

A technique to improve the displaying quality of skin deformation caused by external force

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Abstract— This article continues the research on simulation of preclinical medical practice started by Do Nang Toan and Nguyen Duc Hoang [1]. In previous research, a technique to present colour of the human skin was introduced and in this rearch we continue improve the displaying quality of skin deformation cause by external force. Pressing on the skin and observing changes in capillary refill time (CRT) of human skin to evaluate the patient's health though terms of blood pressure, heart rate, etc. is an indispensable operation in medical examination and treatment. This articale mentions a technique to improve the detail of the deformation of the shape of human skin affected by external force without increasing the detail of the entire object. The proposed technique is applied on a 3D model simulating emergency medical practice of children in Vietnam and proved to be effective in displaying the deformation of the shape of human skin caused by the external force.

Keywords— Skin simulation, automatically tris generated, limited interactive area, virtual reality

I. INTRODUCTION

An area of skin under an external force such as a pressing action, in addition to the color being changed due to the amount of blood in the capillaries in the affected area being pushed out[1], its shape is also stretched belong to the direction of the external force. There are two approaches in simulating this shape transformationz: hand-drawn rendering by 3D animators [2] or physical simulations, called skin slides, by making the nodes on the grid represent the skin slide [3] [4], a number of functions are integrated into the nodes that allow increased fidelity and closer to muscle movement [5] [6].

In 2017, Jun Saito [7] proposed a skin slide simulation technique based on the feature that the effect only occurs locally in a small period of time: points in the affected area will slide to some point on one of the neighboring faces. However, when the points in the affected area slip away, the general trend is to stretch. The detail of the affected skin will mostly be "worse" than the adjacent skin, because the density of nodes, or meshes per unit area shown is smaller. The detail of the affected skin area will have problems in object representation if the surface representing the affected skin area is not smooth, the number of meshes in the skin area is small.

There are many methods for creating meshes for dynamic objects in three-dimensional space, but the most common are two main methods: meshing objects in quadrangle and triangle. Meshing for quadrangle objects is easier for processing and

editing, but not optimal in terms of storage and presentation. There have been many researchs in creating mesh systems for 3D objects quickly and detailedly without compromising on aesthetics [2] [8].Simulation of the subject skin with multiple layers has also been researched to describe the wrinkles of the skin through the overlapping of multiple color layers on the same surface, but only improves the visual effect without changing the real specificities of the subject's skin [9]. Changing the structure of the object shell is now mostly considered with problems related to mechanics and aerodynamics [10]

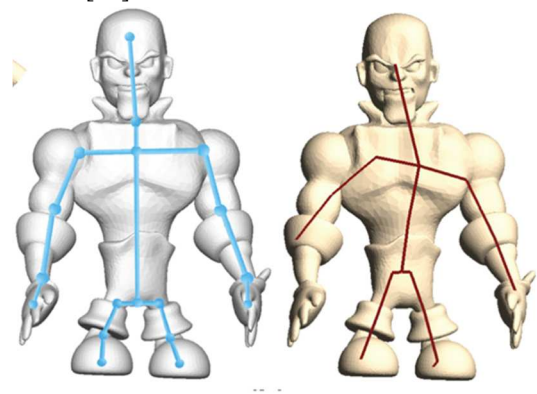


Figure 1. Automatic meshing algorithm for moving objects of Shaojun Bian in 2018

In the previous research, we proposed a skin simulation technique that improved the skin color rendering under external force [1]. The change in skin color under the influence of external force is more accurate based on the change in the coating but does not improve the detail of the subject and it also making the affected skin area streiched uneven

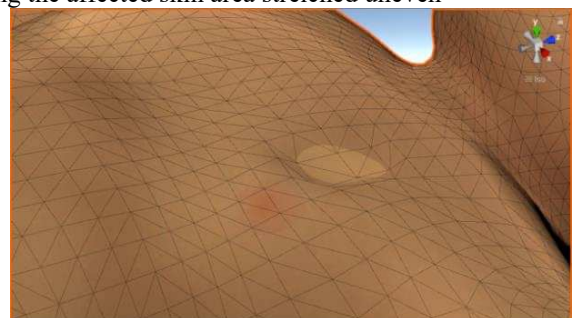


Figure 2. Algorithm for skin color change under external force

In this paper, we present a technique to simulate the change in shape of human skin under the influence of external force by increasing the extensibility of the skin affected by the pressure without increasing the detail of the whole skin. object. The rest of the paper is presented as follows: Section 2 presents the theoretical basis of the research. Part 3 is the proposed simulation algorithm. This is followed by testing and finally conclusions on the proposed technique.

