Computational Simulation on Facial Expressions and Experimental Tensile Strength for Silicone Rubber as Artificial Skin

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Abstract. Applications of robotics have become important for human life in recent years. There are many specification of robots that have been improved and enriched with the technology advances. One of them are humanoid robot with facial expression which closer with the human facial expression naturally. The purpose of this research is to make computation on facial expressions and conduct the tensile strength for silicone rubber as artificial skin. Facial expressions were calculated by determining dimension, material properties, number of node elements, boundary condition, force condition, and analysis type. A Facial expression robot is determined by the direction and the magnitude external force on the driven point. The expression face of robot is identical with the human facial expression where the muscle structure in face according to the human face anatomy. For developing facial expression robots, facial action coding system (FACS) in approached due to follow expression human. The tensile strength is conducting due to check the proportional force of artificial skin that can be applied on the future of robot facial expression. Combining of calculated and experimental results can generate reliable and sustainable robot facial expression that using silicone rubber as artificial skin.

Keywords: facial expresions, tensile strength, silicone rubber, artificial skin, proportional force, FACS

Introduction
Now a days, the robotics application becomes important and world-wide in human life activity. Robot mimics have been developed by following human mimics in facial expression. In order to follow human facial expression, robot needs apply the facial muscle area, muscle movement directions, and the magnitude of force which depends on the facial expression type [1]. This feature of the robot is required for a specific skill in developing communication either verbal or nonverbal [2,3]. In order to imitate a human gesture, several steps should be followed such as face registration and facial expression recognition [4]. The facial object is not necessary to be life which some parts of face i.e, mouth, nose, and eyes will be used in initial face registration. Then the image classification is applied by matching the facial expression with the facial action coding system (FACS) pattern [5]. This method must be integrated in order to solve the problem in detecting facial expression motion. Generally, there are six basic expressions that most people used for facial expression i.e., happiness, sadness, surprise, anger, disgust, and fear[1, 6, 7]. There are 44 actions of motion of the facial
expression that found in FACS including several combinations of the different of facial expression which also known as action units (AUs)[8, 9]. The FACS is not only representing a general facial expression, but also it covers some specific of emotional expression. The AUs is affected the facial expression by the contraction or relaxation of one or more facial muscle in a specific area of the face. Therefore, human can recognize the robot mimics by using that facial expression.

As represented artificial muscle in the robot, some researchers using shape memory alloy (SMA) or DC motor as an actuator when the force needed to be larger[10, 11]. The direction magnitude of force area are determined by type of AUs in facial expression. The boundary condition around the edge of face including at the end-point of eyes is set-up as fixed 6 degree of freedom (DOF)[10, 12].

This study will describe computational simulation of facial expression and experimental tensile strength for silicone rubber as artificial skin and analysis. Firstly, the tensile test was carried out on silicone rubber (RTV2 VP 7550) used as artificial skin of robot face. Secondly, the mechanical properties of artificial skin were identified using the experimental results. Thirdly, the facial shape was measured by 3D scanning. In addition, the facial model was made by meshing the 3D scanning data.

1. Methodology of tensile strength experiment and calculation for artificial skin

1.1 Experimental set-up

![Experimental set-up of tensile strength](image)

Figure 1. Experimental set-up of tensile strength

Tensile strength experimental set-up consists of clamps in two end sides, load, bucket as weight container, ruler scale. All of them are mounted in the aluminium frame with dimension 450mm width and 850mm high. The mass weight is 53gr for each load and the length of test specimen is measured by using aluminium plate ruler, respectively, as shown below in Figure 1.

1.2 Experimental methods

There are seven data (A-G) of tensile strength experiments with different test pieces as shown in Table 1. The length of test specimen was recorded after 10 [sec] from start loading, respectively. The test specimen was clamped vertically in both sides. The top side was stationary and the bottom side is free moving to direction of gravity center. Load the test specimen was continued until the test specimen is broken.

Silicone rubber as the facial artificial skin that will be used as facial robot skin needs test due to define the maximum force that can be applied in facial expression. The dimension of test piece in calculation is $60 \times 30 \times 3$ [mm$^3$]. There are two parameter in material properties in used, which are E
\( \varepsilon = 0.072 \) for Modulus Elasticity and \( \nu = 0.48 \) for Poisson’s ratio, respectively. The number of element in sample test is 200 and the number of nodes is 281. We fixed boundary condition (6 DOF) in one of the end-side for the test piece due to stationary. In force condition, we applied variety magnitude of forces which starts from 0.52 [N] until 15.60 [N], respectively. Since the material is silicone rubber (RTV2 VP 7550) which has high elasticity therefore nonlinear analysis is required in determine strain of test pieces.

