Skin Model and Some Processing Properties of a Drilling Simulation in the Abdominal

Diego Colón[1], Suélia S. R. F. Rosa[2], Danilo S. Oliveira[3] , José M. Balthazar[4], Célia A. Reis[5]

[1] Polytechnic School of the University of São Paulo, Brazil
[2,3]University of Brasilia, Brazil
[4]Aeronautics Institute of Technology, Brazil
[5]State Paulista University, Brazil

Abstract— *We know that the skin is a complex organ, and there is a need to measure the complex mechanical properties of the human skin by means of a mathematical representation capable of simulating the deformations that occur during the movements of the body and surgical procedures. We propose for this modeling an analogy between: a) resistance represented by the shock absorber, in this study the modeling will be based on the compression cycle, which occurs once the needle is inserted in the skin, compressing it; b) elasticity given by a spring with a rigidity k; and c) mass, which in turn constitutes the systems inertia resistance to displacement. With the proposed analysis of skin perforation we aim to obtain a model by relating the force applied by the needle to its velocity in the hypodermis. The results shows the steps outlined to convert the analogous system of human skin into a liaison graph, Bond Graph. As discussed by the authors, all data concerning skin are embedded in uncertainty, due especially to the following factors: spatial distribution of the organ, build and dimensions of the individual and lack of specific literature. The skin was thus modeled through a methodology based on the comparison between the real system and a model of the real system. This paper shows the mechanical model that represents skin and the injection in a procedure of abdominal perforation.*

Keywords—abdominal perforation, bond graph, modelling, bioscience.

I. INTRODUCTION

The main part of the body specifically studied on this case is the thoracic region, since it is known that the skin has mechanical properties that vary according to the body region, having a non-linear behaviour. The reference [1] shows in her work a computational model for skin studying its mechanical properties as a result of age, with application focus in the area of cosmetics.

In this work, the skin is modelled as a multilayer structure, as is the reality. The layers are composed of different tissues with different properties. It is proposed structural model of skin in layers, an effect model for skin deformation using Hooke's Law and a simulation for wrinkles. The results are presented for the two-layer model, as a first approximation, and another threelayer model. The latter showed better results, in agreement with clinical observations. The work [2] displayed, however, higher correlation with the objectives of this work. A proposed model called ASPM (Artificial Surface Pain Model) consists of three parts: a mechanical model for pain using a two mass system, an elastic model for the skin and the piece of gates control theory.

The focus of this work was the application in robot control. The reference [2] considered the skin as an elastomer material such as isotopic [3], and expressed. The reference [4] using Bond Graph modelling tool also for a medical procedure: cutting process of human tibia by an automatic saw. Factors such as the depth and cutting accurately, bone exposure time to the overload and the accuracy of the wedge angle of the bone material being removed directly influence the success or the complications of the surgical procedure [5]. This way, the study of this system is useful for system responses to different situations become known in order to contribute to the development of devices that can improve the procedure.

This paper proposes a mechanical analogy of the human tibia model based on the Maxwell and Voight elements, and through this model is applied the Bond Graph tool to obtain the variables in the state space form. The use in applications in minimally invasive surgery such as uterine biopsies of prostate and others. Active robots, which are those able to move the instrument, are used in surgeries accurately transmitting the movement of the hands, filtering and eliminating the natural shaking and increasing surgical precision [6]. A common medical procedure for many medical treatments is the insertion of the needle through the patient's skin. The skin consists of three layers: epidermis, dermis and hypodermis. The epidermis is a multilayered epithelium practically devoid of extracellular matrix (ECM). The dermis is the thickest of the three layers of the skin and is responsible for most of the mechanical properties of its resilience. It consists of a connective tissue composed of fibroblasts that contains nerves, blood vessels and lymph vessels, and other important characteristics. The hypodermis is the deepest layer, composed of fatty tissue and functions as insulation, cushioning and storage [7].