II. BACKGROUND KNOWLEDGE

The background knowledge we present in this paper include the algorithm to calculate the deformation of the object shell that has been meshed in quadrangle in the process of manual shaping and the algorithm to automatically generate the mesh into a triangle from the given vertices on the object surface. The common feature of manual object shaping is that the mesh system of the object is usually quadrangle. However, to represent in detailed and optimally store the object's shell, triangle mesh is often applied.

To simulate the deformation of the skin layer under external force, we consider the skin layer as a shell that is homogeneous in composition, so the hardness of the skin layer is also considered to be homogeneous. This is commonly seen in 3D graphics products in application products such as games, movies, etc., and in current simulations. It allows simulation operators to focus on solving problem on a single object and is also enough for real-world cases. The theory in determining the deformation of the solid object has been researched in the machine industries, in subsequent research, this theory is also applied to 3D object simulation such as describing the mechanical changes of the human body and the clothing overlaid in the simulation of objects with clothes [11].

The finite element method was introduced in 1972 by Babuska, I., Rosenzweig, M.[12], and its application in calculating the curvature of the Reissner plate was proposed in 1991 [13]. In this paper, Mindlin and Reissner theory and extended finite element method [14] are applied in calculating deformation of the shells of objects with quadrangle mesh system.

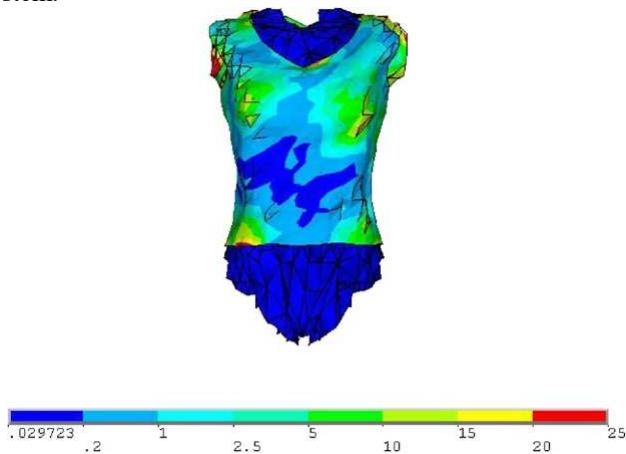


Figure 3. Simulation of pressure on cotton material on the human body

The normal plane to the midplane before the deformation will no longer be normal after the deformation. According to Mindlin and Reissner theory, the cross-sectional strain can be calculated.

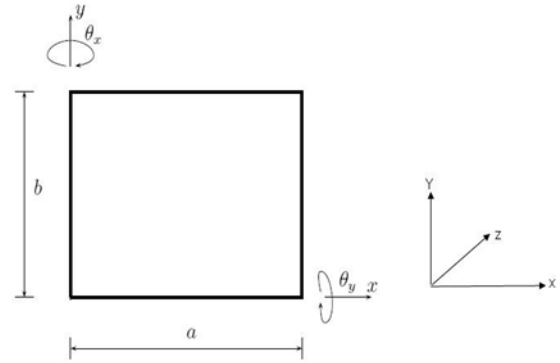


Figure 4. Plates, shapes and degrees of freedom

Figure 4. shows the plate, its geometry and degrees of freedom. The plate is placed on the xy plane, θ_x and θ_y exhibit rotations along the Y and X axes respectively. A plate has a thickness t and has a middle face at a distance $t/2$ from each side. We define the mid-plane position along the xy plane, $z=0$ is the center of the plate. The length of the plate is 'a' and its width is 'b'.

