Ivana Špelić, Slavenka Petrak
University of Zagreb, Faculty of Textile Technology, Address: Prilaz baruna Filipovića 28a, 10000 Zagreb, Croatia

Complexity of 3D Human Body Scan Data Modelling

Kompleksnost modeliranja podatkov za skeniranje 3-D človeškega telesa

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Abstract

3D scanning technology and contemporary CAD systems have enabled various applications of scan data for different industries. 3D scan data have become the basis for the highly accurate digital representation of objects. CAD systems, on the other hand, enabled scan data restoration and modification in order to get precise 3D models. Apart from being used in industries such as engineering and the automotive industries, CAD systems are today used by the textile and the apparel industry. However, there is a great deal of complexity in reconstructing and modelling 3D scan data of the human body. 3D scan data of the human body can be converted into a triangle mesh, while the CAD restoration process is performed using reverse engineering techniques in order to create a realistic model. Reverse engineering techniques involve the extraction of information about manufactured products. The conversion of data regarding the human body acquired by 3D scanning into a CAD model is a complex direct method. The 3D scan data processing of the human body requires a great deal of knowledge of the basic human anatomy, as the human body has an extremely complex geometry. The reverse modelling procedure is extremely multiplex and time consuming due to the large amount of details, while the workflow involved in restoring 3D scan data to even begin the reverse engineering process is complex. In recent studies, non-contact 3D body scanning, together with 3D CAD reverse engineering, could be applied for precise volume measurements for microclimatic volume and area quantification, as the reconstructed model of the human body can serve for the further analysis of the thermal insulation properties of clothing in relation to the volume of air trapped between layers.
Keywords: non-contact 3D body scanning, 3D digital surface model of the human body, reverse engineering techniques, 3D CAD reverse modelling and reconstruction

Izvleček

Tehnologija 3-D skeniranja in sodobni CAD-sistemi so omogočili različno uporabo skeniranih podatkov za različne industrije. Skenirani 3-D podatki so postali osnova za zelo natančno digitalno predstavitev predmetov. Vzporedno pa so CAD-sistemi omogočili preoblikovanje in spreminjanje skeniranih podatkov za doseganje natančnih 3-D modelov. Poleg uporabe na različnih področjih inženiringa in avtomobilizma se CAD-sistemi danes uporabljajo tudi v tekstilni in oblačilni industriji. Vendar sta rekonstrukcija in modeliranje skeniranih 3-D podatkov človeškega telesa zelo zahteven proces. Skenirani podatki človeškega telesa se lahko pretvorijo v mrežo trikotnikov, pri čemer se s pomočjo CAD- sistema z obratnimi inženirskimi tehnikami poustvari realistični model. Obratne inženirske tehnike vključujejo ekstrahirane podatke o izdelku. Pretvorba podatkov o človeškem telesu, pridobljenih s 3-D skeniranjem, v CAD-model je kompleksna neposredna metoda. Obdelava podatkov 3-D skeniranega človeškega telesa zahteva veliko znanj o osnovni človeški anatomiji, ker ima človeško telo izjemno zapleteno geometrijo. Postopek obratnega modeliranja je večplasten in dolgotrajen zaradi množice detajlov in ker je delovni tok obnavljanja 3-D skeniranih podatkov zapleten tudi v obratnem inženirskem procesu. Nedavne študije so pokazale, da se nekontaktno 3-D skeniranje telesa skupaj s 3-D CAD obratnim inženiringom lahko uporabi tudi za

Corresponding author/*Korespondenčna avtorica:*
Ivana Špelić, PhD
E-mail: ispelic@ttf.hr

natančne meritve volumna in površine mikroklimatskih prostorov, kjer se lahko rekonstruirani model človeškega telesa uporabi za nadaljnje analize toplotne izolacije z vidika prostornine zajetega zraka med plastmi.
Ključne besede: nekontaktno 3-D skeniranje telesa, 3-D digitalni model površine človeškega telesa, obratne inženirske tehnike, 3-D CAD obratno modeliranje in rekonstrukcija

1 Introduction

3D body scanners provide a detailed representation of the human body, but not without the need for the further improvements. 3D (three dimensional) body scanning technology facilitates the capturing of the human body. As a result, 3D scanners are able to generate a detailed 3D representation of the human body, called the human body model, within a few seconds.

