. Our open source implementation is freely available for non-commercial research purposes.

A Review of 3D Human Pose Estimation from 2D Images #29

Kristijan BARTOL¹, David BOJANIĆ¹, Tomislav PETKOVIĆ¹,
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Human pose estimation task takes images as input and extracts a set of locations representing the predefined body joints and the sparse connections between the joints, called the body parts. A pose can be estimated from single or multiple frames, in a single (monocular) or multi-view (stereo) setup and for a single person or multiple people in the scene. In this work, we provide an overview of the classic and deep learning-based 3D pose estimation approaches. We also point out relevant evaluation metrics, pose parametrizations, body models, and 3D human pose datasets. Finally, we review state-of-the-art pose estimation results, briefly discuss open problems, and propose possible future research directions.

Algorithmic Issues During the FEM Mesh Preparation of Human Models Based on 3D Body Scans #48

Yordan KYOSEV, Doudou ZHANG

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Generating human finite element models for mechanical or thermal simulations is a complex task. Modern 3D scanning technology offers a fast method of capturing the surface of the human body and thus forms the starting point for the future creation of individual FEM models based on the 3D scan. This paper presents some frequently occurring issues and problems in mesh processing, which have often to be solved and which has to be implemented in an automatic procedure for human modelling.

Meshcapade Overview #50

Ben KILGORE, Naureen MAHMOOD

Meshcapade GmbH, Tübingen, Germany

Meshcapade is an industry leader in the field of 3D body modeling and animated avatars. A spinoff of the Max Planck Institute for Intelligent Systems Perceiving Systems lab, Meshcapade offers licensing and consultation services surrounding many groundbreaking technologies and datasets produced at MPI-PS, including SMPL, VIBE, MANO, DYNA, FAUST, BUFF, PoseLimits, SSM, MoSh, SMPLify-X, SMPL-H, SMPL-X, PROX, and many others. Additionally, Meshcapade has recently launched an open beta of their API frontend and avatar creation platform, digidoppel. Digidoppel aims to democratise the easy, quick creation of rigged, animated, regularised avatars from inputs of scan data or body

measurements. Among many smaller partners, the majority of companies in the NASDAQ top 10 are now using technology licensed by Meshcapade.

Technical Session 9: 3D Foot, Hand & Face Scanning

Correlation of Foot Width and Instep Height for Male and Female Feet #44

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Perfect fit is an important factor of footwear comfort. Previous studies have identified high foot width and instep height dispersions for subjects of similar foot length, which confirmed the need for producing footwear in multiple widths. The aim of this study was to analyze the relationship between foot width and instep height. Over 68000 male and 105000 female 3D foot scans from North America were used in this study. The feet were very similar in foot length within each gender. Pearson correlation coefficients between foot width and instep height were calculated, and joint histograms using hexagonal bins were plotted for both genders. Results show that the correlations of foot width and instep height were low for both genders. This means that feet of any width have a wide range of instep heights. Therefore, shoes should be developed in a way that they can fit a wide variety of instep heights, regardless of the shoe width. These results will provide additional information to footwear brands on how to develop footwear to provide proper fit to a large percentage of their customers.

Arm and Forearm Scanning Methodology for the Development of an Orthotic Device for Tetraplegic Patients #06

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Introduction: The upper limb rehabilitation of the tetraplegic patients in the early stage of treatment consists of the grasp execution with the assistance of another person. The aim is to create an orthotic device for grip rehabilitation and to eliminate the need for assistance from rehabilitation nurse. To accomplish this target, it is necessary to obtain the positives of the patient's arm and forearm.

Method: The subjects with insufficient strength of upper limb movement are the target group of this study. Their physical state complicates the conventional way of obtaining measures and shape of the upper limb for the purpose of designing orthotic devices. Appropriate method for hand and forearm 3D scanning has been proposed to achieve a satisfactory positive model.

Test/Data: The scanning process was divided into two scans of the hand, forearm and fingers with the Artec Eva 3D scanner. It was necessary to develop specific methodology of suitable scanning positions for the purpose of this work.

Results: To hold the correct position of upper limb during scanning process is complicated, because of absence or lack of strength in the upper limb. The scanning position of the hand and forearm is the wrist extension and the thumb opposition to the fingers. This could be done with the assistance of a second person with special instruments. This scanning was performed with the focus on the dorsal part of the hand, the thumb and the radial part of the forearm. The fingers were scanned in the position with the palm placed on a cylinder surface, to achieve a scan with the fingers separated from each other. The focus during the scanning process was on the dorsal part of the fingers.