### Table 1. Experimental stresses-strains data for silicon rubber under \( w = 0.053 \) kgf, respectively

| No | Data A | Data B | Data C | Data D | Data E | Data F | Data G |
|----|--------|--------|--------|--------|--------|--------|--------|
|    | (\( \varepsilon \)) | (\( \sigma \times 10^2 \)) | (\( \varepsilon \)) | (\( \sigma \times 10^2 \)) | (\( \varepsilon \)) | (\( \sigma \times 10^2 \)) | (\( \varepsilon \)) | (\( \sigma \times 10^2 \)) |
| 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 1  | 0.07 | 0.52 | 0.49 | 0.07 | 0.57 | 0.07 | 0.59 | 0.05 | 0.60 | 0.08 | 0.55 | 0.07 | 0.60 |
| 2  | 0.12 | 1.03 | 0.12 | 0.99 | 0.18 | 1.15 | 0.17 | 1.17 | 0.12 | 1.19 | 0.17 | 1.10 | 0.18 | 1.19 |
| 3  | 0.20 | 1.55 | 0.20 | 1.48 | 0.27 | 1.72 | 0.28 | 1.76 | 0.27 | 1.79 | 0.27 | 1.65 | 0.32 | 1.79 |
| 4  | 0.30 | 2.06 | 0.28 | 1.98 | 0.40 | 2.30 | 0.40 | 2.34 | 0.38 | 2.38 | 0.37 | 2.20 | 0.38 | 2.39 |
| 5  | 0.42 | 2.58 | 0.38 | 2.47 | 0.53 | 2.87 | 0.55 | 2.93 | 0.53 | 2.98 | 0.48 | 2.75 | 0.48 | 2.98 |
| 6  | 0.52 | 3.09 | 0.52 | 2.97 | 0.67 | 3.44 | 0.68 | 3.52 | 0.67 | 3.58 | 0.62 | 3.30 | 0.68 | 3.58 |
| 7  | 0.62 | 3.61 | 0.63 | 3.46 | 0.80 | 4.02 | 0.82 | 4.10 | 0.82 | 4.17 | 0.75 | 3.85 | 0.82 | 4.18 |
| 8  | 0.78 | 4.12 | 0.78 | 3.96 | 0.93 | 4.59 | 0.95 | 4.69 | 0.97 | 4.77 | 0.88 | 4.4 | 1.00 | 4.77 |
| 9  | 0.93 | 4.64 | 0.93 | 4.45 | 1.10 | 5.17 | 1.08 | 5.27 | 1.10 | 5.36 | 1.02 | 4.95 | 1.17 | 5.37 |
| 10 | 1.07 | 5.15 | 1.05 | 4.95 | 1.22 | 5.74 | 1.22 | 5.86 | 1.23 | 5.96 | 1.15 | 5.50 | 1.32 | 5.97 |
| 11 | 1.20 | 5.67 | 1.18 | 5.44 | 1.35 | 6.32 | 1.33 | 6.45 | 1.35 | 6.56 | 1.27 | 6.05 | 1.47 | 6.56 |
| 12 | 1.35 | 6.18 | 1.32 | 5.94 | 1.43 | 6.89 | 1.43 | 7.03 | 1.45 | 7.15 | 1.38 | 6.60 | 1.57 | 7.16 |
| 13 | 1.45 | 6.70 | 1.45 | 6.43 | 1.52 | 7.46 | 1.52 | 7.62 | 1.55 | 7.75 | 1.50 | 7.15 | 1.68 | 7.76 |
| 14 | 1.57 | 7.21 | 1.55 | 6.92 | 1.60 | 8.04 | 1.60 | 8.21 | 1.62 | 8.35 | 1.57 | 7.70 | 1.78 | 8.35 |
| 15 | 1.68 | 7.73 | 1.65 | 7.42 | 1.68 | 8.79 | 1.72 | 8.94 | 1.65 | 8.25 | 1.87 | 8.95 |
| 16 | 1.80 | 8.24 | 1.77 | 7.91 | 1.77 | 9.38 | 1.80 | 9.54 | 1.75 | 8.80 | 1.97 | 9.55 |
| 17 | 1.90 | 8.76 | 1.87 | 8.41 | 1.85 | 9.96 | 1.87 | 10.13 | 1.83 | 9.35 |
| 18 | 2.00 | 9.27 | 1.95 | 8.90 | 1.92 | 10.55 | 1.95 | 10.73 | 1.90 | 9.90 |
| 19 | 1.98 | 11.14 | 1.98 | 10.45 |