The resulting 3D model can be exported by the scanning software for further use. Depending on the 3D body scanner used, the 3D model is exported as a mesh or point data cloud forming the shape of the body. 3D scanning devices can be used as scanning systems for capturing 3D full-human body models. They apply the technology of acquiring a structured light or laser to capture the human body. However, this technology is often expensive and requires specific knowledge to operate.

This scanning technology has existed for more than twenty years, while the first 3D whole-body scanning system was developed by the University of Loughborough in 1989 with the aim of conducting anthropometric surveys. By 1998, 3D whole-body scanning technology was being applied commercially for the fashion industry in the United States. In recent years, new technologies have enabled the measurement of the surface of the human body and facilitate a whole-body scan while a person remains fully clothed [1]. The importance of human body 3D measuring has increased over the last decade. Scanning devices based on a structured light or laser scan produce high-quality images of the human body but are expensive and operationally complicated [2].

Whole-body scan data have many applications. The most prominent use, however, is the construction of human figure models that accurately represent body shapes. One of the basic challenges in using whole-body scan data with human figure models is creating an articulated, surfaced geometric model that realistically matches the scan data with a high degree of accuracy [3].

The generation of 3D curved shapes is the basis for all CAD systems. NURBS (non-uniform rational B-spline) curves and Bezier curves were created to represent a mathematical description of a 3D curved line and the resulting surface. NURBS curves describe all of the surfaces in CAD systems. They also represent simple geometries such as flat planes. On the contrary, the approximation of a cylinder with a non-uniform B-spline requires a considerable number of control points, while the optimisation of the B-spline is required. This optimisation can be visualised by independently putting more or less pressure on the elastic band of each Bezier curve. Internally, most CAD systems use triangulation [4].

Human body scan processing is usually performed manually in several stages. Scan processing involves healing defects, the reconstruction of mesh features using the remaining polygons, re-meshing and re-wrapping, and finally smoothing over the surface of scans [5]. A human body model can be used as an original design basis for the manufacture of special clothing, for medical applications, etc.

According to more recent studies, non-contact 3D body scanning and 3D CAD reverse engineering can be applied for precise measurements for microclimatic volume and area quantification. Those precise measurements of clothing garments and the volume of microclimatic air layers serve as the basis for further analysis of the thermal insulation properties of clothing [5, 6]. According to previous studies by Lee et al. [7], Zhang & Li [8] and Mert et al. [9], garment fit and the resulting air volume are crucial factors in determining the thermal insulation value of clothing ensembles. Thermal insulation increases linearly with air gaps, provided that no convection is present [7, 10]. However, in order to measure the impact of the convection on the thermal insulation properties of the clothing, the air volume trapped within the layers of the clothing must be deduced. Because 3D scanning has been reported as the most accurate and reproducible method for air volume quantification under clothing [11], 3D scanning technology has made it possible to precisely quantify microclimatic layers [5, 6, 11–13].

2 3D body scanning

3D body scanning technology generates a complete replication of any human body via 3D scanners by directing detailed scans of human bodies and creating 3D replications. 3D whole-body scanners are useful tools for obtaining and recording anthropometric data regarding the human body. A laser scanner unit is composed of a laser, an optical system and a light sensor to digitise the surface [14].

3D scanning methods are classified as [15] contact 3D scanning methods and non-contact 3D scanning methods. Non-contact 3D scanning methods can be transmission-based methods, such as CT, and reflection-based methods, which exploit the energy reflected by an object during acquisition in order to retrieve geometric information useful to determine a shape. They are further divided into [15] non-optical, such as sonar and microwave radar, and optical, such as structured light scanning, image analysis, triangulation and interferometry.

