Fabrication of Artificial Skin for Robotic Head Based on Silicone Rubber

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***Abstract*—In this study, artificial skin based on silicone rubber is introduced for a robot head of the same size and shape as an actual person. The artificial skin is described from designing to molding the skin for a robot head, which mimics a young woman's head. Fabricated skin is different from regular masks because it has to cover the core mechanical systems and move together. Skin movements create emotions on the face and give the appearance of a robot head. The robot has the same expressive and oral capabilities as humans and is integrated with artificial intelligence platforms. The knowledge of head anatomy and the parameters of the operation of the head will be applied in the design and fabrication of core mechanical mechanisms and their covering skin. This study analyses the basic knowledge of skin anatomy as well as the fabricating steps to make artificial skin made of silicone rubber material. The knowledge of skin anatomy is the foundation to study and analyze the general characteristics of human skin such as elasticity, color, elasticity, etc. Manufacturing methods for artificial skin are researched and selected accordingly. Finally, the artificial skin is created to make the robot head's expression more realistic. Experimental results showed that the robot meets design requirements, has an 89.83% accuracy rate of human identification of robot expressions, and is highly appreciated by users in interactive experiments.**

***Keywords*—artificial skin, anatomy, mold, silicone rubber**

I. INTRODUCTION

Robots are becoming more popular in the world, and many robots have been applied to support humans in daily life and jobs [1, 2]. Every robot needs to have a method for thinking, expressing emotions, and content to communicate. There are many robots built to interact with humans, some robots are capable of expressing expressions. There are also robots developed towards integrating Artificial Intelligence to interact with humans. However, most designed and developed robots only focus on performance, so it does not bring a sense of authenticity and nature in the process of interacting with humans. Nowadays, there are many humanoid robots that were introduced with artificial skin [3, 4]. Artificial skin is created with crucial features including protection and providing artificial sensations for robots to simulate human skin [5].

The robot is introduced to apply for many fields such as supporting medical staff to collect data, and advice, contactless medical examinations, and talking with patients during treatment. This helps reduce the spread of infectious diseases and reduces stress and anxiety for patients in the current COVID-19 situation [6]. The humanoid robot was attended to in recent years with the appearance same human [7]. It means that the behavior and gesture imitate human movements, especially emotion with the desire to create interactive robots like humans. The capacity of robots to interact with people can be improved by giving them a more human-like appearance and feel thanks to artificial skin for the head robot which creates the robot's emotions. It may also open up new opportunities for applications in industries like healthcare, where robots with synthetic skin might be employed for patient assistance or medical training.

In brief, a robot head is the same size and shape as a human head given the artificial skin made of silicone rubber proposed in this study. It explains how to develop and shape artificial skin for a robot head that resembles the head of a young woman. Because it needs to cover the essential mechanical systems and move as a unit, synthetic skin differs from conventional masks. Skin movements translate emotions into the appearance of a robot head that resembles a human face. This study examines the fundamentals of skin anatomy and the manufacturing processes used to create artificial skin using silicone rubber.

II. HUMAN SKIN STRUCTURE

The human skin is an outer part with a complex structure of tissues to form a single structure to perform its functions [8]. The skin includes a comprehensive protective function structure for the body that is: protection, tactile, temperature balance, excretion, metabolism, and blood storage. Skin is made up of cells and tissues, under the skin are blood vessels, sensory nerves, and autonomous and sympathetic nerve fibers [9]. The skin consists of 3 layers: the epidermis, dermis, dermis, and the sub-sections of the skin as shown in Fig. 1. The epidermis is made up of epithelial with many different layers, these layers are all. Depending on the

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location of the skin on the body, the epidermis can be divided into 4 to 5 different layers. No blood vessels exist on the epidermis.

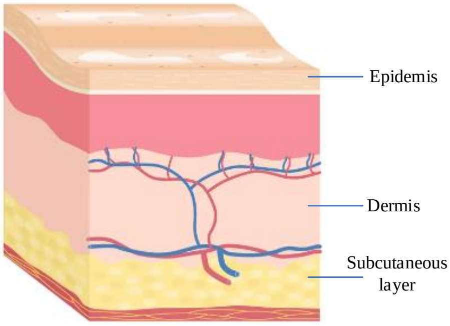


Fig. 1. Human skin structure.