According to their composition, be pierced by a needle, occurs on the skin a pressure distribution and tensile strength that can be covered by the robotic system as a control parameter. The needle insertion direction with guided by robot has the potential to improve the efficacy of current medical procedures, because it allows greater accuracy through more responsive control of the needle tip trajectory, and also the development of new approaches, due to the possibility of reaching targets not accessible by a path straight [8]. For this purpose, since it is a complex organ, there is a need to measure the complex mechanical properties of human skin by a mathematical representation capable of simulating the deformation that occurs therein during movement of the body and surgical procedures, given that this system has mechanical properties nonlinear, anisotropic and viscoelastic ranging from individual to individual, with the location in the body and with age [9]. Therefore, there is a need to represent aspects and essential parameters of this system by means of mathematical modelling in order to understand its functioning due to some important variables. Model a physiological system has as principle reproduce its action and thereby to assess the parameters that can be interfered with or varying this. Due to the natural features of the human body which are composed many complex interactions mathematically modelling physiological systems allows the development of a procedure and generating parameters that can be more effective in robotic guidance systems [10].

Among the modelling techniques in general, according to [11], it is necessary to find mechanisms for building models using concepts of the theoretical modelling and empirical modelling (gray-box). This paper proposes the use of Bond Graph Theory in the representation of physiological systems. Bond Graph theory is a unified representation of dynamic systems in which elements interact with each other via gates allocated within the system where the energy exchange occurs [12] [04]. As stated the reference [04], the method of obtaining the model via Bond Graph tool can be set in three steps: Specify the analogy system based on actual physiological model, determine the energy fields and define simplifying hypotheses and the input variables and system output.

After obtaining the model, there is a need to develop a prototype human skin simulating dynamic characteristics such systems for robotic assays needle guidance. It proposes to build this prototype, the use of biomaterial Latex, highly used in medical devices, which can be used to replace part of a living system or to function in contact with living tissue, aiming to replace, repair, or assist in organ function or damaged tissue in a safe, responsible, economically and physiologically acceptable way [13]. The use of latex also justified by the facility in shaping this biomaterial in difficult formats.

he introduction of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper.

II. MATERIALS AND METHODS

A biomaterial is any synthetic or natural substance that can be used as a treatment to replace part of a living system or to function in close contact with living tissue. Excluded from here pharmaceuticals or substances combinations [14] [15]. They are designed to repair and / or reconstruct parts or functions of organs and tissues can serve as matrix or not, vehicle, carrier, or enhancer of new tissue formation [16][17]. There are many studies that consider the latex application in various tissues as an implant material and all with satisfactory results, as in Roberts 2009 [18].

According to reference [19], Natural latex is composed of 36% rubber particles, 1.4% protein, 1.6% carbohydrates, 1% lipids, 0.6% of glycolipids and phospholipids, 0.5% inorganic components, 58.5% water and 0.4% other substances. The constituents that are not rubber particles are biologically important for the latex metabolism and affect physical and chemical properties of the fluid [20]. To the solid particles are removed, it is necessary that the latex is centrifuged, with the purpose of providing the final elasticity, strength and biocompatibility necessary to manufacture the proposed device. Justified the use of biomaterial Latex in this work, given their characteristics and previous worked contributions mentioned above.

It is intended to develop a simulator prototype of human skin made with the biomaterial latex, in order to evaluate the real characteristics of human skin and represent them in the prototype making use of physical and mechanical properties of latex. The prototype construction characteristics will be evaluated by testing needle in the laboratory.

In this section will be described the preparation protocol of the skin prototype made of biomaterial-based latex. The procedures will be detailed and explained.

III. PARAMETRIZATION MODULE

The main requirement of the prototype is to reproduce the characteristics of human skin for simulation purposes. Therefore, it is necessary to correlate such properties with characteristics than latex biomaterial product confers its derivatives.

For model simplification purposes, the sub-layers fibrous and lamellar blade belonging to the hypodermis layer will not be characterised. The choice of materials was accomplished intuitively looking for materials whose physical composition resembled the characteristics of the constituent cells of each layer. Each layer separately were prepared and after this procedure, the layers were bonded using latex to dry at room temperature. To each layer were applied one specific temperature and time to impart the characteristic of softness or hardness, according to their actual texture. The hypodermis, for example, as form a soft layer, was subjected to room temperature. They resistant layers such as stratum corneum, stiffer, were dried in the oven.