Non-contact 3D scanning methods do not require the probe to come into physical contact with a measured object. The interaction occurs by means of magnetic, light or sound fields, and the system acquires data by capturing the energy transmitted or reflected by an object [15]. Scanned objects are converted into a point cloud or triangle mesh. Based on the obtained point cloud or triangle mesh, the restoration process can be performed. This process is called reverse engineering or back engineering. Reverse engineering is the analysis of components to create a copy of a scanned object. Reverse engineering techniques involve the extraction of information about manufactured products. The conversion of data acquired by a scanning system to a CAD (Computer Aided Design) model is a complex but direct method, as opposed to a model created from scratch [16].

Optical methods are the most frequently used and are characterised by a high acquisition speed compared to other methods. There are four important types of optical methods: triangulation, interferometry, structured lighting and image analysis [15]. 3D body scanning is usually obtained using the optical method of triangulation.

The main disadvantage of the 3D scanning process is that the some of the details of the original element are usually lost, and those lost features must be recreated using shapes and curvatures. The surface modelling technique is used to recreate the form of an object, resulting in the creation of a hybrid model consisting of the surface and solid structures with the final details added [17]. A virtual model is obtained using a 3D scanner [18].

3D body scanning technology facilitates a detailed analysis of the anthropometric characteristics of the body, which is critical for an accurate computer-based simulation on the human body. It also assists in the acquisition of 3D data regarding an individual body in the format of point clouds, using implicit, parametric and triangulation methods. The data obtained can be used for continuous human model reconstruction from a measured point cloud or mesh of polygons. 3D body scan data provide a comprehensive and accurate set of measurements. Each measurement is provided individually for a particular scanned human subject. 3D scanners offer an unlimited number of linear and non-linear human body measurements, in only a few seconds, with greater precision and reproducibility compared to traditional physical measurements [19]. Point cloud or mesh data can be exported using 3D scanning software. After the data are imported to other CAD software, they can be merged and refined through virtual sculpting before being used to create NURB surfaces and to build a solid CAD model [4]. Because 3D scanners obtain millions of points, the human body model is created with a large number of details and high degree of accuracy.

The basic principle of adopting scan data regarding the human body in order to create a precise model is fairly new. 3D scanning technology and CAD systems are used in order to investigate the complex geometry of both the human body and clothing. 3D scanning technology is currently the most accurate and reproducible method according to Daanen et al. [13].

Because 3D body models are of significant importance in virtual try-on systems and applied for garment simulation, the study of 3D body modelling has great potential in both research and application [20]. Reconstructed 3D models of the human body can further serve as the basis for 3D virtual garment prototyping [20]. In addition to using 3D scanning and virtual simulation technologies for obtaining precise human body dimensions or the development of garments, a reconstructed 3D model of a scanned human body can also be used for the precise analysis of a garment's thermal properties in relation to the volume of air trapped between clothing layers [5, 6].

The laser-scanning triangulation method is a common, basic principle of whole-body scanning, with a laser light as the source and couple-charged device (CCD) cameras as the detectors of light movement on the surface of a body. It works by determining two angles and one side of the triangle. The laser light source is projected on the human body, while the light sensors simultaneously capture the surface by applying simple geometrical rules called triangulation. Due to this ability, 3D images are acquired using a stripe of light that is emitted from eight laser diodes onto the scanning surface. The laser light is viewed simultaneously from two points using an arrangement of mirrors, while (CCD) cameras record deformations during the process. The CCD cameras are positioned within each of four scanning heads and digitised. The cameras record surface information. The separate data files from each scanning head are combined in the software to create a complete integrated image of a scanned object [21].

Raw scan data are not sufficient for further use. Most 3D scanners are equipped with standard software for the visualisation, treatment and exporting of data [14].

