Finite element modelling of textile-soft material interaction using 3D/4D scan data

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Abstract:

The interaction between textile and soft material occurs in different areas. It can be found in the clothing, medicine or automotive sector.
In this paper the textile-soft material interaction has been investigated using the example of the breast-bra interaction. 4D scan data of a test person dressed with a bra and unclothed were acquired in two scan poses. The scans were analysed by cross section comparisons. A finite element model was developed from these scans. Three different meshing methods were modelled.
A FEM model of a bra compressing the female breast was successfully developed. The breast deformation is modelled the best with a solid body model. In the validation comparison of the modelled breast deformation and the original breast deformation, a very good agreement can be seen.

Keywords: Soft body simulation, FEM, breast-bra interaction

1 Introduction

The interaction between textile and soft material occurs in different areas. In clothing, the textile interacts with the body. Especially when wearing tight-fitting garments, the interaction with the body is important for the function and comfort of the garment.
An important close-fitting garment is the bra. Physical activity causes the breast to move in relation to the female body and this can cause pain and discomfort [1]. Wearing a bra can reduce the relative movement of the breasts and lead to a higher level of comfort. In [2] the breast-bra interaction was analysed using 4D scanning technology. Different bras were compared during different running movements. However, it is not only the relative movement of the breasts that is relevant for the development of the bra. The pressure the bra exerts on the body is also important for comfort. Therefore, individualised FEM models are beneficial to study the interaction between a textile and a soft material to achieve an optimal alliance between soft body deformation and pressure distribution.
Different approaches have been used to model the breast-bra interaction (e.g. [3]). [4] modelled a rigid body and softened the breast areas. [5] modelled the whole thorax and breast with solid elements and added a skin surface layer. This research includes motion analysis but not textile-breast interaction.
Another big area is the interaction between compression stockings and legs. For elderly people, pregnant women, people with prostheses, a good fit and correct pressure contribution individualised to their leg and purpose is essential [6]. Therefore, an FEM model for predicting the textile-soft-body interaction is beneficial.
In addition to these examples from the clothing sector, the textile-soft-material-interaction is also relevant in the automotive industry. Foams are compressed by textiles to achieve a certain seating comfort. These cushions can be found in the seat, armrest or headrest. Thus, also here a FEM model is beneficial to investigate the influences of the textiles cut pattern and foam interaction.
In this paper the textile - soft body interaction at the example of the breast-bra interaction is presented. The implementation approach to incorporate 4D scan data of the human body into an FEM model is presented. Different modelling techniques of the soft human body based on scan data are showed. The deformation of the human body due to the compressive textile is validated using the 4D scan data.

2 Methods

2.1 Textile – soft material interaction investigated by 4D scans

In the first step the 4D Scan data for the investigation and modelling of the textile – soft material interaction is made. The Move4D Scanner by IBV is used. Twelve cameras are capturing the scan objects surface at the same time (Fig. 1 (a)). The simultaneously captured images are internally merged together and a 3D object can be exported e.g. as a mesh or point cloud. [7] The Move 4D scanner is used because of its high accuracy in scanning human bodies. A 3D-object is captured within milliseconds, which decreases inaccuracies due to breathing or moving the body during the scan process. Additionally, a homologous mesh can be exported and used for further Finite Element Modelling (FEM). A manual improvement of the mesh is not necessary and leads to a faster modelling time. In this research, the captured scans are processed as a homologous mesh and exported as an OBJ-file.

The scan plan contains one scan object, two different poses and two different dressing states. The scan object is a 29-year-old female with a 75C-bra size. One scan pose is the A-pose (Fig. 1 (b)) and the other scan pose is a T-pose (Fig. 1(c)). To compare the influence of the textile deforming the soft body, one dressing state is undressed and one dressing state is wearing a bra. In total four static poses are captured. The worn bra is made of an elastic material and is a medium supportive sports bra.

The exported scans are analysed by comparing horizontal and vertical cross-sections (Fig. 2). The cross-sections are placed to the breast points. The scans are aligned by the back part of the model. For the cross-section comparison the open source software ParaView [8] is used.