Assuming that transverse deformation occurs in the plate, the deformations and stretching will be determined by (1): The double normal plane to the midplane before the deformation will no longer be normal after the deformation. According to Mindlin and Reissner theory, the cross-sectional strain can be calculated:

$$\begin{aligned} u &= z\theta_y & \varepsilon_x &= z \frac{\partial \theta_y}{\partial x} \\ \gamma_{xy} &= z \left[\frac{\partial \theta_y}{\partial y} - \frac{\partial \theta_x}{\partial x} \right] \\ \gamma_{yz} &= \frac{\partial w}{\partial y} - \theta_x \\ v &= -z\theta_x & \varepsilon_y &= -z \frac{\partial \theta_x}{\partial y} \\ \gamma_{yz} &= \frac{\partial w}{\partial x} - \theta_y \end{aligned} \quad (1)$$

where,

u, v, w : are displacements in the x, y, z directions

$\varepsilon_x, \varepsilon_y$: is the long strain in the x, y direction

$\gamma_{xy}, \gamma_{yz}, \gamma_{xz}$ is the angular strain on the plane xy, yz, xz

θ_x, θ_y is the rotation angles in the x and y axes, respectively

The moment curvature relationship for the shear and shear strain is determined by:

$$\begin{Bmatrix} M_x \\ M_y \\ M_{xy} \end{Bmatrix} = D \begin{bmatrix} 1 & \nu & 0 \\ \nu & 1 & 0 \\ 0 & 0 & \frac{1-\nu}{2} \end{bmatrix} \cdot \begin{Bmatrix} \frac{\partial^2 w}{\partial x^2} \\ \frac{\partial^2 w}{\partial y^2} \\ 2 \frac{\partial^2 w}{\partial x \partial y} \end{Bmatrix} \quad (2)$$

$$\text{Where } D = \frac{Eh^3}{12(1-\nu^2)}$$

E is elastic Young's module

ν is the poisson coefficient

h is the thickness of the plate

for bending and

$$\begin{Bmatrix} Q_x \\ Q_y \end{Bmatrix} = \begin{bmatrix} Gt & 0 \\ 0 & Gt \end{bmatrix} \begin{Bmatrix} \gamma_x \\ \gamma_y \end{Bmatrix} \quad (3)$$

$$Gt = \frac{Eh}{2(1+\nu)}$$

for cross-sectional deformation.

where Q_x and Q_y are the cross-sectional force.

The stress on the cross section of the plate is shown in Figure 5.

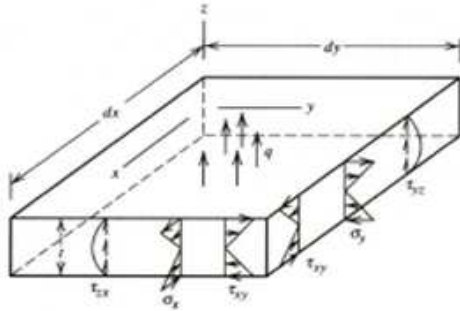


Figure 5. Stress and force distribution on the plate

Finite element method for plates:

Mindlin theory for plates is calculated in finite elements of plates. Displacement interpolation for plates is given by:

$$\begin{Bmatrix} w \\ v \\ \theta_y \end{Bmatrix} = \sum_{i=1}^n \begin{bmatrix} N_i & 0 & 0 \\ 0 & N_i & 0 \\ 0 & 0 & N_i \end{bmatrix} \begin{Bmatrix} w_i \\ \theta_{xi} \\ \theta_{yi} \end{Bmatrix} = N_d \quad (4)$$

where N_i is the shape function associated with the plate.

w is the long displacement in the z . direction

θ_x is the angular displacement about the x-axis

θ_y is the angular displacement about the y-axis

Most commonly used shape functions are Q4 and Q8.

III. THE SIMULATION TECHNIQUE

A. Technical analysis

A 3D object in the simulation environment is made up of a mesh system, when an external force is applied to the surface, the object will be deformed. If there is no interference to the affected mesh area, it is easy to see that the detail of the deformed area is equivalent to the number of meshes that make up the 3D object. To increase the detail of the deformed area, you can use the method: increase the number of meshes of the 3D object. However, this increases the weight of the simulation program, especially if an automatic meshing system is used and the subject is subjected to many continuous impacts, the object will have an uncontrolled increase in the number of meshes.

