Comparative Analysis of Tools for Processing 3D and 4D Scan Data to Study Deformations in the Human Body

Ann-Malin SCHMIDT *, Yordan KYOSEV
TU Dresden, Institute of Textile Machinery and High Performance Material Technology (ITM), Chair of Development and Assembly of Textile Products, Dresden, Germany

https://doi.org/10.15221/23.19

Abstract

Methods for capturing human body motion and deformation are constantly evolving. In order to analyse human body deformations, it is necessary to capture the body surface by performing a 3D or 4D scanning process.
Various tools for processing and analysing 3D and 4D scan data are available as open source and commercial software. These software and programming languages are compared. Therefore, an overview of commonly used scan data output files is described. Scan data analysis parameters for body deformation analysis are presented. Different software is compared with respect to these parameters. Finally, a self-developed framework for automatic scan data analysis is described. By using the presented framework, the processing of scan data can be made more efficient, thus making a valuable contribution to the development of realistic human models.

Keywords: 3d body scanning, 4D scanning, automated processing, library, requirements

1. Introduction

Modern hardware is already capable of providing sequences of high frequency 3D scans [1], which are an excellent source for studying the dynamic fit of garments. The analysis of large data series [2] requires the processing of information from a larger list of larger files with 3D coordinates or polygons with colours. At present, such procedures can be effectively implemented only by using a programming language with a suitable environment, where the maximum number of already available libraries can be used.
A large number of studies have been carried out to identify specific features on series of 2D images (2D + time), static 3D scans for defined lengths or circumferences or for following markers, or series of 3D scans for autonomous driving (3D + time). For example, TANAX (Tomography-derived Automated network Analysis of Xylem) is able to automatically extract the vascular dimensions of the xylem network from MRI [3] while analysing slices of the structures. The original greyscale images are converted to binary images and a skeleton of line segments is used for analysis. Such methods can be successfully applied in biology and medicine with solid structures [4], but they are less useful for analysing the surface of clothing based on 3D scans.
The authors of this paper have already created several small tools (scripts) for automatic processing of 4D scans. One of them is a Matlab-based procedure for the analysis of series homologous meshes [5], where only the coordinates of the examined vertices are extracted from the individual frames and stored in a time-dependent list. These data allow the analysis of changes in the lengths of specific curves on the body [5], and it has also been applied to the angles of the hands of skilled people [6]. Based on the availability of more suitable libraries in Python, another Python-based tool was developed by the authors for the case of analysis of breast movement and breast-bra interaction [7]. The latest version of the processing software tool for the MOVE4D scanner from IBV [1] offers the possibility to analyse and visualise 19 predefined dimensions of the human body in time. The current version available to the authors does not allow the addition of additional user-defined curves or the recognition of specific features.
Outside of clothing, similar algorithms are being intensively developed, for example for LIDAR (Light Detection and Ranging Scanner) [8] for autonomous driving systems [9]. The authors report several open challenges and show that for such complex systems, the deep learning-based object detectors will play a crucial role in finding and localising the objects in real time. Although there are several works in these areas, a complete system that meets the requirements for clothing analysis is not public available and so there is a need for this development.
This paper presents a comparison of body deformation analysis tools. The main focus is on analysation parameters which are needed in the clothing development.

[1] Ann-Malin Schmidt, Ann-Malin.Schmidt@tu-dresden.de

2. Characterization of 3D and 4D Scan Data Output for Body Deformation Studies

4D scan data is a series of 3D scans taken over time. The output files are similar. Depending on the scanner used, the main difference is the availability of an automated homologous mesh. These homologous meshes consist of pre-defined avatars that are applied to the scanned surface. Table 1 shows a comparison of 3D and 4D data. The scanners used are the commonly used handheld 3D Artec LEO 3D scanner and the permanently installed MOVE4D 4D scanner from IBV.

The output file types can be divided into point clouds, meshes, surfaces with rigged skeletons, CAD files and measurement file types. The Artec Leo 3D Scanner has common output file types such as PLY, OBJ and STL. Compared to the Move4D scanner, it does not have the option to create a homologous mesh. In addition, it is not possible to capture motion files as they are available in FBX files on the 4D Scanner. The 4D Scanner does not have a direct export of CAD files, but these can easily be created using, for example, Meshlab as a converter.