The basal layer is the deepest layer of the epidermis, below are the layers of the dermis, the cells in the basal layer are connected to the dermis through interwoven collagen fibers, called the basement membrane [10]. The structure of the basal layer is mainly composed of basal cells, basal cells have a cylindrical shape, located perpendicular to the line between the epidermis and the dermis (basal membrane), the precursor of the horny cells of the epidermis. Between the basal cells exist two other types of cells.

The correct component of the dermis consists of 2 layers of connecting tissue forming a network, these 2 layers of tissue include collagen fibers and elastin fibers. Elastin is one of the most important components of elastic fibers, which is the source of the elasticity of human skin. The dermis is composed of two layers, the papillary layer and the reticular layer.

The hypodermis is the layer just below the dermis that connects the upper layers of skin with muscle and bone tissue. This layer also contains blood vessels and part of the sensory nerve fibers. The majority of cells in this layer are fat cells, this fat layer has the function of retaining heat and is a cushion to avoid strong impact for the muscle tissue inside. Some special locations do not have the hypodermis such as the skin of the nose wings, the red border of the lips, the skin of the eyelids, the nail base, and the ear lobes.

Based on the results of the studies on skin elasticity and deformability, it can be concluded about the parameters of the leather are as follows: Young's modulus or elastic modulus of human skin varies from 0.42 MPa to 0.85 MPa for torsion test. For the tensile test, the parameter varies from 4.6 MPa to 20 MPa, in the suction test the elastic modulus always varies from 0.05 MPa to 0.15 MPa [11]. The maximum tensile strength of human skin is 27.2±9.3MPa. The destructive strain (maximum elongation) is 25.45±5.07% [12, 13].

III. Characteristics of Silicone Rubber

For humans, the skin is an indispensable part, this is the main part that helps people have the ability to express themselves, in addition, the skin is also a determinant of a person's beauty. For a conventional robot, it is almost impossible to have the same expressive ability as a human, but the robot humanoid is completely different. The integration of artificial skin into the surface of humanoid robots has been around for a long time and achieved admirable results. Silicone rubber is an elastic or elastomer, which itself is derived from silicone (a polymer) and other compounds such as carbon, hydrogen, and oxygen. Silicone is the name given to the formula of the compound containing many functional groups R_2SiO, the name of this functional group is siloxane [14, 15], silicone is made up of many siloxanes molecular chains so it is also known as polysiloxane. In which R is representative of radicals such as methyl, phenyl, vinyl or triflouropropyl, when binds to the base of methyl CH_3, the newly formed compound called Polydimethylsiloxanes (PDMS), which is a very highly applicable silicone in many fields of technology. The main bond in silicone is the Si-O bond. Due to its non-carbon content, it is considered an infertile polymer, which is different from many other organic polymers with carbon-derived ribs. In terms of stability, the bond between Si and O is very stable, and the bond force between Si and O is much greater than between C and C, which is the reason why silicone is highly resistant to many different types of effects, especially temperature resistance. In addition, silicone is resistant to oxidation and less affected by electromagnetic radiation and ultraviolet rays, alpha rays, and gamma rays. Another important feature of silicone is its biological compatibility, so silicone is also used in medicine and pharmacy.

IV. Developing Process of Artificial Skin

To create a skin suitable for the robot head, it is necessary to go through 3 steps including: designing the face shape, designing the mold, and manufacturing the skin.

A. Designing the Face Shape

The shape of the face is the most important factor determining the aesthetics and beauty of the robot head. This is also one of the two main factors that determine the gender of the face, the other factor is decided by the manufacturing parameters of the mechanical parts. A face with a balanced proportion creates expressions with very high realism that measures anthropometric data on the human face based on medicine sustainability theory [16]. There are many cases where the facial proportions are not balanced, making the expressions easy to confuse, one of which is the confusion between the face when the expression is scared and when it is angry. Therefore, determining the shape of the face is the most important step in the leather processing process. The parameters of the mechanical part include the distance between the outer corners of the eyes: 11.6 cm; pupillary distance: 6.0 cm; distance from lips to the top of head: 17.5 cm; distance from eyes to the top of head: 10.5 cm; distance between the temples: 13.3 cm; Height from top of head to chin: 21.8 cm. These parameters determine the proportions of organs such as the eyes and nose of the face. This is the main data to create the face design drawing. To ease visualization and facilitate the designing process, face drawings are created on the basis of 3D models. This can be achieved by using 3D design software to conduct face modeling, the parameters of the face follow the predetermined parameters of the mechanical part.