IV. DEFINITION OF MANUFACTURING PROTOCOL

The softness and hardness of the latex are characteristics that can be modified with the addition of water. The pure latex confers greater resistance layer, whereas the diluted latex is softer. Latex specifications used to manufacture the prototype are: brand Ki-Latex, pre-vulcanized, natural, acquired in the domestic market. As a first procedure, at three plastic containers the following volumes of water and latex were mixed and stirred: 1 Container: 50 ml latex, 15 ml water, 2 Container: 50 ml latex, 35 ml water, 3 Container: 50 ml latex, 0 ml water.

The containers were covered with foil and transparent PVC film to reduce exposure to light and air, avoiding premature vulcanization. The environment temperature was 33.9ºC. The latex application methods used in materials were drip, spreading and baths. The number of baths was determined according to the thickness of the layer. More resilient layers were prepared with the latex of the container 3, intermediate resistance layer with the container 1 and soft layer with the latex of the container 2. After latex application on the material, the system was brought to the greenhouse, depending on the layer, for a specified time. The oven used was from the Marte brand, set at 50ºC.

The materials choice additional to the module of each layer was accomplished based on the characteristics of cell constituents of the layer. For example, the sublayer reticular of the dermis is the layer where the blood vessels present, lymph, nerves and sensory organs, the sewing thread seemed a good choice to represent the shape of the vessels. That is, attempted to combine the features of each layer of cells with a material that present such characteristics. For the dermis, three sublayers were prepared separately: two of these layers, made with the sewing thread stretched on a metal plate and the other forming small clusters with the sewing line, immersing them into the latex. These agglomerations represent nerves, glands and sensory organs. It was noticed, in the making of the layers, the disposal system inside the greenhouse has direct interference in the final characteristics of the module.

Three modules were made to the stratum corneum, two arranged inside the greenhouse hanging with metal hooks, and others in direct contact with the metal surface of the stove. The module in direct contact with the surface of the stove proved to be more hard, tough and clearly with marks from the contact surface. It was decided, then, to have the materials hanging inside the greenhouse. Only the layers in which vulcanization was made possible by the ambient temperature, the materials were arranged horizontally at rest. Here, a simplification was made in the model referring to the thicknesses of the layers. As the thicknesses are extremely small, it becomes difficult to manufacture layers much thicknesses in the laboratory, so we chose to focus on the cell shape aspects, strength and function layer, such as waterproof and cushioning. It should be noted that the greenhouse temperature was hovering over the proceedings.

V. RESULTS

So that the data from experimental trials were captured, the design of a circuit for the acquisition of these signals and a program to process that data through the microcontroller was essential. The following will describe the devices and circuits used for this purpose. The sensor used for acquisition was the FlexiForce A201 model, Tekscan manufacturer. This sensor is used in applications to detect and measure force variations applied to a sensitive area, to detect contact or touch. The choice of sensor is justified by its flexibility, good linearity and accuracy, by suit a scope of extensive powers and the simplicity of their conditioning circuit.

Specifically in this case, has the purpose of isolating the stage relating to the stage of acquisition sensor circuit relating to the micro-controller, and connect them. Two important features of this configuration is the high input impedance and low output impedance, to ensure that the V_{in} voltage is present at the buffer output. The microcontroller used to perform the manipulation of data captured by the sensor was the MSP 430 eZ430-RF250 from Texas Instruments manufacturer. Its function is to collect the data captured by the acquisition circuit. This development tool has the hardware and software modules needed to perform wireless communication, sending the collected data and getting through the receiver module coupled to a USB recorder, connected to the laptop. The micro-controller is powered with two AAA batteries. The following is a schematic of use of the micro-controller terminal, which receives the signals from the acquisition circuit.