The proposed technique aims to increase the display quality for objects in virtual space subject to shape changes by forces acting on the surface. The basis of improving display quality in our research is increase the number of instantaneous grids in the affected area. Compared with the previously proposed techniques, this technique only increases the number of local

meshes at the affected area without affecting the entire object surface.

The main problems to deal with when doing this include: determining the point of application of the force and the main impact zone on the object surface, determining the deformation on the main impact area and showing it.

At the point of impact, find the nearest nodal point and apply the force on it with the same direction and direction as the applied force. Identify the main affected area and increase the number of peaks in this region to detail the deformation occurring. The displacement of the new vertex system is calculated through the finite element method described above. From the position of the newly created vertex system, the new mesh system is built and visualized. This mesh system will be removed from the object when the deformation returns to its original position (elasticity of the skin) so it does not weigh down the simulated object.

At the point of impact, delineate the main affected area (the largest deformation occurs in this area). For human skin, where the impact force is considered not to break the human body structure, the deformation of the skin is not more than 10cm, for 3D objects hierarchical according to the minimum number of constituent meshes:

TABLE 1. MESH RADIUS AFFECTED ON HUMAN SKIN.

Number of grids	5000	10.000	30.000	50.000	100.000
Main impact grid radius	1	2	3	4	5

Find the nearest point: The force acting on any point on the 3D object will cause deformation, but considering this force right at the point of contact, it will be difficult to calculate the displacement matrix of the nodes on the mesh system of object. There are some exceptions in finding this point of impact for the human skin such as the complex folds and faces of the skin. However, these cases will be handled with specific conditions, the article will only focus on solving general problems, the skin layer is considered to be relatively flat and plate-shaped. Algorithm to determine strain is presented in section II.

There are many methods for automatic mesh generation, such as Delaunay, Earclipping, ... but in terms of compactness in experimentation, earclipping is more commonly used [15]. By definition, a polygon is simply an ordered sequence of n points, V_0 to V_{n-1} . Consecutive vertices are connected by an edge (V_0, V_{i+1}), $0 \leq i \leq n-2$ and an edge (V_{n-1}, V_0) connecting the starting point and the end point. Each vertex shares exactly two edges. The only points where edges are allowed to intersect are vertices.

B. Description of technical details

Input:

The surface of the affected object is designed in the form of a quadrangle grid. The algorithm is installed on the vertex system of the quadrangle meshes on the model. The impact force is generated by placing a force vector at a point on the object surface.

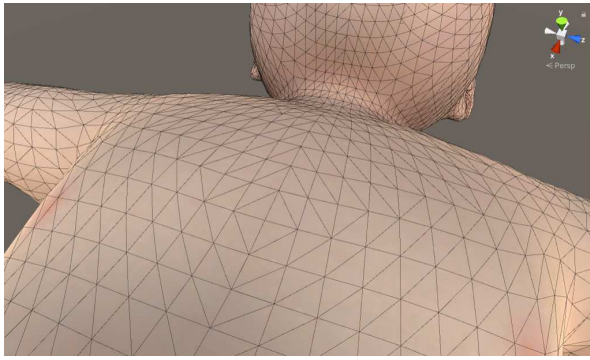


Figure 6. Child skin object surface represent as a mesh

To demonstrate that the new technique has better performance compared to the old method, we install the deformation algorithm but do not generate a new mesh on the testing object. The result of the surface deformation when not applying mesh generation is shown in Figure 6.

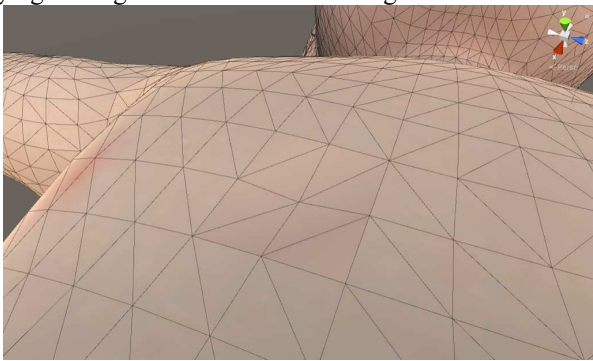


Figure 7. Deformed child skin object surface under force using finite element algorithm without mesh generation

Methods of implementation:

Step 1: From the point of placing the force on the mesh, find the nearest node and apply the force on that node

Step 2: Determine the area affected by the force on the grid system and increase the number of nodes.