In order to make the face easily customizable and changeable with many different shapes, the parameters of face width, height and width of nose, chin shape are not fixed but can be easily changed. easy to edit. Through the change of each part, the number of face models that can be built is very diverse. In this way, it is only necessary to use an original mechanical frame but still be able to produce a lot of face models with many different shapes. Several face templates have been created to select the most suitable face. Fig. 2(a) shows a face model with rather large width, large nose, and round chin, face in Fig. 2(b) has narrow width with pointed chin and high nose, face in Fig. 2(c) has square chin, sunken cheeks and nose large, Fig. 2(d) shows a face with a rounded chin, high nose, and moderate width. This study focuses on building a robot head with the face shape of a Vietnamese woman, so it is necessary to experiment to determine the most similar face. There are 4 designed models for a prototype. Through surveying results, the selected face is model 4 (Fig. 2(d)) to make this face model, this face has very proportionate and similar proportions with Vietnamese women. The 3D printing technology has been applied and obtained the finished product as shown in Fig. 2(e).

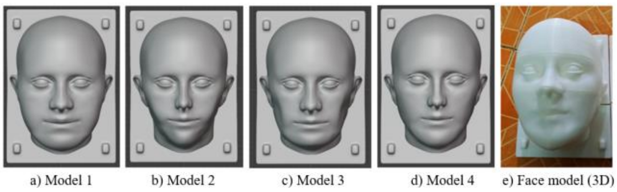


Fig. 2. Face models and 3D model of the face.

B. Designing the Mold

Silicone rubber is a material that is currently being produced and widely applied in many different fields [17]. For artificial skin and mold preparations, a wide variety of silicone rubbers have been developed. Depending on the manufacturing process of different manufacturers, the physical properties of silicone rubber after solidification are also very diverse in terms of hardness or elasticity. To choose the right type of silicone rubber, it is necessary to determine the maximum load that the motor in the robot head can pull. The selected silicone rubber needs to have a modulus of elasticity lower than 0.9 kg/cm^2 to ensure the traction ability of the motor. EcoFlex–0030 is the preferred choice because this silicone rubber has a 100% modulus of 0.7 kg/cm^2, which is very suitable for the research requirements. The EcoFlex–0030 specifications are all tested based on ASTM D412 standard [18], which requires the test piece to be 3 mm thick. Therefore, to ensure the quality of the skin and facilitate the product inspection process, the thickness of the skin is selected as 3 mm, which is the same as the standard data.

A mold is a tool (equipment) used to shape products by a shaping method, a mold is designed and manufactured to be used for a certain number of cycles, which can be one time or many times. The structure and size of the mold to be designed and manufactured depending on the shape, size, quality, and quantity of the product to be produced. A set of molds is made up of many different parts and consists of two main parts: negative mold (cavity) and positive mold (core). The negative mold is the concave part that has the function of creating the outer shape of the product, the positive mold is the protruding part that has the function of creating the inner shape of the product. The thickness of the skin is determined by the distance between the two mold parts. The positive mold determines the inner surface of the skin, which is directly connected to the mechanisms that control facial movements. In order to create a connection point with the skin for the mechanisms and help the skin adhere more firmly to the robot head, the positive mold is designed with convex points on the surface. After completing the design and fabrication process by the 3D printing method, the obtained positive mold has the shape shown in Fig. 3(a).

C. Fabrication of Mold for Artificial Skin

The mold is the only part of the mold that needs to be made by casting instead of 3D printing. The negative mold material of choice is Mold Star 15 SLOW silicone rubber with a tensile strength of up to 400 psi and a maximum elongation of 440%. By using silicone material, the skin peeling process is easier, instead of completely breaking, the mold can be reused many times. In addition, since the mold is made of solidified silicone rubber, it is difficult to remove the product, this problem can be solved by using mold release compounds, in this study using release agent Mann Ease Release 200. To obtain a negative mold, it is necessary to place the fixed face specimen on a flat surface, spray the release agent evenly on the surface of the specimen, to ensure surface smoothness, it is necessary to spray 2 coats and after each time. Spraying needs to wait 5 min (time may vary depending on different mold release agents) for the release agent layer to dry and adhere to the surface of the sample. After both layers are completely dry, proceed to sweep the mixed silicone rubber mixture on the sample. In order to limit excess flow and increase the thickness of the silicone layer, it should be divided into several different scans, the number of times depending on the amount of silicone rubber to be used. The silicone rubber is completely dry after 4 h (time may vary depending on the different mold silicone rubber), when the sample is removed, the outer layer of solidified material has the same shape as the sample, this is the negative mold (Fig. 3(b)). However, because it is made from a flexible material, the negative mold part is not fixed but has a shape that changes depending on the applied force, so it is necessary to fix the shape of the negative mold. This can be solved by applying wet plaster to the outer surface of the negative mold and separating the plaster into two equal parts, making it easier to remove the specimen and remove the skin later. After 10 to 15 min, the plaster begins to dry and completely harden by 2 days of exposure to air. When the sample has been completely removed, the remaining plaster and silicone plaster is the fixed negative mold (Fig. 3(c)).