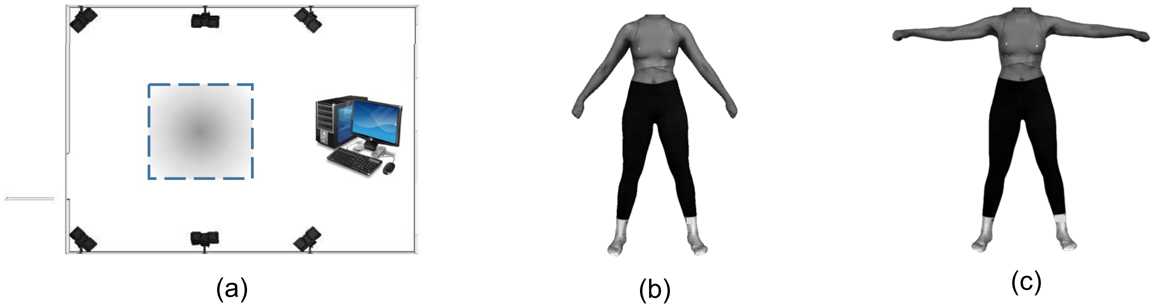


Fig.1: Scan set up: (a) 4D scanning lab, (b) A-pose bra, (c) T-pose with bra

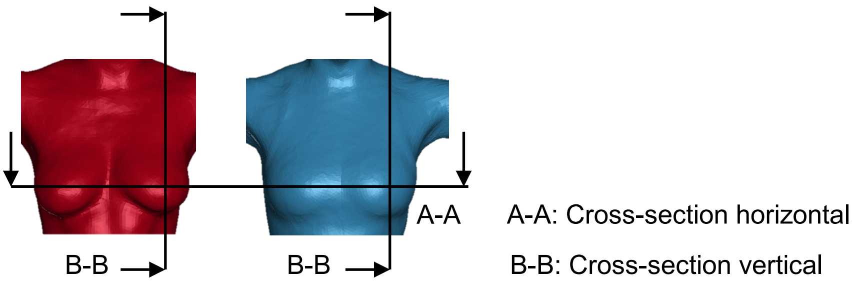


Fig.2: Cross-section analysis of scan data

2.2 Textile – soft material interaction investigated by finite element modelling

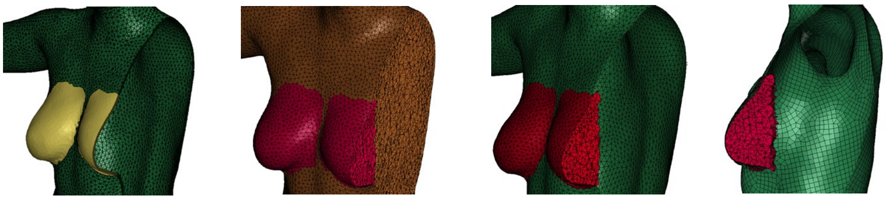
The in section 2.1. made scans are used to model the textile – soft body interaction. The aim is to model the breast deformation due to a bra and compare the deformed breast with the original scan data.

For the human body the scan of the unclothed body is imported into LS-PrePost [9]. The two scans of the two postures without clothing are imported and compared in terms of mesh errors. Due to the mesh errors presented in section 3.2.1. for further meshing only the T-pose scan is used.

In a processing step, the imported scan body is divided into a body and a breast part. The body part is set to rigid; the breast part is modelled soft. Three different meshing methods have been tested. They all have the same division in breast and body part.

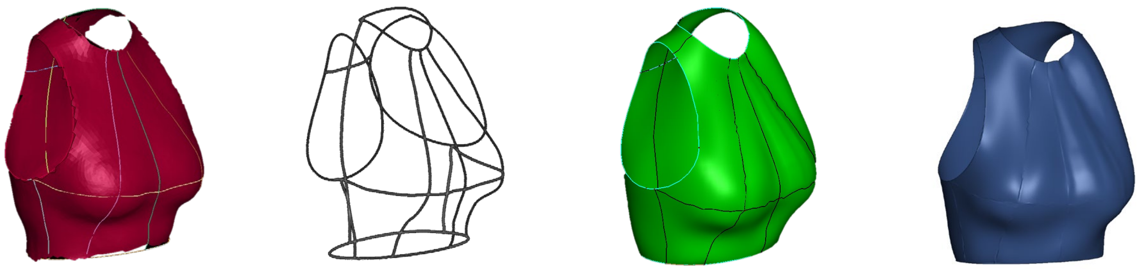
The first meshing method contains a full body shell mesh (Fig. 3 (a)). ELORM is set to 16. Two shell thickness are compared. One shell thickness is 2 mm and the other shell thickness is 4 mm. The approximated average skin thickness is around 2 mm [10, 11]. The values are based on this experimental tested skin thickness and double the thickness to improve the stability.