A. Computer Simulations: Drilling Force

Fig. 1a shows the final circuit used. As already explained above, FlexiForce were used five sensors each with its conditioning circuit. That way the final circuit is able to capture the signals generated by FlexiForce sensors and send them to the computer via wireless communication and enables the data storage on an SD card, this module not used in this work. The components used in the modules of this work were: 5 force sensors FlexiForce A201, 1 MSP 430 eZ430-RF250, 1 CI LM324, TL061 IC 1, 1 voltage regulator 78L33, 5 33K resistors, 2 AAA batteries, two resistors 4, 7K? used by the real time controller (RTC). The TL061 IC was used only due to insufficient number of available operational amplifiers in IC LM324. Possession of differential equations arising from mathematical modelling of a system, simulations can be made to study their behaviour. For this, we must choose a scenario (initial values, boundary conditions, variations planned) and solve the equations with this model, even simplified, show system behaviour. The piercing strength was simulated with the parameters used in [21], which are shown in Table 1, and the behaviour of this force is shown in Fig. 1b.

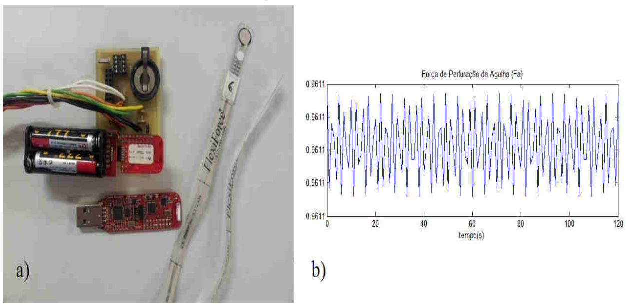


Fig. 1 - a) Made circuit used in laboratory testing. b) Behaviour drilling force.

Table 1 - Parameter simulation drill strength.

Parameter	Value
K	39.1×10^{-8} [N/m]
X	0.0008 [m]
α	1
E	1529.57 [N/m²]
I	0.5 [kg.m²]
L	0.050 [m]

For carrying out the experimental tests on human skin, we used two types of the needle shown below. The difference between them is present in calibre. In Fig. 2 is illustrated the abdomen outline where the needle will be pressed for data acquisition using the circuit described in previous sections.

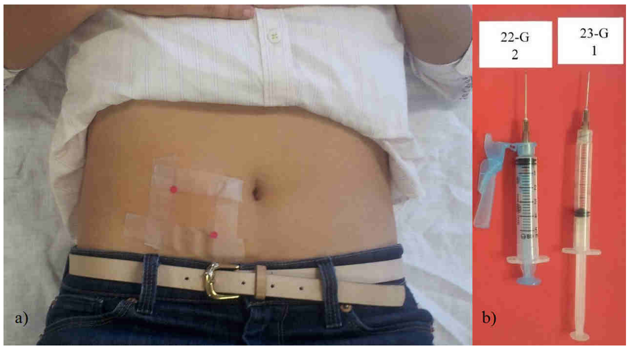
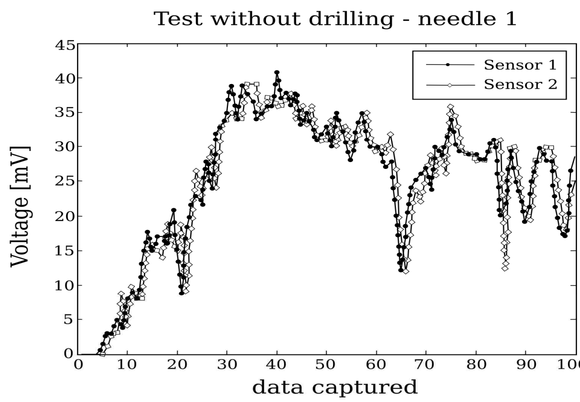
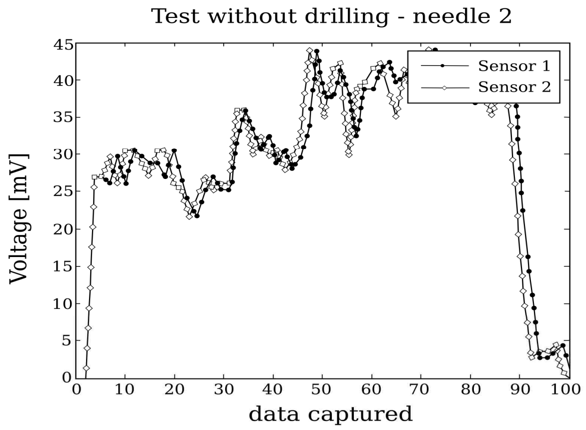


Fig. 2 - a) Place Test. b) Needles used in the experiments on human skin.