The problem is to determine the points that are 2 neighboring nodes. Generate new nodes with optional density according to desired granularity. $k=1, 2, 3, \dots$ To increase the detail easily seen with the naked eye, choose $k = 4$

Step 3: Find the displacement matrix of neighboring nodes under the action of the force according to the finite element method

The steps to perform calculations through the finite element method on a flat plate according to Mindlin's theory are performed as follows:

A1: Discrete the sheet object into side-by-side quadrilaterals.

A2: Perform iteration for each element:
Find the element's flexural stiffness matrix

$$K_b = \frac{h^3}{12} \int_{A_e} B_b^T D_B B_b dA \quad (5)$$

Where:

h is the plate thickness

B_b is the deformation and displacement relation matrix

D_b is the bending coefficient matrix

A_e is the area of the element

Find the element's shear stiffness matrix

$$K_c = \frac{5}{6} h \int_{A_e} B_s^T D_s B_s dA \quad (6)$$

Where:

h is the plate thickness

B_s is the deformation and displacement relation matrix

D_s is the matrix of the shear coefficient

Find the element stiffness matrix

$$K_e = K_b + K_c \quad (7)$$

A3: Concatenate the element stiffness matrix, obtain the overall stiffness matrix of the whole system

A4: Find the nodal force matrix of the system

Here, for the sake of simplicity, we convert the force acting on the surface to the concentrated force acting on the bearing node.

A5: Find the transpose matrix

Based on the principle of minimum potential energy: For a conserved system, of all possible moves, the actual move with equilibrium will bring the potential energy to the extreme. When the potential energy reaches a minimum, the object is in stable equilibrium. We can build the equation:

$$Q = K^{-1} F \quad (8)$$

Where,

Q is the displacement matrix

K is the overall stiffness matrix

F is the overall nodal force matrix

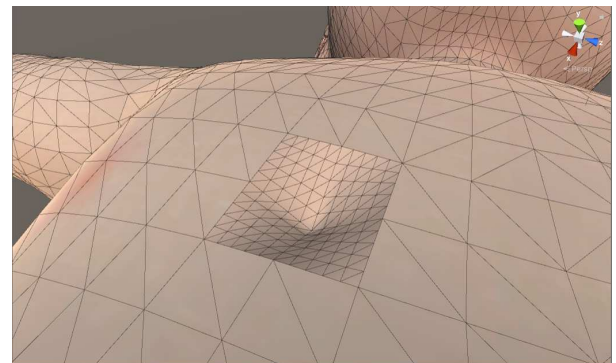


Figure 8. Deformed object surface under force using finite element algorithm with $k = 4$

Step 4: Build a new grid system on a new system of nodes using Earclipping technique

B1: Find the vertex M with the largest x value in the polygon

B2: Intersect the ray $M=t(1,0)$ with all edges $(,)$ of the outer polygon where M lies to the left of the line containing the edge (M lies inside the outer polygon). I is the visible point closest to M on this ray.

B3: If I is a vertex of the outer polygon, then M and I are covariates and the algorithm terminates

B4: Otherwise, I is the point above the edge $(,)$. Let P be the endpoint of the maximum x value for this edge.

B5: Look for symmetries of the outer polygon (excluding P if it happens to be symmetric). If all these vertices are outside the triangle (M,I,P) then M and P can see each other and the algorithm terminates.

B6: Otherwise, at least one vertex is in (M,I,P). Find the integer value R that is the smallest angle between (1,0) and the line segment (M,R). Then M and R can see each other and the algorithm terminates. In this step, there can be multiple vertices that reduce the angle, in which case they lie on the same ray with M being the origin. Select the re-vertex of this ray closest to M.

Step 5: Render the shape of the object based on the newly built mesh system

The rendering process uses the automatic renderer of the 3D object rendering software.