The second meshing option is a full body solid mesh (Fig. 3 (b)). The mesh consists of tetrahedrons with the ELFORM 13. The third meshing option (Fig. 3 (c)) is a combination of the previous presented meshing options. The breast is meshed with solid, tetrahedron elements and the rigid body with shell elements. The same element-formulations are used.
For all body-models the rigid body is modelled with `*MAT_RIGID` and the soft breast with `*MAT_VISCOELASTIC`. `MAT_VISCOELASTIC` has been investigated as an accurate and fast computing material model. Material parameter from [12] have been used.
The textile garment is remodelled by the original worn bra in the scan process. The scan of the test person in a A-pose wearing a bra is imported to LS-PrePost. Elements, which are not part of the bra are deleted (Fig. 4 (a)). The bra is recreated by drawing construction lined on the surface (Fig. 4 (b). With these lines a surface is reconstructed ((Fig. 4 (c)) and meshed by shell elements ((Fig. 4 (d)). The shell thickness is 1.1 mm, which has been measured in the original bra. ELFORM 16 is set. The material properties were firstly set to elastic with `*MAT_ELASTIC`, with a smaller E-Modulus of 50 MPa. The main focus is firstly to create a stable textile – soft body interaction.
The contact between textile and body is modelled `*AUTONATIC_NODES_TO_SURFACE`**.** After modelling the textile – breast interaction, the meshing models are compared in terms of stability and realistic deformation behaviour. Additional cross-section of the modelled compressed breast are compared to the compressed breast captured due to the scan process in section 2. 1..



(a) (b) (c)

Fig.3: Soft body modelling based on scan data: (a) full shell modelling, (b) full solid modelling, (c) combined solid and shell modelling



(a) (b) (c) (d)

Fig.4: Clothing reconstruction based on scan data: (a) Original scan data, (b) reconstruction lines, (c) surface reconstruction, (d) meshed clothing

3 Results

3.1 Textile – soft material interaction investigated by 4D scans

Figure 5 shows the comparison of the scanned subject with and without a bra in an A-pose and a T-pose. Figure 5 (a) shows the effect of a small change in pose on the deformation of the breast. The raised arms cause the breast to move slightly upwards. The activated neck muscles can be seen in the vertical section. Figure 5 (b) compares the cross-sectional areas of the A-pose and the T-pose wearing a bra. The effect of the change in posture is not visible. Only the activation of the neck muscles can be seen. This is because the bra has already lifted the breast. The bra-induced breast lift can be seen in Figure 5 (c) in vertical section (blue line). In addition, the breast deformation due to the bra can be seen in the horizontal section (Figure 5 (c) left). The breasts are not as close to the body as they would be without the bra.
In conclusion, a deformation of the soft material due to a garment can be captured by a 4D scanner. The A-pose and the T-pose should show similar deformations of the breasts when wearing a bra and slightly different breast cross-sections when unclothed. Accordingly, both scans can be used for further modelling steps.

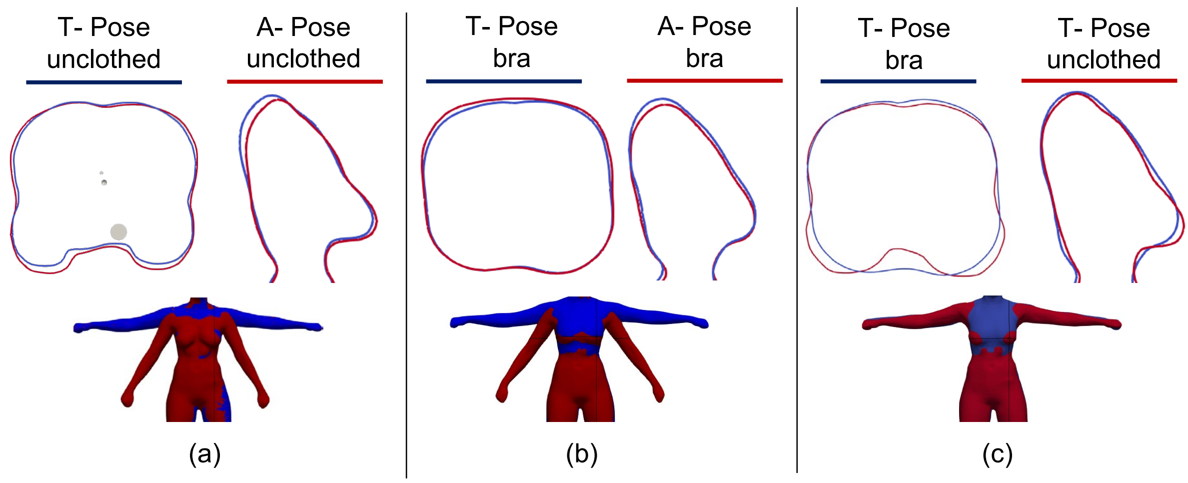


Fig.5: Comparison 4D scan data: (a) T-pose and A-pose: unclothed, (d) T-pose and A-pose: with bra and (c) T-pose: unclothed and with bra