Among the five sensors of the acquisition circuit, only two were used to perform signal acquisition. The sensor was fixed with adhesive tape on the centre of the region bounded not to generate noise by movement, and the needle was pressed on the sensor surface against the skin. This procedure was done for the two sensors, each one being pushed by each needle separately. As a result, the captured data were not related to the propagated force in the inner skin layer but over the surface. The acquisition in the inner layers would only be possible if the assay was performed on cadaver body, so that the force sensor could be inserted into the human body.



(a)



(b)

Fig. 3 - a) Data captured from the trial in human skin with the needle 1. b) Captured data in the test on human skin with the needle 2.

The results achieved in the layers production of human skin derived from latex, demonstrated here in the Fig. 4, illustrates the complete prototype, with the addition of all layers made separately to form this final compound.

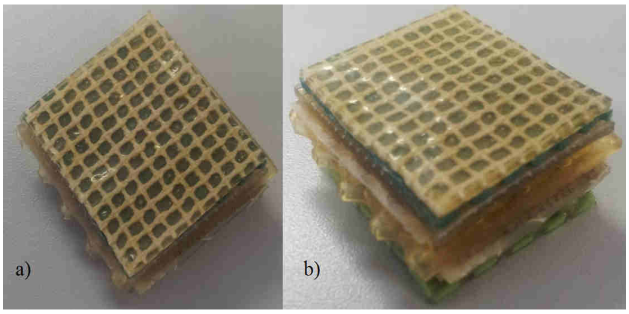


Fig. 4 - Prototype skin made. a) Top view. b) Side view.

After the prototype made of latex derived human skin, assays were performed with two types of needles described for the tests on human skin without perforation. The prototype assay was performed by pressing the central region, but without perforation so that the conditions of the tests were the same for results comparison purposes, Fig. 5.

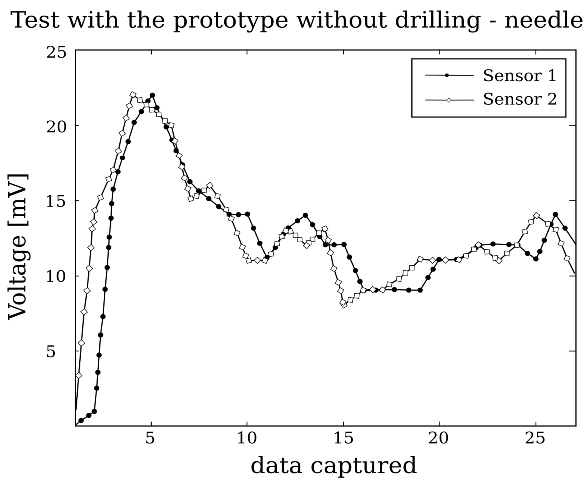


Fig. 5 - Captured data in latex derived skin with a needle 1.

VI. CONCLUSION

In the review of the literature performed is concluded that there is no standardization of a mathematical model that describes the dynamic skin mechanism. Were proposed through this research, two other models to be evaluated from this perspective. Furthermore, it has implemented a prototype of human skin derived from biomaterial latex to be evaluated as a simulator option for needle by piercing procedures.

With reference to the prototype implemented with the biomaterial latex, it is observed that the final prototype led to a higher resistance than that of human skin. This indicates that the idea to fabricate each layer may not seem like a good option due to the layers thickness and the difficulty of achieving these thicknesses in the laboratory.

ACKNOWLEDGEMENTS

The authors thank the University of Brasilia, in Brazil, for their support. The authors would like to thank an anonymous referee for pointing out several mistakes in a preliminary version.

REFERENCES

[1] Magnenat-Thalmann N, Kalra P, Leveque JL, Bazin R, Batisse D, Querleux B. A computacional skin model: fold and wrinkle formation. IEEE Transactions on Information Technology in Biomedicine, Volume 6, Issue 4, December, 2002.