Several problems arise while scanning human subjects:

- Maintaining a proper firm position, without moving, while performing the scanning procedure. To ensure scanning precision free of a subjects' movements in the same position, and to minimise scan errors due to motion, footprints should be marked on the surface of the pedestal inside the scanning booth. A subject must maintain the same upright position, stare at the same spot in the scanning booth and hold their breath to avoid changes caused by breathing [5]. The reference starting position of the arms is with arms hanging by the side of the body with the elbows straight and the palms of the hand facing inward.
- Marking the body while scanning any posture, beside the reference posture, is a difficult task. According to ISO 20685:2010, the chosen human subjects should be scanned in an upright standing position with the elbows straight and with the palms of the hand facing inward. However, some of the analyses regarding human anthropological measurements, particularly during ergonomic analysis, require different postures in order to validate body anthropometry or clothing geometry. The scanning area captured by CCD cameras can thus be too narrow. One example is scanning human subjects for vertical superior functional reach, simulating the full upper extension of the arm in the vertical position. The scan is unable to capture the whole human body during a single scanning procedure and multiple scans should be merged to create a simple human body model that will be analysed. Another problem is changes to clothing due to wrinkling and the shifting of clothing around a clothed subject while performing other body postures. If a scan must be cropped at a specified position, it will be hard for a scanning expert to mark the position where the scan should be cropped. It is even more difficult with clothing marking, as the clothing deforms substantially as the result of movements.
- The third problem is the reconstruction of missing scan data, which should be acquired with a great deal of knowledge of the human anatomy, and based on realistic physical proof. It is always better to take pictures of a scanned human subject in any of the selected postures to be able to realistically reconstruct a scanned object.

3D laser body scanners are usually the most precise. Most devices are four-column laser scanners with eight scanning heads that provide a 360˚ image of a scanned person in a 3D space over a time span of around ten seconds. They usually work within a temperature range of 15 to 30˚C to avoid the mechanical failure of the scanning system, and they usually have an average girth error of less than 1 mm and a point density of 27 pts/cm^2. Non-contact active 3D scanners use a laser to illuminate the object surface to measure distances or to recognise surficial curves. In contrast, whole-body 3D scanners are equipped with four wide-view, high-resolution scanners that rotate around a person to scan every angle.

3 CAD modelling and scan reconstruction

The next step is to convert a polygon model into an accurate 3D digital surface model suitable for use in a CAD system. CAD reverse engineering software is used to convert the 3D scan data of physical objects into watertight 3D digital models. 3D CAD tools are used for design, engineering and preparation for manufacturing, and for scan modelling.

3D CAD systems are divided into two main groups according to purpose: surface modelling and so-called solid modelling CAD systems [4]. Contemporary 3D CAD systems facilitate human body modelling on account of 3D scanning technology. This technology enables the acquisition of 3D data regarding an individual body in the format of point clouds, using implicit, parametric and triangulation methods. A human model reconstruction from measured point clouds is used as the basis of a CAD model for other applications, such as the user-fit interface of a product and CAD design [4].

Surface parameterisation is usually performed by CAD systems in order to obtain the 3D mesh surface. One of the most important steps in the parameterisation processes is texture mapping. The application of parameterisation involves scattered data fitting, the re-parameterisation of spline surfaces and the repair of CAD models [22]. 3D scanners generate polygonal approximation to a human model. Scanning technology facilitates the generation of a polygonal mesh as a network of connected triangular polygons to wrap the object surface. On account of this ability, it reduces point cloud data without compromising surface quality. For this reason, volume and surface area can be obtained.

Non-contact active 3D scanners use a laser to illuminate an object's surface to measure distances or to recognise surficial curves. Whole-body 3D scanners are equipped with four wide-view, high-resolution scanners that rotate around a person to scan every angle. Such a high-powered, precision scan is able to capture even the smallest details, such as hair, wrinkles on clothes and buttons. The scanning process generates millions of triangulated surfaces. Although 3D scanners provide detailed accurate geometric data from objects, they are limited to producing a discrete representation due to irregularities, discontinuity, a massive dataset and missing areas [23].