1.3 Results and discussion of tensile strength experiment

The calculated result shows that the length of test pieces are different from each other. It depends on the material properties including Modulus elasticity and Poisson’s ratio. The test pieces were give force start from 0.52 [N], respectively. The test pieces were treated with different Poisson’s ratio which start from 0.11 until 0.49. From the perspective of view, it shows large deformation effects and the elasticity effects larger for the low Poisson’s ratio. For test piece which has Poisson’s ratio 0.20 and given force 0.52 [N] generates Normal stress \( 7.08 \times 10^{-3} \) [MPa]. Therefore, the Nominal strain from the calculated is 0.08. In another test case, when the test piece has Poisson’s ratio 0.49 and given force 0.52 [N] generates Normal stress \( 4.38 \times 10^{-3} \) [MPa]. Hence, the nominal strain from the calculation is 0.04. Both cases aforementioned can be explained that the Poisson’s ratio as mechanical properties has determining the magnitude of strain that generated.

The shaped deformation of test piece can be seen clearly when the large force is given. For the test pieces which have Poisson’s ratio 0.20 and 0.11, the maximum force that given in the calculation of test piece was 11.43 [N]. The average method in calculation was used to approximate Poisson’s ratio for the test piece in the experiment. Table 1 shows several stresses in vary axis (\( \sigma_x, \sigma_y, \)
$\sigma_z$) including $\sigma_s$ which determine Mises stress. The purpose of Mises stress is important to consider in analyzing the stress-strain for 3D in order to apply the proportional forces in test pieces. The maximum value of Mises stress was the standard value to determine whether the stress was still in the proportional area for strain. Designation of strain will determine the value of Poisson’s ratio that acquired.

In tensile strength experiment, we provides seven test pieces where the condition of the experiments were similar including the room temperature, loading time method, and also material properties of test pieces.

Figure 2 shows that data A was the highest nominal strain among all the experiment data, $\varepsilon = 2$, and nominal stress, $\sigma = 9.77\times10^{-2}$ [MPa], as the first tensile test. However, data C was the shortest nominal strain among all the experiment data, $\varepsilon = 1.6$, and nominal stress, $\sigma = 8.04\times10^{-2}$ [MPa]. Data A has reached the maximum strain for the 18th loads, but the maximum strain for data C occurs on the 16th loads. These phenomenon have proved that the strain for all specimen tests were not the same because of coincide broken. The test specimens also have creep during loading time, where the test specimen keep stretching toward the gravity center even without adding weight. Figure 2 shows that the characteristics of tensile strength for all the data are almost similar where these represented in polynomial graph.

![Figure 2. Graph of tensile strength experiment for silicone rubber which shown all data experiments](image)

![Figure 3. Determined value of poisson’s ratio based on nominal strain for silicone rubber](image)
Figure 3 shows the relationship between Nominal strain and Poisson’s ratio where the strain value is determined by the stress value. The Poisson’s ratio of silicone rubber was 0.48 that found after pass several tests in calculation to approach the approximate Poisson’s ratio for the test pieces in experiment.

Figure 4 shows the comparison deformation of test pieces in calculation and experimental. The shapes of test pieces in calculation and experimental are tend to be similar until the 8th loads. However, the shapes deformations between calculation and experiment were changed after the 9th loads. Since we cannot define the poisson’s ratio on the experiment, therefore we approached poisson’s ratio on the calculation by try-and-error methods.

(a) Calculated results for normal stress in y-axis $\sigma_y = 6.06 \times 10^{-2}$ [Mpa] and $\nu = 0.48$

(b) Calculated results for mises stress in all axis $\sigma_s = 5.86 \times 10^{-2}$ [Mpa] and $\nu = 0.48$

(c) Experimental results at the 8th loads under $f = 4.16$ [N]

Figure 4. Condition of test pieces in calculated and experimental results when it loaded

2. Methodology of facial shape measurement

2.1 Experimental Set-up

In order to obtain an image from a facial data, we capture images using a 3D line laser. The geometry and color information has been setup in 3D by employing 3D laser scanning. The experimental devices consist of a 3D line laser, a charge coupled device (CCD) video camera, and a calibration panel background with a scale point to adjust the size of an object. The 3D laser scanning software allows to manipulate different angle points of facial surface. The position of the scanned object is in front of the background board. The positions of the video camera and 3D line laser are parallel to each other and in front of the scanned object as shown in Figure 5.

The dimension of the background board is 240 [mm], which is based on the size of facial object. Calibration process performed in the software determines the proportional image results and the vividness of image surface. The laser scanner is attached to a tripod and can be moved up and down
during scanning process. The CCD video camera is attached to another tripod which is positioned next to the tripod for the laser scanner. The recording of facial image is started as soon as the laser scanner start working.