Table 1: Comparison of Artec LEO 3D Scan data and MOVE4D 4D scan data

Scan data output type	3D Scanner (Artec Leo)	4D Scanner (Move 4D)
Point cloud	PLY C3D BTX	PLY
Mesh	OBJ STL	OBJ (Homologous) OBJ (non- homologous)
Surface with rigged skeleton	/	FBX BVH
CAD file	Step, IGES, X_T	/
Measurements	CSV	CSV

The most commonly used scan data output file formats are the PLY and OBJ. The PLY format is a point cloud format (Figure 1 (a)). It contains information about the 3D position of each point and thus can therefore contain texture information. The OBJ format is a mesh-based file format (Figure 1 (b)). The file format contains information about the processed mesh. The mesh is described in terms of its points (nodes), faces and texture.

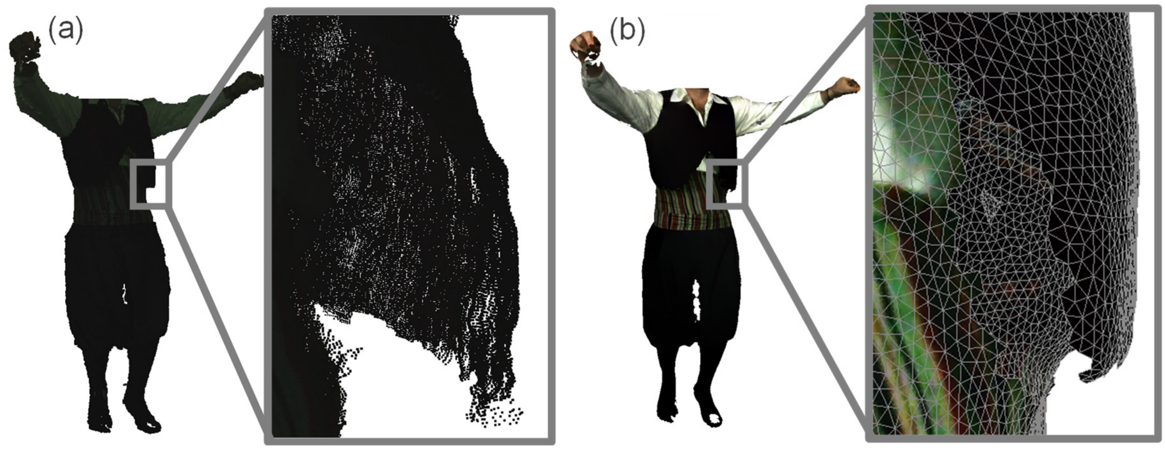

Figure 1: Comparison of an 4D Scan exported as a (a) PLY and (b) OBJ output file

Figure 2 shows a statically scanned Greek folklore costume. Figure 2 (a) is the costume processed as a mesh by the 4D scanner. Figure 2 (b) shows the processed mesh from the 3D scanner used. Both scanners capture the costume with a high level of detail. However, it can be seen that a higher level of detail can be achieved due to the closer capture distance of the handheld 3D scanner. Fewer areas of missing points are visible, and colors and small decorative details have a higher resolution. However, the 3D scanning process takes more time to capture and post-process.

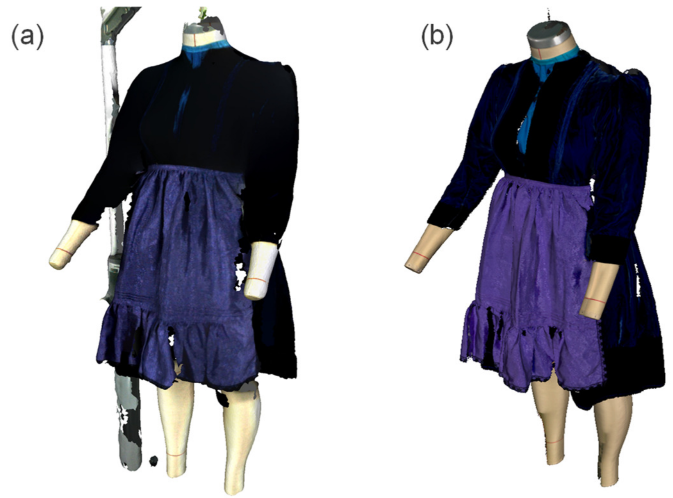

Figure 2: Comparison of the level of details of the (a) MOVE4D Scanner and (b) Artec LEO 3D Scanner of a traditional Greek folklore costume