Conclusions: The required and important segments of the hand and forearm have been successfully scanned with Artec Eva 3D scanner and were used for the CAD designing of an individual rehabilitation hand orthosis. This orthotic device can later be manufactured with additive manufacturing technology.

Make It Easy: Reliability of Automatic Measurement for 3D Hand Scanning #38

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The purpose of this research was to test the accuracy of automatic measurement systems on 3D hand scans compared to conventional digital measurements. 15 participants' right hand was 3D scanned with Artec Leo scanner, analyzed, and compared for seven measurements (five linear and two surface measures) in Anthroscan measurement software by Human Solutions. Means and standard deviations for each measurement were analyzed between conventional and automatic measurement conditions. Paired t-tests were used to understand significance between the two types of measurements. There was virtually zero difference for all the linear length measurements such as thumb breadth, hand breadth, hand length, wrist-index finger length, and palm breadth. However, a significant difference was found between conventional and automatic surface circumference measurements. Both hand and wrist circumference measurements showed nearly 4% difference between conventional and automatic conditions.

Reliability of Mobile 3D Scanning Technologies for the Customization of Respiratory Face Masks #34

Jonathan BORDUAS, Aude CASTONGUAY-HENRI, Patrick LAURIN,
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This paper compares the reliability of four mobile 3D scanning technologies and provides insight and recommendations as to which are of sufficient reliability for the customization of respiratory face mask. More specifically, we will compare the reliability of ARCore: Augmented Faces SDK by Google, the ARKit: Face Tracking SDK by Apple, the ScandyPro app using the raw information of the TrueDepth Structured Light sensor by Apple, and the 3DSizeMe app using the Structure Sensor by Occipital. ARKit and ARCore only provide a 3d model of the face, while providing no information of the head shape, we will compare the reliability of extrapolating the head shape from the face scan using Flame AI. ScandyPro and 3DSizeMe do not provide landmarks of the head, as such landmarks for measurements are found using a Deep-MVLM. A subset of anthropometric measurements as suggested by the standard ISO 16976-2:2015 part 2 will be used to assess the reliability of each method and device. We express the reliability of the process in terms of Standard Error of Measurement (SEM).

Context: The COVID-19 pandemic has created situations where healthcare providers must wear off-the-shelf N95 masks for long and uninterrupted periods of time. Without applying excessive pressure to the face, it is often difficult to achieve the required airtight seal for the respiratory mask to be effective. Inflammation, pain, and discomfort caused by N95 masks are now the daily reality of numerous healthcare workers. This problem has ignited efforts around the globe to develop custom-fitted respiratory face mask based on the 3D scan of the face.

Results: Reliabilities of different heads scanning technologies have been compared over various measurements. Preliminary results suggest that ARCore, ARKit and 3DSizeMe have sufficient reliability, but are lacking intermethods consistency.

Technical Session 10: 3D Body Scanning for Apparel II

Analysis of Clothing Deformation During Motion and its Application for the Design of Functional Clothing #09

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On the one hand, functional clothing often requires materials with low elongation –for instance conductive wires for signals or antennas, stiff tapes for force transmission or multi-layer membranes with special protective functions. On the other hand, wearing comfort depends on the physical freedom of movement, which can be enhanced by larger gaps in clothing or elastic materials. Hence, this work presents a method for the analysis of clothing deformation during motion and the detection of areas with lower deformation, where wires and tapes can be placed. For the analysis, a human leg with a specially designed elastic textile material was scanned with a 3D scanner in different poses, and

subsequently, the 3D data was processed in a two-step procedure: areas with an elongation below a set limit can then be marked and selected for the placement of inelastic functional elements.

Using 3D Scanning to Create 4D Motion Data for Clothing Simulation #13

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Digital product development processes have become increasingly established since the 1980s, especially in the clothing industry. In the last decade, technological progress has accelerated enormously and the subject of garment simulation is being discussed more and more intensively in industry and the garment industry. The advantages for companies that integrate digital product development into their process chain are already measurable. Through more accurate design, process and fit planning, physical prototypes can be saved, saving time and money. A clothing simulation includes the cutting data, the physical material parameters and a digital fit model. Fit models can be provided in all sizes and a simulation over the entire size range is possible. This allows the grading of a garment to be qualitatively checked and validated over several sizes. However, the quality of garment fit assessment depends on accurately measured avatars and simulated fabric behaviour, combined with a deep understanding of the simulation processes of the systems used and garment engineering know-how. 3D simulation software for the virtual visualisation of garments and virtual try-on is continuously being improved. Previous statements on the fit of garments by simulation are based on a static avatar. In the project Kinematic Human Models, it has already been established that the fit control must also be carried out in different body positions. By testing the fit in typical body positions from the fields of sports, ergonomics and medicine, it is also possible to test and optimise cut constructions that have so far paid no attention to functional clothing comfort.