3.2 Textile – soft material interaction investigated by finite element modelling (FEM)

3.2.1 Comparing the meshing process of two 4D scan poses

When importing both scan postures into LS-PrePost, it was found that importing and meshing the T-pose resulted in fewer mesh errors and a faster modelling process. As can be seen in Figure 6, the arms are closer to the body in the A-pose. As a result, the exported homologous mesh from the Move4D scanner has an overlapping mesh structure at the pits of the arms. This self-penetration requires manual editing of the mesh. Therefore, the T-pose meshes will be used in the following.

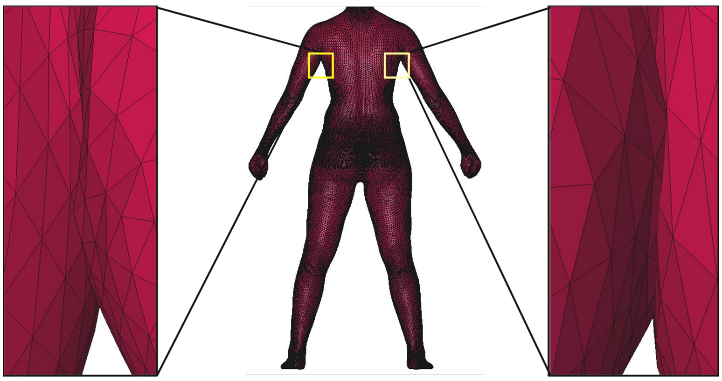


Fig.6: Mesh penetration of A-pose scans

3.2.2 Analysis of textile – soft body interaction

Figure 7 (a) shows the modelled textile soft body model. This bra fits tightly to the torso. Due to the compression fit, the breast is deformed. Figure 7 (b) - (d) shows the deformed soft body model due to the bra. The models in figures (b) and (c) are modelled entirely with shell elements and differ in their shell thickness. As expected, the model with the thinner shell elements (2 mm) has a shorter computation time, but the simulation is more unstable and the breast deformation has unrealistic folds. The full shell model with a thickness of 4 mm gives better results. A lifting effect of the breast occurs, but unrealistic notches are created. Figure 7 (d) shows the breast deformation of the solid modelled breast and the shell modelled body. It can be seen that this model has a more realistic breast deformation. However, the more the breast is compressed, the more the soft breast is pushed into the rigid body, creating unrealistic notches. However, for smaller deformations this modelling approach should give good results.

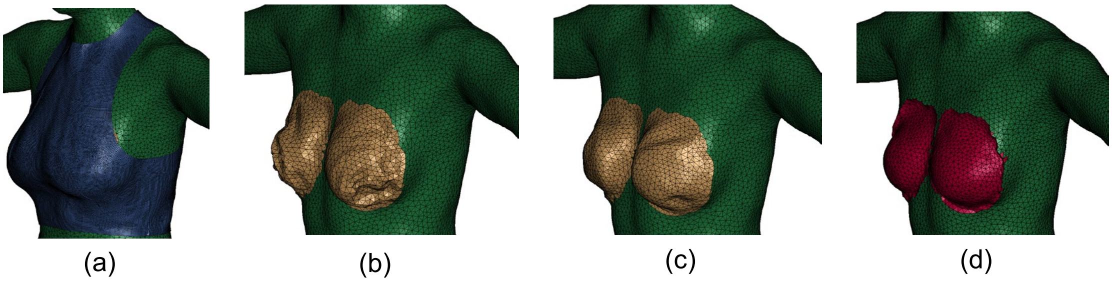


Fig.7: (a) Modelled bra and soft body, (b) deformed shell-body with 0.5 mm thickness, (c) deformed shell-body with 5 mm thickness and (d) deformed solid-shell-body

The best modelling approach in terms of simulation stability and realistic breast deformation is the full body model. The computation time of six minutes was the longest, but is still considered reasonable. Figure 8 (b) shows the compression and lifting of the breast. Parts of the soft breast tissue are moved to the upper part of the breast. The sides of the breast are compressed. Figure 8 (c) shows the x-y displacement. A displacement of up to 16 mm can be achieved, which is consistent with the experimental data.