3. Parameters for analysing deformations in the human body

Different parameters can be selected to analyse the deformation of the human body. These differences are due to the use of the data and the subsequent application. In

In particular, 4D scan data can be used to track the movement of specific points on the body as they move in three-dimensional space. The tracked point(s) can be pre-marked and/or determined by anthropometric measurements.

The distance measurement can be done in two ways. One distance measurement is the straight line between two or more points. The calculation of this measurement is simple and fast, and a large number of software tools have implemented it. The other distance measurement is the area distance. The length between two points is calculated based on the shortest path on the surface between them. The curvature of the body is taken into account in this calculation. This method can be used, for example, to measure skin strain due to movement. Clothing can be designed on this dynamic measurement to improve the fit and comfort.

Coloured surface motion is used in the apparel industry to analyse fit. The scan data must contain texture information. Wrinkles or a garment that slides up can be detected.

Volume measurement is used to analyse the effect of movement or time on the human body. Volume changes due to muscle activation can be studied. But also, volume changes due to medical treatment, e.g. leg volume while standing or wearing compression socks over time is an application. Thus, the pattern design and validation of an garment can be performed

Table 2 lists and describes generalised and commonly used parameters for analysing human body deformations are listed and described.

Using especially 4D scan data, the motion of certain body points can be tracked in their movement in the three-dimensional space. The tracked point or points can be marked beforehand and or can be set by using anthropometric measurements.

In particular, 4D scan data can be used to track the movement of specific points on the body as they move in three-dimensional space. The tracked point(s) can be pre-marked and/or determined by anthropometric measurements.

The distance measurement can be done in two ways. One distance measurement is the straight line between two or more points. The calculation of this measurement is simple and fast, and a large number of software tools have implemented it. The other distance measurement is the area distance. The length between two points is calculated based on the shortest path on the surface between them. The curvature of the body is taken into account in this calculation. This method can be used, for example, to measure skin strain due to movement. Clothing can be designed on this dynamic measurement to improve the fit and comfort.

Coloured surface motion is used in the apparel industry to analyse fit. The scan data must contain texture information. Wrinkles or a garment that slides up can be detected.

Volume measurement is used to analyse the effect of movement or time on the human body. Volume changes due to muscle activation can be studied. But also, volume changes due to medical treatment, e.g. leg volume while standing or wearing compression socks over time is an application. Thus, the pattern design and validation of an garment can be performed

Table 2: Analysis parameters to analyse body deformations

Analysis parameter	Description
Motion tracking of a point	Movement analysis of a pre-marked or anatomical recognizable point on the human.
Straight distance	A line is connecting two points to measure their shortest distance.
Surface distance	The shortest distance of two points based on their geodesic length.
Colored surface movement	The motion of colored surface is analysed to analyses e.g. clothing-body interactions.
Volume measurement	Volume changes of the human body during the motion is calculated.

4. Available tools to analyse human body deformations

4.1. Comparison of software tool – general

Referring to the analysis parameters presented in section 4, different programming languages and available software can be used for the analysis process. Table 3 presents and compares different software tools in terms of their ability to extend their functionality through programming, scan data handling and licensing policies. The programming option is necessary to realise automated and individualised analysis workflows. The scan data handling provides information on the use of scan data loading and processing. The technical information gives further details about the programming language/software. Especially the commercial or open-source licence is important for the usability for a large number of people.

The tools compared in Table 3 are only a selection of analysis tools. Open-source tools in particular have been included in this comparison. It is possible to combine several tools and thus increase the analysis possibilities.