Each image is composed of a matrix of pixels whose value depends on the captured light intensity. The column data that corresponds to the maximum light energy is extracted in real-time using electronics. Each value comprises a digitised point based on special algorithms. The column resolution obtained by this process, combined with the triangulation angle and optical parameters, directly corresponds to the metric resolution and precision. There is, however, an irregularity due to light reflections that can be caused by the part being scanned, and due to uncertainty in locating laser points, which leads to the incorrect measurement of some points referred to as spurious points. These can be recognised because they are not connected to the rest of a scanned model.

Spurious or noisy points frequently arise when the laser scanning activity is carried out by the processing software and subsequent software operations must be performed to clean the point cloud [15].

The scan reverse engineering procedure includes different steps, typically point cloud data pre-treatment, point cloud blocking, contour extraction, curve fitting and surface construction [24].

The steps required in the reverse engineering procedure of the human body are as follows [24]:

Point cloud treatment (involves point cloud alignment, noise point removal, data reduction, point cloud location and point cloud blocking) through:

- point cloud alignment (not all the data points of a product can be obtained through one scanning because of its complex shape or large volume. The model must thus be moved or rotated and several single scans should be aligned),
- noise point removal (the limitation of measurement tools and measurement methods will produce some noise points that must be removed in order to ensure the accuracy of the results),
- data reduction (the reduction of data points),
- point cloud location (if the point cloud is not placed in a reasonable position, this may impact 3D reverse modelling, and thus requires the positioning of the point cloud), and
- point cloud blocking.

A. Curve treatment (involves the creation, construction, editing and analysis of curves).

B. Surface treatment involves surface construction using a variety of surface generation methods divided into two main categories (surface from cloud and surface fit with curve), surface editing (merge, extend, trim or re-parameterise) and surface analysis (checking of the surface smoothness and continuity).

Contemporary CAD software facilitates:

- multiple file format importing (polygons, point data and CAD formats),
- the integration and reconstruction of cloud of points and triangle meshes,
- the repairing of meshes using different tools,
- automatic surface creation,
- surface comparison and validation,

– model exporting for use in other CAD systems, and
– CAD model creation and visualisation.

3.1 Human body scan reverse engineering and 3D modelling

In general, CAD modelling is similar to the bio-CAD process and involves the non-invasive acquisition of images, imaging process and 3D reconstruction to form volumetric image representation and the construction of a CAD-based model. CAD-based solid modelling systems are usually represented as a boundary representation through non-uniform rational B-Spline (NURBS) functions. However, the direct conversion of scan data into a NURBS solid model is not a simple task [25]. The production of a copy of an existing object of complex shape is one of the typical applications of the integration of two modern computer-based technologies: reverse engineering and rapid prototyping [15].

3D scan data requires processing after it has been imported. Because the human body, whether clothed or unclothed, has an extremely complex geometry with a large number of details, the reverse modelling procedure is extremely multiplex and time consuming. The workflow to restore scan data to even begin the reverse engineering process thus requires a great deal of knowledge of the basic human anatomy. When working with any available software used to manipulate scan data, each operation can take a long time to process. The aim of such procedures is to prepare scan data for 3D printing and other applications. Scan data can be imported as mesh data or point data, and as any kind of model file (ASCII, obj. file, stl. file, dxf. file, etc.). Multiple scans are typically imported in order to get the high quality model at the end of reverse engineering procedure.

3.2 Importing and initial preparation of scan data

Raw scans can be saved in obj. format. Subsequently, multiple scanned obj. formats can be imported by the CAD software for processing and reconstruction (Figure 1). Other 3D CAD tools, which are usually intended for design, engineering and manufacturing preparation, can be a powerful tool for scan reconstruction and analysis. Scans should be aligned, combined into a single fused mesh and then reconstructed manually in stages to restore many of the surface features of the complicated human body geometry [5, 6].