Morpheus: A Platform for the Representation, Manipulation and Secure Access of Standardized Morphological Data for the Digital Age Textile Industry #08

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This document presents Morpheus: a platform for the representation, manipulation and secure access of standardized morphological data for the digital age textile industry.

Global Trends in Body Measurement and Shape Development - and Their Impacts on Technical Product Development, Size and Fit #54

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Measurement surveys currently completed by Avalution in various European regions and in North America show both similarities and fundamental differences in the development of body measurements and proportions. When comparing the results, it becomes clear that there are fundamental differences in the development of length measurements and relations between Europe and the USA. Also with regard to the development of girth measurements, both similarities and differences between the continents can be found, which can now be substantiated with concrete numerical values. In addition, for the first time body shape comparisons were carried out, frequencies of certain body shapes were quantified and their differences in the course of height or with regard to the age group were evaluated.

What consequences do these global trends have for the product development of clothing and other products that must fit the body? How should the findings be taken into account in the development of size systems and fit concepts? What influence do these trends have on the development of other products? How can they be taken into account when implementing virtual product development in 3D? In the course of the presentation, the differences will be quantified and implementation strategies will be shown using concrete examples from company practice.

Technical Session 11: 3D Body Processing

Working Group Progress for IEEE P3141 - Standard for 3D Body Processing, 2019-2020 #05

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4 Centre for Sports Engineering Research, Sheffield Hallam University, UK;

5 Vital Mechanics Research, Vancouver BC, Canada;

6 University of British Columbia, Vancouver BC, Canada;

7 Web3D Consortium, Mountain View CA, USA;

8 Size Stream LLC, Cary NC, USA;

9 Fashion Should Empower, Vancouver BC, Canada

The 3D Body Processing Industry Connections (3DBP IC) group, an adjunct to IEEE P3141 Working Group (WG) is developing recommendations for 3D body processing interoperability to enable the exchange of 3D human body anthropometric related information across an ecosystem encompassing consumers to creators. Representatives from diverse industries aim to establish operating principles to aid in the transformation of the retail experience. This paper also updates the status of the IEEE P3141 Working Group, Standard for 3D Body Processing (3DBP) Working Group.

This paper summarizes the 3DBP activities conducted during the past year (Q4 2019 - 2020) and provides an overview of the topics to be addressed in 2021. During 2020, the working group published two white papers focused on the Comparative Analysis of Measurement Methods, Past, Present, and the Future of 3D Scanning, and 3D Foot Measurements Terminology.

Comparative Analysis of Anthropometric Methods: Past, Present, and Future #28

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Alice BULLAS 3, Tim DEVLIN 4, Emma SCOTT 5, Carol MCDONALD 6

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3D imaging has experienced rapid market growth since its development in the 1980's. There are now many types of 3D surface imaging systems - each using different hardware, software, computer vision techniques and landmarks resulting in differing measurement locations and degrees of accuracy and precision.

Whilst manufacturers and independent studies have evaluated systemic and random errors of particular 3D surface imaging systems, diverse factors such as population samples, landmarking, measurement definitions, data cleaning processes or analysis methods inhibit informed judgements between systems and against manually collected data.

The IEEE 3D Body Processing Industry Connections (3DBP IC) Group is developing recommendations for 3D body processing interoperability to enable an ecosystem from consumers to creators to use and interchange 3D human body anthropometric information. The Quality subgroup is focused on developing preliminary methods, tools, benchmarks, resources, and testing procedures to define and quantify the quality of 3D models, as well as the quality of the critical metadata for use cases such as body landmarks and measurements. To further this goal, The IEEE 3D Group has completed a Comparative Analysis of anthropometric methods.

The aim of this study is twofold: to determine and compare the compatibility and repeatability of different body measurement extraction methods (e.g. body scanners, smartphone apps and traditional anthropometry) using consistent criteria, and to conduct a data collection and corresponding analyses as a first example of the application of the proposed methodology.