Output:

The output of the algorithm is a new mesh system of deformed objects under the impact of external forces. This mesh system can be retained after the skin is subjected to force, but our recommendation is to restore the subject's old mesh system to reduce the load on the system.

IV. EXPERIMENTAL RESULTS

The simulation is performed on a 3D model of a 1-year-old child's body with the number of meshes: 64,004 (tris); Reference height: 80cm; head length: 20cm; Sleeve length: 63cm.



Figure 9. 3D model for a 1-year-old child

The impact force is placed at any position on the model. In this article, apply impact force to easy-to-sink points such as abdomen, calves, biceps so that the effect can be seen most clearly. Areas of skin directly below that are bony such as the skull with small settlement or joint areas that vary in settlement depending on the current position of the body are more difficult to show results.

Step 1: Determine the node that puts the force

First, we apply the Raycast algorithm to the object surface to find the coordinates of the intersection of the ray with the surface and the position of the mesh that intersects the ray.

Then, calculate the distance from the intersection to each node of the found mesh and choose the node with the smallest distance as the node that applies the force.

Step 2: Define the impact area and generate new nodes

Find the points adjacent to the load-bearing node, here we find the nodes within a mesh from the point of application of the force. Choose $k=4$

Step 3: Find the displacements of the new nodes using the finite element method

Set the material's parameters:

Corresponding to each type of material, there will be a Poisson coefficient ν and elastic Young modulus E respectively. With materials being human skin, there is no detailed research on Poisson coefficient and Elasticity Module due to the complexity and diversity of the materials. To serve the test of the study, we choose the Poisson coefficient and the modulus of elasticity belong to rubber material (closer to the form of skin material):

$$\nu = 0.4$$

$$E = 1 \text{ GPa}$$

$$h = 0.1f \text{ (thickness of the plate)}$$

$$\text{length} = 6 \text{ (size of sheet } 6 \times 6)$$

Step 4: Generate a mesh for a new set of nodes using grid generation algorithms. Here we use EarClipping algorithm

Step 5: Update new node set, new mesh set for object to render

Experimental results:

It is easy to compare the simulated surface using the new technique is more detailed distortion than the original surface:

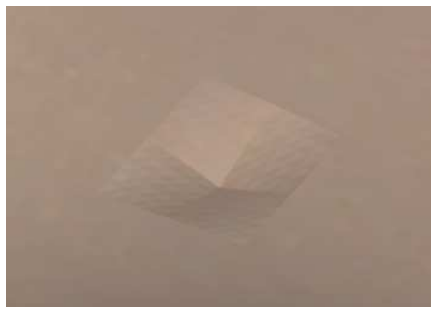
When the new technique is not applied, the surface is decomposed into very clear arrays according to the mesh edges, when using the proposed technique, the deformation is expressed as a set of straight lines gradually asymptotically becoming a curve.



(a)



(b)



(c)

Figure 10. Surface representation of object deformed under force
a) unaffected skin (b) impacted skin without proposed technique c) impacted skin using the proposed technique

V. CONCLUSIONS

Simulating emergency medical practice with children in Vietnam is an important issue for research on digital transformation applications in the medical industry. In particular, the manipulation of pressing on the skin and observing changes in the time of subcutaneous capillary filling (CRT) to assess the patient's health in terms of blood pressure, heart rate, etc., is an indispensable operation in medical examination and treatment. The article proposes a technique to increase the detail of the shape change of the skin under pressure by using the theory of deformation of Mindlin and Reissner plates combined with the finite element method to determine Specifies the transformation of the nodes on the 3D object surface mesh.

The proposed technique is applied on a 3D model simulating emergency medical practice with children in Vietnam and proved to be effective in displaying the change in the shape of the skin when subjected to external forces.