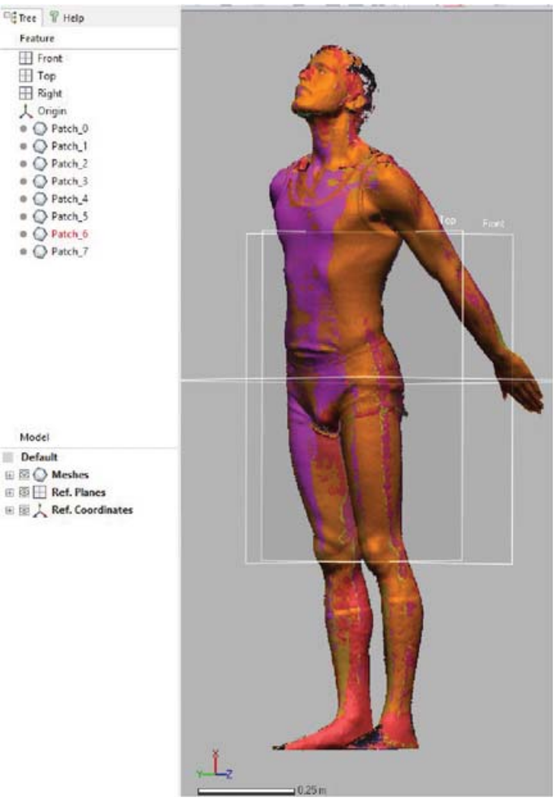

Figure 1: Imported obj. file of the scanned human body

3.3 Editing of scan data using CAD software and model creation

There are two basic ways to begin, one being the manual editing phase and the other being the automatic editing phase. The main disadvantage of current CAD systems is the slow speed at which they make necessary changes and the amount of time required for regenerating a complex parametric model. The other major problem is the complexity of the human body, with its many different features. It is almost impossible to restore the human body model automatically using any software. Even in the initial stage, in which files are imported to the CAD software where editing will be performed, there is no automatic mesh build-up. If it is possible to import the obj. data through automatic mesh build-up, the new model will have far more irregularities than the one imported manually with all the meshes fused gradually through manual editing.

The most obvious scanning errors are seen in the form of unnecessary points. Each cloud must be therefore cleaned. The clouds are then joined together, typically by means of manual editing and accurate positioning. Pre-arranged clouds or meshes are merged together. The triangle mesh can then be simplified. However, the process is time-consuming and inefficient [17].
Each scan usually consists of the eight scanned meshes, if a 3D four-column laser scanner with eight scanning heads providing 360˚ image is used (Figure 2).

Figure 2: Multiple polygon meshes of a scan

3.3.1 Fusing multiple scanned object files

Multiple imported scans should be fused together. This is performed through scan alignment (Figure 3). The mesh data is aligned with the coordinate system and then with the whole scanned object. Initially, a choice should be made between the reference mesh and moving mesh that will be aligned with one another. There is a special method of local alignment based on a selected point. When dealing with human body scans, this is by far the safest method, instead of relying on auto-alignment. Reference points are placed on the reference scan. The points of the same position are then applied to the corresponding moving scan. The moving meshes will align and overlap with the reference meshes to create the basis for global alignment. The safest way is to compare as many of the points on the moving and reference scans as possible to achieve a higher level of precision.
After the scans have been aligned, two or more scans should be combined into a single fused mesh (Figure 4). The aim is to create a unified mesh for further editing. Although the aim is