(a) (b) (c)

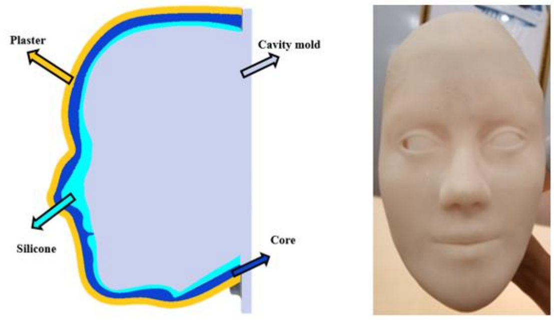
Fig. 3. The remaining plaster and silicone plaster are the fixed negative mold (a) Core (b) Cavity (c) Fixed cavity.

V. FABRICATION AND EVALUATION OF ARTIFICIAL SKIN

A. Manufacture of Robot Skin

In order to obtain a skin sample with Asian color, it is necessary to use a separate color mixing for silicone rubber. Necessary colors include tan (yellowish brown), red, yellow, and blue. Asian skin color is mainly yellow, so the color ratio when mixed with silicone rubber is 8:4:4:1 in order of yellow, red, tan, and blue. Pigment is mixed and divided into two equal parts, similarly, silicone rubber is also divided into two equal parts. Each part is mixed with pre-prepared pigment and continuously mixed until the color of the mixture becomes uniform. If the mixture of EcoFlex-0030 is exposed to air for more than 45 min (time may vary depending on the type of silicone rubber used to make leather), the viscosity is double, if mixed after a while. This time makes the solidification process more difficult. Therefore, color mixing and final silicone preparation must be done in less than 45 min.

To make the curing silicone rubber easier to peel off and limit tearing due to peeling, it is necessary to spray the release agent on the surface of both the positive and negative molds, each face is sprayed with 2 layers and the spray layers are spaced 5 min. After the mold release spray is completed, the well-mixed silicone rubber mixture must be poured directly into the recess of the negative mold. When inserting the positive mold directly into the negative mold, the liquid silicone rubber is forced to expand and gradually fill the gap between the two mold parts. Fig. 4(a) shows the cross-section of the entire mold box when fully filled with silicone rubber. The mold box is kept in place, the silicone rubber layer is completely cured after 4 h (time may vary depending on different types of silicone rubber). When removing the positive mold and the outer plaster layer, the remaining part consists of the skin and the negative mold, the step of removing the skin from the mold should be carried out carefully to avoid tearing the skin, after completion, the finished skin The resulting product has the shape as shown in Fig. 4(b).



a) Cross section of the mold b) Final product

Fig. 4. Mold cross section and final product.

B. Evaluation of Robot skin

The process of evaluating or testing the quality of skin takes place for quality control, which is directly related to the performance of the product being made. The evaluation will also be a measure of the product's properties, thereby overcoming the shortcomings and improving the quality, which will be important design data for subsequent fabrications. To evaluate the quality of silicone leather, it is necessary to conduct a strength test of the specimen according to the ASTM D412 standard [18]. From the results compared with the parameters of real human skin, it is possible to conclude about the quality of silicone leather.

After fabricating artificial skin, the specimens were selected according to ASTM D412 standard, the type of shape selected is the dumbbell Die C model, Fig. 5 shows the drawing of the prototype. The thickness of the sample is 3 mm, the values specified by the standard include A = 115 mm, B = 25 mm, C = 33 mm, and D = 6 mm.

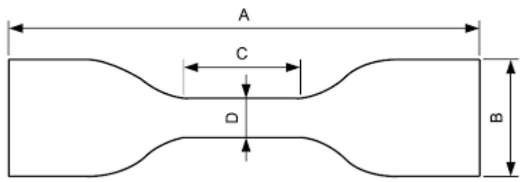


Fig. 5. Testing specimen.