REFERENCES

- [1] Nguyen Duc Hoang, Do Nang Toan, Nguyen Tuan Minh, Pham Ngoc Toan, "A technique which consider the capillary refill time CRT for simulation of skin deformation and change of skin color caused by external force", *TNU Journal of Science and Technology*, Vietnam, 226(07): 50 - 58., 2021
- [2] Dmitriy Pinskiy, "Sliding Deformation: Shape Preserving Per-Vertex Displacement.", In *Eurographics (Short Papers)*, Hendrik P. A. Lensch and Stefan Seipel (Eds.). *Eurographics Association*, 1-4. <http://dblp.uni-trier.de/db/conf/eurographics/eg-ghort2010/html#Pinskiy10>, 2010.
- [3] Xiaosong Yang, Richard Southern, Jian Jun Zhang, "Fast simulation of skin sliding". *Computer Animation and Virtual Worlds* 20, 2-3 (2009), 333-342, 2009.
- [4] Dou Li, Shinjiro Sueda, Debanga R Neog, Dinesh K Pai, 2013, "Thin Skin Elastodynamics". *ACM Trans. Graph. (Proc. SIGGRAPH)* 32, 49:1-49:9, 4 (July 2013).
- [5] Sean Comer, Jacob Buck, Brice Criswell. "Under the Scalpel – ILM's Digital Flesh Workflow". In *ACM SIGGRAPH 2015 Talks (SIGGRAPH '15) ACM*, New York, NY, USSA, Article 10, 1 pages. <http://doi.org/10.1145/2775280.2792584>, 2015.
- [6] Andy Milne, Mark McLaughlin, Rasmus Tamstorf, Alexey Stomakhin, Nicholas Burard, Mitch Counsell, Jesus Canal, David Komorowski, Evan Goldberg, "Flesh, Flab, and Fascia Simulation on Zootopia". In *ACM SIGGRAPH 2016 Talks (SIGGRAPH '16) ACM*, New York NY, USA, Article 34, 2pages. <https://doi.org/10.1145/2897839>, 2016.
- [7] Saito, Jun; Simon, "Efficient and robust skin slide simulation", *ACM Press the ACM SIGGRAPH Digital Production Symposium – Los*

Angeles, California, Proceedings of the ACM SIGGRAPH Digital Production Symposium on – DigiPro'17, 1-6, 2017

- [8] Shaojun Bian, Anzong Zheng, Ehtaz Chaudhry, Lihua You and Jian J. Zhang, "Automatic Generation of Dynamic Skin Deformation for Animated Characters", *Symmetry*, 10(4), 89, 2018.
- [9] Pengbo Li, Paul G.Kry, "Multi-layer skin simulation with adaptive constraints", *MIG '14: Proceedings of the Seventh International Conference on Motion in Games*, Pg 171- 176, 2014.
- [10] A.V. Struchkov, A.S. Kozelkov, K.N. Volkov, A.A. Kurkin, R.N. Zhuckov, A.V. Sarazov, "Numerical simulation of aerodynamic problems based on adaptive mesh refinement method". *Acta Astronautica*, Vol 172, Pg 7–15, July 2020.
- [11] Ruomei Wang; Yu Liu; Xiaonan Luo; Yi Li; Shuai Ji, "A finite-element mechanical contact model based on Mindlin–Reissner shell theory for a three-dimensional human body and garment", *Journal of Computational and Applied Mathematics*, Vol 236, Issue 5, Pg 867-877, 1 October 2011.
- [12] Babuska, I., Rosenzweig, M., "A Finite element scheme for domains with corners", *Numerical Mathematics* vol 20, Pg 1- 21, 1972.
- [13] Joseph, P., Erdogan, F., "Bending of a thin Reissner plate with a through crack", *Journal of Applied Mechanics* Vol 58, Pg 842-846, 1991.
- [14] John Dolbow, Nicolas Moes, Ted Belytschko, "Modeling fracture in Mindlin-Reissner plates with the extended Finite element method", *International Journal of Solids and Structures*, Vol 37, Pg 7161-7183, 2000.
- [15] David Eberl, "Triangulation by Ear Clipping", *Geometric Tools*, Redmond WA 98052, Created 2002, Last modified 2015
- [16] Xinwei Shi; Patrice Koehl, "Adaptive skin meshes coarsening for biomolecular simulation", *Computer Aided Geometric Design*, Vol 28, Issue 5, Pg 307-320, June 2011.
- [17] Yan, X.; Ballu, A. "Assembly simulation of Skin Model Shapes: a comparison of two methods taking into account external forces". *Procedia CIRP*, 75(), 303–308, 2018.



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