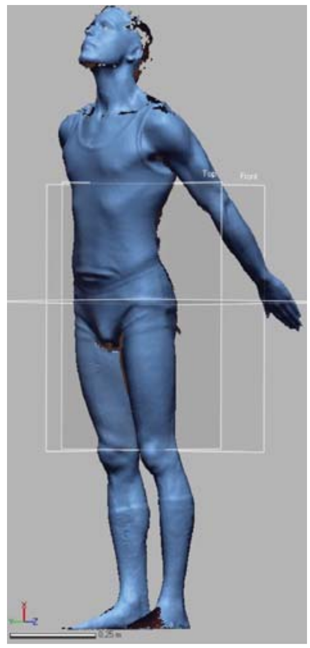

Figure 4: Multiple scan's meshes fused together

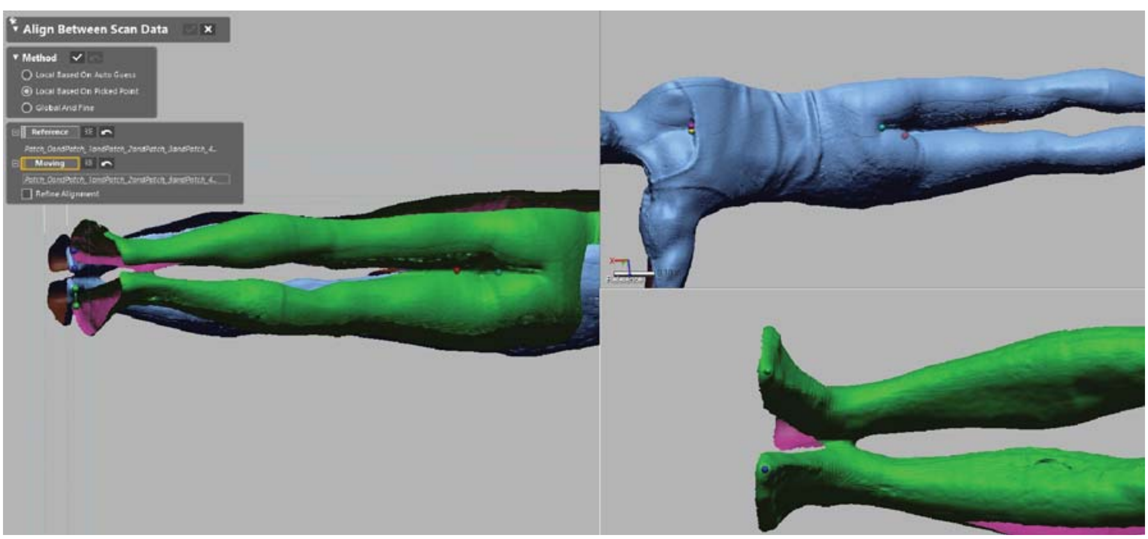

Figure 3: Multiple scan alignment

to create the unified mesh without holes and missing geometry, this is impossible when dealing with human body representations. Once the meshes have been fused, the editing phase can begin.

3.3.2 Defect healing and the restoration of missing areas

Editing usually begins with the identification of defects that could compromise the editing of scan data. The identification of defects illustrates all of the irregularities in the scan geometry that should be corrected during editing, such as intersecting. The two major concerns while editing are to correct those irregularities and to heal defects.
Major irregularities typically include:

- a non-manifold poly-vertex,
- folded poly-faces,
- dangling poly-faces,
- clustered poly-faces, and
- crossing poly-faces.

The major concern in this step is to fix these irregularities in order to improve the overall surface. However, the healing of irregularities can take a very long time, depending on how dense the mesh is and on the number of identified irregularities.
After minor irregularities have been fixed, major defects take centre stage. The first major defect is missing data and the remodelling thereof. If there are large areas of the scan left blank, an attempt should be made to fill those holes, taking full account of the complex geometry and the anatomy of the human body. There are two methods to accomplish this: by adding polygons to create the curvature surface or by adding polygons to create the flat surface. This is the most complicated step (except scan alignment), and it typically takes up to few hours to fill in all the missing areas in the correct manner (Figure 5).