[2] Matsunaga N, Kuroki A, Kawaji S. Superficial Pain Model using ANNs and its application to Robot Control. Proceedings of the 2005 IEEE/ASME International Conference on Advanced Intelligent Mechatronics. Monterey, California, USA, 24–28 July, 2005.

[3] Kinoshita G, Mori M. An Elastic Model of Skin and Some Properties on the Variable Threshold Processing of an Artificial Tactile Sense. Journal of the society of instrument and control engineering, Volume 8, Issue 4, Japan, 10–17, 1972.

[4] Rosa SSRF, Altoe ML. Bond Graph modeling of the human esophagus and analysis considering the interference in the fullness of an individual by reducing mechanical esophageal flow. Revista Brasileira de Engenharia Biomedica, Volume 29, Issue 3, Brazil, 86–297, September, 2013.

[5] Rosa SSRF, Souza KF, Urbizagstegui PAA, Peixoto LRT, Rocha AF. Modelagem Matematica da Tibia Humana usando Bond Graph. Revista Brasileira de Engenharia Biomedica, Volume 29, Issue 4, Brazil, 1–15, December, 2013.

[6] Bann S, Khan M, Hernandez J, Munz Y, Moorthy K, Datta V. Robotics in surgery. J AmColl Surg, United Kingdom, 196–784, 2003.
[7] Chen M, Przyborowski M, Berthiaume F. Stem Cells for Skin Tissue Engineering and Wound Healing. . Crit Rev Biomed Eng. 399–421, 2009.
[8] Reed KB, Majewicz A, Kallem V, Alterovitz R, Goldberg K, Cowan NJ, Okamura AM. Robot Assisted Needle Steering. Robotics and Automation Magazine, IEEE Volume 18, Issue 4, 35–46, 2011.
[9] Flynn C, Taberner AJ, Nielsen PMF. Characterizing skin using a three-axis parallel drive force-sensitive micro-robot. Engineering in Medicine and Biology Society (EMBC), Annual International Conference of the IEEE, 6481–6484, 2010.
[10] Ritter AB, Reisman S, Michniak BB. Biomedical Engineering Principles. Boca Raton, CRC Press, 2005.
[11] Aguirre, LA. Introduo a identificao de sistemas: tecnicas lineares e nao-lineares aplicadas a sistemas reais. Issue 3, Editora UFMG, Brazil, 2007.
[12] Karnopp D, Margolis DL, and Rosenberg RC. System Dynamics: Modeling and Simulation of Mechatronic Systems. Issue 3, Horizon, USA, 2000.
[13] Rosa SSRF. Desenvolvimento de um sistema de controle de fluxo esofagiano para tratamento da obesidade. Issue 1, Edgard Blcher Ltda, Brazil, 2009.
[14] Guastaldi AC. Biomaterial ? ponderaes sobre as publicaes cientficas. Rev. Assoc. Paul. Cir. Dent., Volume 58, Issue 3, Brazil, 205–206, 2004.
[15] Petrel H. Ao de Biomateriais e LASER de baixa intensidade na reparao tecidual ssea. Estudo histolgico em ratos. UNESP, Brazil, 165–166, 2005.
[16] Cunha ALCP. Desenvolvimento de adesivos biolgicos degradveis., Universidade de Coimbra, Portugal, 2008.
[17] Dallan PRM. Sntese e Caracterizao de Membranas de Quitosana para Aplicao na Regenerao de Pele. Universidade Estadual de Campinas, Brazil, 212–213, 2005. Roberts -, 2009.
[18] Alves MRC. Estudo da borracha natural para utilizao em perodos de entressafra num mesmo composto., Universidade Estadual de Campinas, Brazil, 2004.
[19] Paula PMC, Rodrigues SSR, Brasil LM, Silva RC, Rocha AF. Analysis of Biomaterial Latex-Derived Flow Mechanical Controller., 32nd Annual International Conference of the IEEE EMBS, Argentina, 2010.
[20] Souza EK, de Modelagem da pele humana usando Bond Graph para desenvolvimento de um simulador derivado de ltex - Monografia (graduao)Universidade de Braslia, Faculdade UnB Gama, Curso de Engenharia Eletrnica, http://hdl.handle.net/10483/8238, 2014.