These visual impressions are verified by comparing the vertical and horizontal cross-sectional areas of the FEM model of the breast deformed by a bra with the original scans of the subject wearing a bra. In Figure 9, the scanned bra-wearing subject in a T-pose is indicated by a black line. In Figure 9 ((a) left), this black line perfectly matches the lower breast area, showing the very good match of the breast lift. The upper side of the breast is slightly different, which may be due to the fit of the bra or the restriction of breast movement due to a too small defined breast area. In Figure 9 ((a) right) the horizontal cross-sections also show very good agreement between the scanned image and the model. Figure 9 (b) shows the cross section of the deformed solid shell model and the 4D scan. The breast is pushed into the body and therefore the upper breast area differs from the original scan data. The breast lift in the lower breast area is similar to the original data. However, with more restrictions for the soft breast area, this modelling approach is also promising.

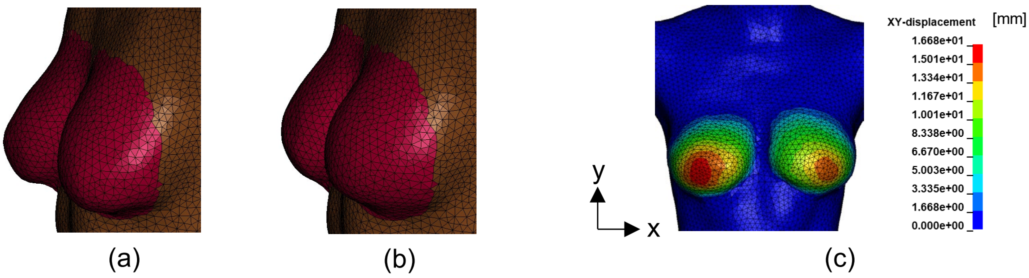


Fig.8: Full solid body model (a) initial model, (b) deformed breast by bra and (c) displacement map

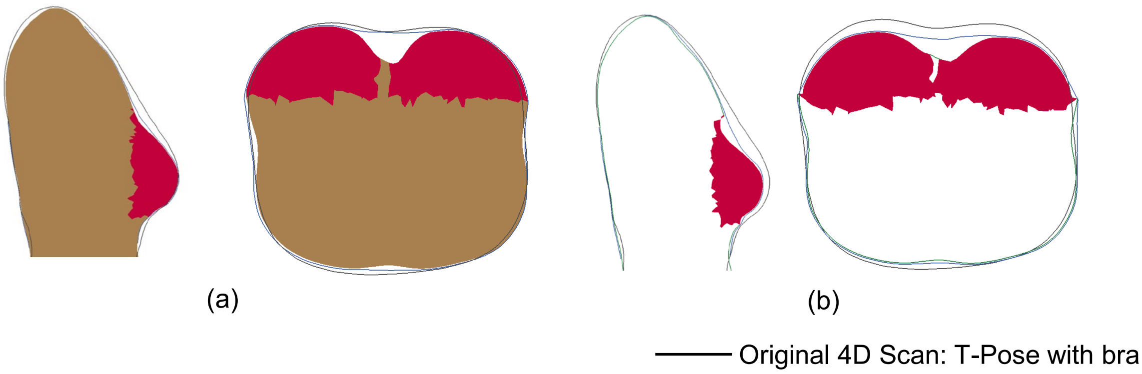


Fig.9: Cross-section comparison of modelled and original scanned breast deformation (a) full solid body model and (b) solid – shell body model

4 Conclusion

In this paper the textile-soft material interaction was investigated using the example of the breast-bra-interaction. 4D scan data of a subject wearing and not wearing a bra were acquired in two scan poses. The scans were analysed by cross section comparisons. A finite element model was developed from these scans. Three different meshing methods were modelled. Cross-sectional comparisons of the 4D scans were used to investigate a breast lift caused by the bra. In addition, a deformation of the breast can be seen.
A FEM model of a bra compressing the breast was successfully developed. A body model with solid elements gave the most realistic breast deformation. In the validation comparison of the modelled breast deformation and the original breast deformation, a very good agreement can be seen.
In the following research, the model can be extended with a movement. The dynamic breast movement can be analysed and compared with the breast movement scanned by the 4D scanner. The automatic 4D scan data analysis approaches from [13] can be used. In addition, the solid shell breast model is further developed as it is a promising method due to the division of a more detailed modelling in areas of higher interest (breast, solid elements) and a less detailed modelling approach in areas of lower interest (body, shell elements).
Furthermore, these modelling approaches can also be applied to technical textile-soft material interactions such as car seats or mattresses.

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