This methodology synthesizes different mathematical tools widely used, including statistical models, minimum sample size required for the analyses, several estimators and plots appropriate to describe the data and quantify the repeatability and compatibility of the different measurement extraction

methods. It provides commonly used criteria to assess most of the statistics. In addition, it includes a procedure to obtain comparable snapshots of the 3D outcomes from digital technologies that facilitate its assessment by potential data consumers.

The study consisted of two phases: Phase 1 - Portland, Oregon (USA), December 2018 and Phase 2 - Valencia (Spain), October 2019. A total of 133 subjects (61 in Phase 1 and 72 in Phase 2) participated in the study. All participants were selected to cover a wide range of body height and weight. Each subject had 11 body measurements collected twice by different measuring stations (3D scanning booth, smartphone apps and traditional anthropometry experts). Phase 1 included two 3D scanners - Vitus bodyscan (Human Solutions GmbH) and SS20 (Size Stream LLC); and four experts. Phase 2 included two 3D scanners - MOVE4D (Instituto de Biomecanica) and Portal MX (Texel LLC); four smartphone apps -3D avatar body (Instituto de Biomecanica), SSatHome (Size Stream LLC), 3DLOOK (3DLOOK Inc.) and eM+ (PolyU); and two experts.

Automatic Extraction of Anthropometric Measurements from 3D Body Scans which are Misaligned or in Natural Posture #53

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3D Measure Up, ProtoTech Solutions Pvt. Ltd., Pune, India

Given the rise of portable scanners and the evolution of new techniques for extracting 3D body scans from photos and videos, it is becoming increasingly difficult to get body scans, which are in standard poses ('A', 'T') and aligned correctly to the standard axes. In this presentation, we discuss the challenges faced due to this and some techniques that we have applied to solve them.

Quantitative Comparison of Manual vs. 3D Scanner Human Body Measurements #35

Andrei KOVAL

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Human body measurements are actively used in the clothing industry for production or finding the best possible garment fit. For the last few years digital methods based on 3D scans are replacing the traditional manual measurement techniques. In this paper we determine the quality of measurements obtained with a 3D scanner in terms of reliability and validity. Tape measurements from two expert measurers were used as a reference. Reliability comparison was evaluated in terms of Standard Error of Measurement and difference from mean distribution. Validity was analyzed according to ISO 20685. Data used for the analysis were gathered during Phase 2 of "Comparative Analysis of measurement methods of 3D body scanning" organized by IEEE Industry Connections 3D Body Processing group hosted in Instituto de Biomecanica de Valencia (IBV).

For all 3D scanner measurements 90% of differences from mean are inside the ANSUR (Anthropometric Survey of US Army Personnel) allowable error interval. It was also shown that reliability of measurements obtained with Texel Portal MX 3D scanner is nearly twice better than reliability of manual measurements. Upon application of constant offsets these two measurement techniques are compatible according to ISO 20685.

Technical Session 12: 3D Body Scanning for Apparel III

Development and Usage of 3D-Modeled Body Shapes for 3D-Pattern Making #14

Gabriela KOSEL, Katerina ROSE

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Today's pattern making methods for industrial purposes are including construction principles, which are based on mathematical formula and sizing charts. As a result, there are two-dimensional flats, which can be converted into a three-dimensional garment. Because of their high linearity, those patterns are incapable of recreating the complexity of the human body, which results in insufficient fit. Subsequent changes of the pattern require a high degree of experience and lead to an inefficient product development process. It is known that draping allows the development of more complex and demanding patterns, which corresponds more to the actual body shape. Therefore, this method is used in custom tailoring and haute couture to achieve perfect garment fit but is also associated with time.

So, there is the act of defiance to improve the fit of garments, to speed up production but maintain a good value for money. Reutlingen University is therefore working on the development of 3D-modelled

body shapes for 3D draping, considering different layers of clothing, such as jackets or coats. For this purpose, 3D modelling is used to develop 3D-bodies that correspond to the finished dimensions of the garment. By flattening of the modelled body, it is then possible to obtain an optimal 2D Pattern of the body. The comparison of the conventional method and the developed method is done by 3D simulation. Finally, the optical fit test is demonstrated by the simulated basic cuts, that a significantly better body wrapping through the newly developed methodology could be achieved. Unlike in the basic cuts, which were achieved by classical design principles have been created, only a few adjustments are necessary to obtain an optimized basic cut. Also, when considering the body distance, it is shown that the newly developed basic patterns provide a more even enclosure of the body.