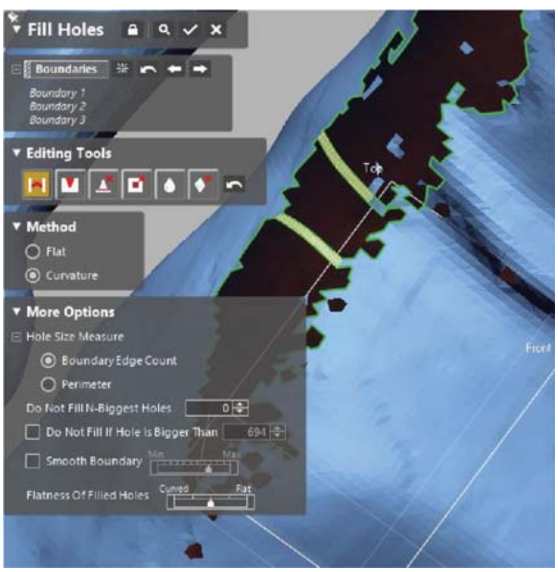

Figure 5: Filling of holes in order to heal missing areas

The process also involves a great deal of re-editing and correcting, as the restoration and scan reconstruction procedure depends on knowledge of the human anatomy. If there are large missing areas, the process of filling will require the addition of many curved bridges, hole boundary editing and experimentation. When editing boundaries around the missing area, the boundaries around the holes in the fused mesh are distorted, shrunk and smoothed. Each missing area can be edited by shrinking, smoothing, fitting, extending, extruding and filling in around the boundaries. Geomagic Design X software also provides the option of sewing the missing areas or splitting the fused mesh in order to remove unwanted data.

3.3.3 Surface editing phase

Once the unified mesh has been reconstructed in the proper manner to follow the real human body, surface editing can begin. The entire mesh surface should be edited using a global smoothing effect to create a smooth base. The fine details are then edited through multiple steps.
Global texture changes can be applied through smoothing operations, by enhancing the shape, and through manual editing by applying smart brush options to smooth and even the mesh roughness, to decimate or simplify the mesh and reduce the denseness of the mesh, to reduce the sharp angles of intersecting poly-faces, to enhance mesh details, etc.
However, work does not end there. In order to prepare the human body model for further use, the mesh must be continuously edited for output. The first step is decimation. This operation reduces the polygon count and mesh denseness, while retaining feature definition and quality. Most 3D software will require a model with a simplified mesh. This is achieved by applying a reduction percentage to reduce the density. The global remesh procedure is then complete. The global remesh will re-triangulate the entire mesh to create a new mesh appearance. It will also improve the mesh quality by cleaning all of the unnecessary

data and by finally creating a uniform mesh with fewer defects for other 3D programs. However, rewrapping the entire mesh will recreate the mesh at the underlying points, and by fixing defects and rough areas. The reconstructed model of the human body can be exported to other 3D CAD software for further use (Figure 6).

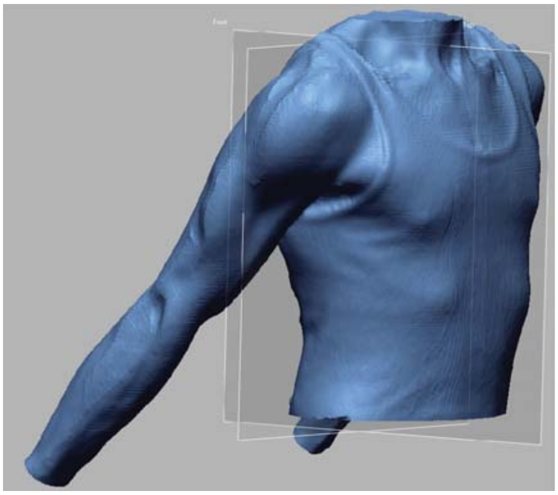

Figure 6: Reconstructed model of the human torso

4 Conclusion

The reverse engineering and modelling of the 3D scanned human body is a complex and time-consuming process due to the large amount of manual editing required, as the human body has a complex geometry with many details that require editing. It is almost impossible to restore the human body model automatically using any software. If it is possible to import the obj. data through automatic mesh build-up, the new model will have far more irregularities than the one imported manually with all the meshes fused gradually through manual editing. The main disadvantage of current CAD reverse engineering systems is the slow speed at which they make necessary changes and the amount of time required for regenerating a complex parametric model of the human body. 3D scan data require a great deal of processing, as the human body, whether clothed or unclothed, has an extremely complex geometry with a larger number of details. The workflow to restore scan data to even begin the reverse engineering process thus requires a great deal of knowledge of the basic human anatomy.

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