In experiments, a specimen is placed at the clamp end of the gauge, the sample should be placed so that it is symmetrical and straight to the clamp end so that the force can be evenly distributed in all locations. The displacement speed of the clamps is set at a value of 50 mm/min. A dilation meter is used to record the length of the material at certain times. The machine will stop when the sample is completely pulled off and the figures at the time of destruction will also be saved. The results obtained from the machine include the length of the sample at the time of destruction C_F = 320.47 mm, the applied force at the time of destruction F_{BE} = 22.86 N. Using parameters obtained from the meter can calculate the maximum tensile stress of the material using the following Eq. (1).

$$TS = \frac{F_{BE}}{A} = \frac{22.86}{6 \times 3} = 1.27 MPa \quad (1)$$

where: TS (Tensile Strength) is the maximum tensile stress or tensile stress at the time of failure (N/mm^2); F_{BE} is the force acting at the time of failure (N); A is the cross-sectional area at the unstretched sample position (mm^2).

The maximum elongation (failure strain) is determined by the following Eq. (2).

$$E = \frac{100 \times (C_F - C)}{C} = \frac{100 \times (320.47 - 33)}{33} \approx 871\% \quad (2)$$

where: E (elongation) is the maximum elongation or length of the specimen at the time of failure (%); C is the initial length of the sample (mm); C_F is the length of the sample at the time of destruction(mm).

TABLE I. COMPARE PROPERTIES OF HUMAN SKIN AND ARTIFICIAL SKIN

	Human skin	**Artificial skin**
Elongation (%)	25.45±5.07	871
Ultimate tensil strength (MPa)	27.2±9.3	1.27

Table I represents a comparison of the parameters of ultimate tensil strength and maximum elongation between human and artificial skin made from silicone rubber. Based on the comparative results, it can be seen that the ultimate tensil strength of artificial skin made from silicone rubber is much lower than that of human skin. This is explained by the fact that because the structure of human skin is made up of many different layers of tissue and cells, these cells bind together and are coated with a layer of cells so they have great durability. Although the artificial skin has a lower ultimate tensile strength, this result is calculated based on the load capacity of the motor to the skin layer, so this ultimate tensil strength still ensures the ability of the structures to operate without causing tearing or complete deformation of the skin area. For maximum elongation, artificial skin has a maximum elongation of up to 871%, nearly 35 times that of human skin. These are silicone rubbers' general properties thanks to the connection between the molecules that form the siloxane with the SiO bond. This parameter also ensures that the skin is not completely deformed when the mechanisms are active. In general, the artificial skin model has fully met the requirements for the robot head. The fabricated artificial skin covered the core structure and give several emotions based controlling robotic head shown in Fig. 6.

Fig. 6. Six facial expressions of robotic head with artificial skin.

With the development of science these days, the robot head is an interesting topic that was developed in various studies [19–20]. The humanoid robot can have the ability to learn, improve processing and respond through long-term contact with humans with different applications, especially in medicine. It can support to do screening and classifying diseases and helps to limit contact between patients and medical staff to reduce the spread of infectious diseases. In general, research on intelligent interactive head robots has initially made promising progress. It also promotes the development of the humanoid robot field, especially the application in supporting remote medical consultation, medical service, and other fields.

VI. CONCLUSIONS

An artificial skin based on silicone rubber is introduced for a robot head of the same size and shape as an actual person proposed in this study. The face is the focus of the expression of emotions in human-robot communication. Therefore, the skin designed for the robot is extremely important to increase the satisfaction with the communicator. The change in the appearance of the robots in a positive direction will give people a different view of robots, instead of being seen as a working tool, the robot can become a friend through its communication and expression ability. This study showed that artificial skin had been fabricated from silicone material for the robot head with the same parameters as human skin. Experimental results showed that the robot meets design requirements, has an 89.83% accuracy rate of human identification of robot expressions, and the interactive experiments are satisfied. In future work, tests for more flexible materials, and experiments to evaluate the quality of artificial skin is be expected. Moreover, the humanoid robot is expected to move with flexibility and help humans with more difficult jobs, such as talking to and caring for the elderly in a hospital or nursing home to lessen patient anxiety.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Nguyen Minh Trieu is the first author-methodology, writing–original draft, visualization, validation, configured; Nguyen Truong Thinh is correspondent, writing–review and editing, methodology, project administration. All authors had approved the final version.

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