Table 3: Comparison of the analyzation tools regarding their handling properties

Tool	Programming		Scan data handling			Technical information	
	Scripting possible	Extension possible	Loading OBJ PLY	Point Cloud handling	Mesh handling	Type	License
Matlab	Yes	Yes	Yes* (third party)	Yes	Limited	LCE	Com
Python	Yes	Yes	Libs	Libs	Yes	LCE	OS
C++	Yes	Yes	Libs	Libs*	Libs	LLL	OS
Rust	Yes	Yes	Libs	Libs*	Libs	LLL	OS
Blender	Yes (Python)	Yes	Yes	Libs	Libs	3DVE	OS
Rhino3D	Yes (Python)	Yes	Yes	Yes	Yes	3DVE	Com
Paraview	Yes (Python)	Yes	OBJ, PLY, FBX-not	yes	yes	3DVE	OS
MeshLab	Yes (Python)	Yes	Yes	Yes	Yes	3DVE	OS
Cloud-Compare	Yes (Python)	Yes	Yes	Yes	Limited	3DVE	OS

Abbreviations:

Libs:	Libraries required, but available	3DVE:	3D Visualization Environment
LCE:	Language and Computational Environment	Com:	Commercial
LLL:	Low Level Language	OS:	Open Source

4.2. Comparison of software tool regarding the body deformation analysis parameter

Table 4 compares the presented software tools in their realisation to investigate the described analysis parameter. Only the software already used by the author is included in the comparison. The comparison of the open-source software is made in terms of their standard user interface and in terms of their ability to extend their functionality through scripting. It can be seen that the programming languages are able to analyse all the presented parameters. In particular, the ability to use certain libraries and bindings to open-source software extends their capabilities. As these programming languages do not have a user interface like the other software presented, their usability is limited for users with programming skills. The software Blender, Paraview, Meshlab and CloudCompre are similar in their analysis tools. The software differs in its usability depending on the analysis tool. Since motion tracking and coloured surface movement involve the analysis of several scanned data over time, the software is not able to analyse these parameters within its standard user interface. However, this functionality can be added using their Python bindings.

Table 4: Comparison of the analyzation tools to investigate the analysis parameter

Tool	Analysis parameter				
	Motion tracking	**Straight distance**	**Surface distance**	**Colored surface movement**	**Volume measurement**
Matlab	Yes (self-developed library and/or third party)				
Python	Yes (self-developed library and/or third party)				
C++	Yes (self-developed library and/or third party)				
Blender	No	Yes	Yes	No	Yes
Paraview	No	Yes	Yes	No	Yes
MeshLab	No	Yes	Yes	No	Yes
CloudCompare	No	Yes	Yes	No	Yes

4.3. Description of the presented software tools

Matlab

Matlab is a commercial product, developed and maintained by The Mathworks, Inc, which was created to radically simplify the numerical computations and move them from the area of Fortran and C Programming into user friendly environment, which can be executed line per line (as interpreted language). It uses text files for the programs and simplified programming language and since is publication in 1984, is continuously extended with toolboxes. This was the initial first choice of the authors for investigations [2], because it allows loading of 3D files with own or several free third party libraries and quick 3D visualization of the data. It has as well own Point Cloud Processing toolbox, which can read PLY files, perform segmentations, register points and make some basic fits, too. For pure academic applications this is probably the fastest and the best way to develop additional libraries. If commercial application of the library is intendent, then the developer have to consider in the business plan the license fees for the Matlab itself and the Matlab Compiler if potential users do not have own Matlab licenses.

Python

Python itself is an interpreted programming language and very similar to Matlab. As interpreted language, it allows running single lines of code and observing the results, which is very efficient during the testing and development of new algorithms. After the first publication in 1991 it became more and more popular and today belongs to one of the most used programming languages for scientific computations. The interpreter is free and currently there are already very large number of libraries for image processing, point cloud loading, geometric data processing. From computational point of view, Python provides today the equivalent set of tools for 3D processing. It has the advantage of being free even for commercial use, contrary to Matlab; but it has the disadvantage, that the user has to take care about the compatibility between the versions of Python and the libraires, which sometimes become challenging task. In order to overcome this problem, the so named “environments” was introduced, so that the user can define separated environment for each project and in this way can work with different versions of Python and different libraries in the different projects.