![Diagram of scanning system](image)

(a) Arrangement of scanning system

![Scanned object and calibration panel](image)

(b) Scanned object and calibration panel

**Figure 5.** Experimental setup for facial scanning

In order to obtain vivid images from the scanning process, the face of the object need to be cleaned before scanning so as to reduce reflection. One way of doing this is by using cosmetic foundation on the face of the object which can make the color of the skin uniform and flawless. In addition, the eyes of the object need to be shielded using eye protection made of paper. The reason for using eye protection is not only to avoid eye injuries but also to define the shape of the eyes. The below figure shows the experimental setup including the arrangement and position of scanning device as well as the object of scanned.

### 2.2 3D scanning method

Scanning of the object face is done in front of a white background. The distance between the object face and the CCD video camera is approximately 1000 [mm]. Before scanning is done, a picture of the object is taken under a bright light condition. This picture will be used as a reference feature of the object. After taking the picture, laser scanning is then done under a dark condition. Calibration of object face is needed to synchronize the color of the target face with the color obtained from laser scan. The CCD camera connected to a computer capture images through scanning.

The initial process is start scanning process under a dark condition. During the scanning process, the laser scanner is manually moved up-and-down and is positioned at certain angle. The trajectory of the scanning process can be seen on the monitor process as shown in Figure 6.
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It is important to note that in this simulation we need to obtain data of the image for the whole face. Therefore, scanning of the object face is done from three directions, i.e. from normal direction, 45° left side facial direction, and 45° right side facial direction.

The depth of the image color that appears on the monitor during scanning represents image in a real time. The time frequency of scanning depends on the area of the face that has been covered. A face shape is a relative model and consist of multiple points that need to be scanned in a consistent speed.

2.3 Results and discussion of measurement
Results of the scanning process are shown below. The image consist of three parts: front face, 45° right side, and 45° left side. Figure 7 shows the result in 3D scanning for the three scanning angles used in the experiment. Scanning results from the three viewing angles are collected and combined to create a 3D image with a proportional dimension. Shape fusion step allows scan results to align conveniently and to fill the gap if there is a minor imprecision during merge of the scans. During the registration process, the alignment and merging for among several distinct shape images are indicated by many surface penetration points. Sometimes the first time registration process is not perfect (i.e. overlap surfaces or a coordinate axis not match), but it can be repeated using randomized algorithm in software until we get the best result.

After the registration process is completed, we then define the resolution of the image. In this experiment, we use 120 image resolutions (with 20,865 nodes and 41,026 elements) from the image resolution range of 50-400. If we use the lowest image resolution, the fusion process is much more robust against noise and imprecise alignment. However, applying the highest resolution has a consequence in a longer processing time.

3. Making meshes of facial model

3.1 Meshing by scanned 3D facial data
The image data is retrieved from the shape fusion result where it needs meshing in the surface of the object face. The meshing procedure consists of a several steps that start from analyzing the geometry model until optimizing the meshing in all the surface of elements. Meshing the facial model is determined by the shape object surface. The quadrilateral also known as quad type is applied in
meshing face because of the best quality surface. The quad type consists of four nodes (grid points) and four lines as shell element.

The image resolution of meshing is start from 80, 100, 120, and 250. We selects the resolution 120, smoothness grade 7 and removal value 5, which is reliable in model shape element and the ability of computer to run the mesh program. The angle degree of quad type is not always 90°, but the range is between 45° and 135° due to pass the parameter editor including maximum-minimum interior angle quad and skew criteria. The edge of facial object can be reshaped and smoothed including around the mouth and eyes circle as shown in figure 8.

Making the quad type of element needs several remove and merge line methods. It starts from one element with triangle type and then two type of it will be merged. The empty element sometimes found and need to be recovered by creating a new element.

3.2 Result and discussion of mesh optimization
Recondition needs to apply after meshing, since there are still bad element sector left behind on the surface as shown in Figure 9. This is caused by overlapping element in one area, so that it needs to remove the bottom or the top element. Another cause of element dent is disconnection of line between one element and the other one. Therefore, it needs weld step for the line connection.

Figure 8. Comparison of facial model between initial condition and final model

Figure 9. Red spots indicate defect elements after meshing
The optimized facial object can be done by selecting the proportional image resolution where the best image resolution that we apply is 120. We can see the difference smoothness of element surface where the image resolution affect the sharpness image with a shape proportionally.

**Conclusion**

The facial expressions for robot in calculation is not exactly similar with the human facial expression. However, this research is applying FACS due to imitate the muscle face of human based on the facial expression in require for robot. A Facial expression robot is determined by the direction and the magnitude external force on the driven point which depends on the facial expression type of robot. Silicone rubber as artificial skin for robot face has been tested by conducting tensile strength. The reason for conducting the tensile strength for is due to examine the capability in hold the large deformation of artificial skin for facial robot.

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