Scalable Fit Testing and Visualization with VitalFit Soft Avatars #37

Dinesh K PAI 1,2, Yuan TIAN 1,2, Ye FAN 1,2

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Predicting fit of garments is a major application of human body scanning and processing technologies. Fit prediction is particularly challenging for close-to-body garments such as intimate apparel, personal protective equipment, and wearable devices. Recent advances in measuring and modeling human soft tissues has made it possible to simulate fit more accurately, using finite element models of soft avatars. We describe a cloud computing solution for secure and scalable fit testing. It allows any number of computationally demanding soft avatar simulations to be run, from any computer. We also describe new methods for visualizing fit attributes, such as tissue compression and garment ease, and to compare different fits quantitatively.

Enhancing Pattern Construction by Body Scanning: The Importance of Curves #56

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The University of Manchester, Manchester, UK

This paper will discuss the enhancement of trouser pattern construction through the utilisation of 3D body scanning. It will discuss the lower body shapes -pattern -garment relationship. It will focus on the curves that are required to suitably develop trousers from 3D body scans.

It is acknowledged that 3D Body scanning offers more anthropometric data on the body than had been previously possible to collect from traditional methods of measurement. However, there exist differences between these two methods of measurement and limitations within the existing 3D body scanning process at certain locations of the body; namely the armhole curve, the armscye, the bust, the neck curve and the crotch.

This research began with eighteen methods of pattern cutting for trousers, the measurements were taken from a 3D body scanner in order to draft the pattern using Lectra. The data outputs from this were then entered into Excel for analysis and comparison and to see if there were any inconsistencies for ease or arc definition for different morphologies. It was noticed that during the pattern making process traditional linear Euclidian methods of measurement were used, whereas the body is shaped with curves, convex or concave, and these seem not to be given their importance in the pattern construction process within a 3D environment. This necessitated an investigation into a new approach using hybrid calculations using Euclidian and non- Euclidian geometry to incorporate and calculate the curves in 3D.

The increased adoption of technology and environmental issues caused by fast fashion have propelled the concept of mass customisation to the fore. Greater precision in 3D scan data which relates directly to the lower body shape has huge implications for customer satisfaction and the garment manufacturing industry.

3D Body Scanners' Ability to Improve the Cutting of Patterns for Traditional Saudi Garment to Assimilate Them into Modern-Day Clothing #25

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3D body scanning and CAD tools offer opportunities to develop traditional pattern cutting methods, that better contextualise the body, whilst retaining the traditional appearance. The costumes that are traditional to a particular region of Saudi Arabia represent a key aspect of that area's cultural identity. These traditional costumes offer a glimpse at the region's heritage and how this has evolved throughout history. Current pattern drafting methods that utilise flat patterns are relatively simple compared to the traditional methods based on a one-to-one interaction with the person who would

ultimately wear the finished garment. There are various measurements required for each method for example, (Bust circumference, Waist circumference, Hips, Shoulder, back length, Sleeve length, Bust-length, Waist to Hip, Chest, Neck size, Back width, Nape to the waist, Armscye depth, Pattern length, Wrist, Sleeve length). This paper focuses on how traditional methods for creating Saudi Arabian garment can be enhanced through the use of 3D body scanning. Specifically focusing on the traditional Sawwan garment, a traditional dress, and developing a thorough understanding of the traditional methods the benefits afforded by 3D body scanners can be incorporated to enhance the process. Body scanners offer a highly efficient means of measuring various parts of the human body that can then be used to produce well-fitted garments. Scanners also provide opportunities for new measurements which are more difficult to capture using existing manual tools. Traditionally all aspects of the process apply little technology, from the taking of body measurements, the construction process and the use of geometric shapes. Body scanners have opened up new opportunities to take more measurements in quickly, thereby ensuring that the human form can be central in the pattern construction process. Whilst still making use of 2D pattern drafting methods, this study utilises additional measurements when producing pattern blocks so as to ensure that the resulting garments can more accurately reflect the wearer's shape and proportions. In addition to taking measurements using a Size Stream body scanner, the current study assesses a well-known garment draft based on measurements taken with the scanner relative to an innovative means of garment drafting that makes full use of the body scanner's precision. Accordingly, digitally tailored garments need to precise measurements as a key to make a well-fitting garment. Besides, the current research will hopefully encourage others to explore how technology can retain traditional designs and improve our understanding of pattern theory. Results indicate that the scanner can provide data in more depth than traditional approaches. Therefore, the current study extends the existing knowledge base, by using body scanning to enhancing the system of patternmaking. This enables the creation of custom computer-aided pattern drafting, thereby improving the range of clothing available in the Saudi market.

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