C++

C++ is standardized both low-level and high-level programming language, which is used for fast computations. Larger part of the python libraries for image processing and numerical computations are available or are initially programmed on C++ and then ported to python, so principally from the selection of libraries there is no limitation or some disadvantage using C++ instead of Matlab or Python. The difficulty in implementing new libraries in C++ is the long learning curve for programmers, the need of definitions of all functions for access the variables and the need of compilation of the code in order to test it. Especially for development of 3D visualization and analysis applications, for each test or change of variables, additional time is required and the process of testing new features takes significantly longer than in Matlab or Python. This was the main reason not to choose C++ as language for the library.

Rust

Rust is a new, modern language, which considers to have all advantages of C++ which can be one of the future languages. It seems, that there are already enough libraries for mesh and point cloud loading and processing. It was not tested by the authors mainly due to limited time and personal resources.

Blender

Blender is free, open-source 3D computer animation software, which has its build in python scripting tool, can import and export meshes in various format and make realistic visualizations. It can be considered as tool where the results gets visualized, but at the current point the missing point cloud and mesh processing libraries inside makes the integration more complex and reduces the advantages of having useful graphical user interface. Anyway, it has the potential to be basis tool for working, enriched with additional libraries.

Rhino3D

Rhino 3D is used mainly from 3D designer and is one very powerful free form processing tool available at acceptable price for the artists. It has as well scripting functions both in forms of blocks (for people who are not willing to write pure code) and python and several integrated functions for analysis and import, but it seems to be suited for working mainly with one object and not with large series of files.

Paraview

ParaView is free, open source graphical user interface to the VTK Library, which is very powerful library for 3D visualizations in medicine and science. It provides import functions, actually currently without FBX format, larger list of predefined filters which can used for analysis and modification of the meshes and script recording tool. Principally, Paraview has the potential to be a front-end of a library for automated processing of 3D Data.

Meshlab

Meshlab is free, open-source program for opening, visualization and modification of meshes, with similar possibilites as Paraview. It can use own scripts and since the latest time can be run from python code as pymeshlab, and with this function is has as well potential to provide larger set of functions for main tool for analysis of list of 3D files.

CloudCompare

CloudCompare is free and open-source library and application, written in C++, with the main aim to compare two meshes, including measuring different distances there, registration of these and similar operations. It has several useful functions, but does not provide enough libraries to be main tool, it can be used as additional one library for processing to some of the previous mentioned.

5. Framework development to analyse scan data

A framework has been developed to analysis 3D and 4D scan data (Figure 4). The environment of the self-developed analyzation tool is written in python and MATLAB. The frame work can be sectioned into a data import, a data processing and a data analyzation. Depending on the data processing different analyzation methods are implemented. In a first step the location of the scan data to be processed in located and saved. Afterwards in a loop each frame to be processed is opened and the required data for the data analyzation are exported and saved. This can be for example vertex coordinates. In the data analyzation step the exported coordinates are processed in terms of movement tracking or length measurements. Finally, the analysed data are visualized. The framework can easily be extended. Several open-source binding like pymeshlab have been used.

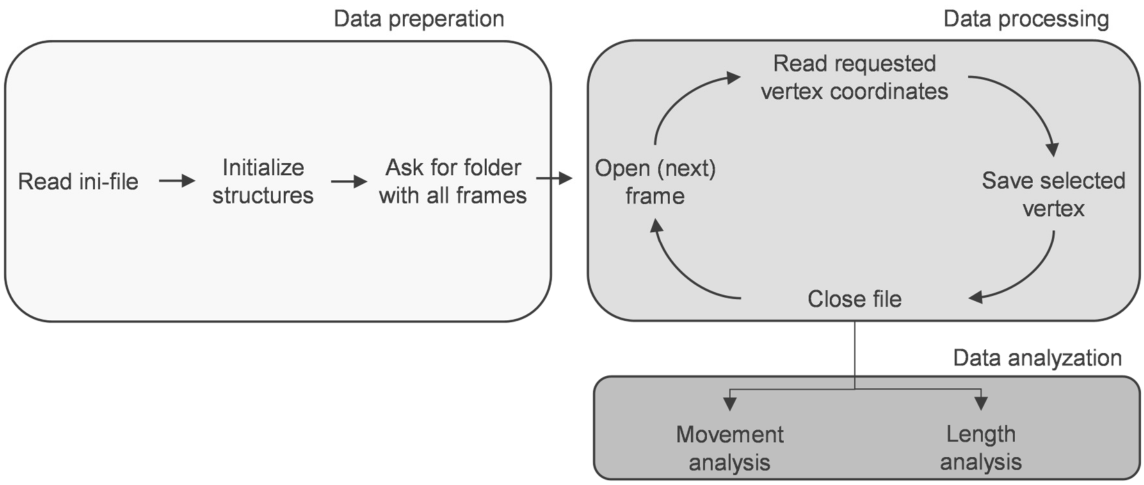

Figure 3: Workflow for a automated scan data analyzation

5. Conclusion

Different software was compared in terms of its ability to analyse body deformations. For this purpose, analysis parameters have been defined and described. Different software is presented and compared. It can be concluded that the presented programming languages have a great potential to be used for automated and individualised analyses. However, the open-source software presented, such as Paraview or Meshlab, show a high number of possibilities to also analyse the presented analysis parameters. This software has the advantage of an easy-to-use interface and no programming skills are required. Nevertheless, the combination of using a programming language to bind the software and customise its functions according to needs is the best option. A framework where this step has been done is presented.

Acknowledgement

Co-funded by the European Union, Project reference number 2021-1-EL01-KA220-ADU-000028466

References

[1] IBV (2020) MOVE4D. Instituto de Biomecánica – IBV, Spain
[2] KYOSEV Y, TOMANOVA V, SCHMIDT A-M (2022 - 2022) Method for Automatic Analysis of the Clothing Related Body Dimension Changes During Motion Using High-Speed (4D) Body Scanning. In: D'Apuzzo N (ed) Proceedings of 3DBODY.TECH 2022 - 13th International Conference and Exhibition on 3D Body Scanning and Processing Technologies, Lugano, Switzerland, 25-26 October 2022. Hometrica Consulting - Dr. Nicola D'Apuzzo, Ascona, Switzerland
[3] Brodersen CR, Lee EF, Choat B et al. (2011) Automated analysis of three-dimensional xylem networks using high-resolution computed tomography. New Phytol 191:1168–1179. https://doi.org/10.1111/j.1469-8137.2011.03754.x
[4] Zijdenbos AP, Forghani R, Evans AC (2002) Automatic "pipeline" analysis of 3-D MRI data for clinical trials: application to multiple sclerosis. IEEE Trans Med Imaging 21:1280–1291. https://doi.org/10.1109/TMI.2002.806283
[5] KYOSEV Y, TOMANOVA V, Spahiu T (2023) Processing Data from High Speed 4D Body- Scanning System for Application in Clothing Development. In: Sayem ASM (ed) Digital Fashion Innovations. CRC Press, Boca Raton, pp 99–123
[6] SADRETDINOVA N, KYOSEV Y (2022 - 2022) Method for Evaluation of the Motion Comfort of the Clothing for Deaf People Using of High Speed (4D) Scanning. In: D'Apuzzo N (ed) Proceedings of 3DBODY.TECH 2022 - 13th International Conference and Exhibition on 3D Body Scanning and Processing Technologies, Lugano, Switzerland, 25-26 October 2022. Hometrica Consulting - Dr. Nicola D'Apuzzo, Ascona, Switzerland
[7] SCHMIDT A-M, Schmidt R, Gonzalez GSI et al. (2023) Automated Investigation of the Breast - Bra Interaction Using 4D Scan Data and Oscillation Analysis. In: Scataglini S, Harih G, Saeys W et al. (eds) Advances in Digital Human Modeling, vol 744. Springer Nature Switzerland, Cham, pp 52–61
[8] Wolcott RW, Eustice RM (2014) Visual localization within LIDAR maps for automated urban driving. In: 2014 IEEE/RSJ International Conference on Intelligent Robots and Systems. IEEE, pp 176–183
[9] Balasubramaniam A, Pasricha S (2022) Object Detection in Autonomous Vehicles: Status and Open Challenges