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Development of a Skincare Robot

Yuichi Tsumaki*[1], Takayuki Kon*[2], Asami Suginuma*[3], Kei Imada*[4],
Akinori Sekiguchi*[1], Dragomir N. Nenchev*[5], Hajime Nakano*[6] and Katsumi Hanada*[6]

***Abstract*— With aging, human skin develops a dry condition called senile xerosis. The skin lesion can be prevented by daily skin care such as applying an ointment containing moisturizing factors several times a day. Aged persons, however, have difficulties in accessing the back and rely therefore on nursing care for such treatment. Unfortunately, in underpopulated areas such nursing care may not always be available. To tackle this problem, the concept of a skincare robot is proposed. The feasibility of the concept is then confirmed by designing a real skincare robot and by performing experiments for applying ointment on human's back. The robot developed is able to recognize the shape of the body, to plan the appropriate motion paths for the hand, and to execute the task without applying any excessive forces.**

I. INTRODUCTION

Dry skin is a well known phenomenon related to normal aging. The phenomenon is referred to as senile xerosis, in general. As reported in [1], in Japan, 95% of the over-sixties population is affected by senile xerosis, with half of the patients feeling inconvenience due to skin itching. To ease the inconvenience, daily skincare is required. Usually, an ointment with moisturizing factors is applied several times a day. Note, however, that self-treatment may be a problem for aged people, because of body inflexibility, and especially, due to the difficult access to the back. Therefore, nursing care is usually needed for the treatment. Unfortunately, such help may not always be available. This problem is due to an increasing aging population and the shortage of human resources in hospitals, related also to the declining birthrate in Japan and in other countries as well.

To tackle the problem, we propose here the concept of a skincare robot and discuss related fundamental technologies. We also introduce a design of an experimental setup for such a robot, including mechanisms for applying the ointment and a system for measuring the body shape. Several experiments on a human back have been performed to demonstrate the feasibility of our concept.

The automatic breast cancer palpation robot [2] developed in the past can be related to our research from the viewpoint of physical intractions between a robot and a human body. The studies on the "Hippocrate" robot [3] and the robot for ultrasonic diagnostics [4], that are able to perform surface tracking of a human body, are related as well. Automatic massaging devices are also somewhat linked to the problem. All these systems, however, do not aim at applying an ointment to the human body. In this sense, the system described here is unique.

*[1] Graduate School of Science and Engineering, Hirosaki University, 3 Bunkyo-cho Hirosaki 036-8561 Japan
tsumaki@cc.hirosaki-u.ac.jp
*[2] Mitsubishi Electric Corporation
*[3] MEC Information Development Co., Ltd
*[4] Vuteq Corporation
*[5] Faculty of Engineering, Musashi Institute of Technology
*[6] Graduate School of Medicine, Hirosaki University

II. SKINCARE ROBOT

First, we propose the concept of a skincare system using a robot instead of a nurse. We name such a system a "skincare robot" [5]. In this paper, back of a human is selected as the target of the skincare robot because of the reason pointed out in the previous section. To realize such a system, the following requirements should be satisfied.

- Establishment of robot skills for applying the ointment
- Establishment of a scheme of supplying the ointment
- Ensuring physical safety
- Ensuring medical safety
- Keeping the cost as low as possible
- Easing the psychological resistance against robotized care

Except for the need of ensuring medical safety, all the other requirements can be handled as engineering problems. To ease the psychological resistance against robotized care, achievement of comfortable feeling will play an important role. The recent increased use of massaging devises is a good example. On the other hand, robot care has the eventual psychological advantage that patients do not have to expose their naked body to others.

Hereinafter, we focus on the skill of applying the ointment, as well as on ensuring physical safety. We would like to emphasize that the way of applying the ointment depends on the type of medicine used, that can be in liquid form (lotion) or in form of a cream (ointment). In case of a lotion, a spray gun or a roller can be utilized. In this paper, we consider ointment only, because it is more effective for dry skin. From the viewpoint of robotics, the following techniques should be achieved.

- Surface tracking of complicated (body) shapes
- Compensation for small displacements of the body
- Handling a soft object (body) with non-uniform distribution of flexibility

The task of applying the ointment is achieved by robotic surface tracking with proper velocity and proper pressure on the human body. However, we note that the shape of a human body is complicated and there are significant individual differences. Therefore, the robot should be able to measure the shape of the body in advance. One possibility is to

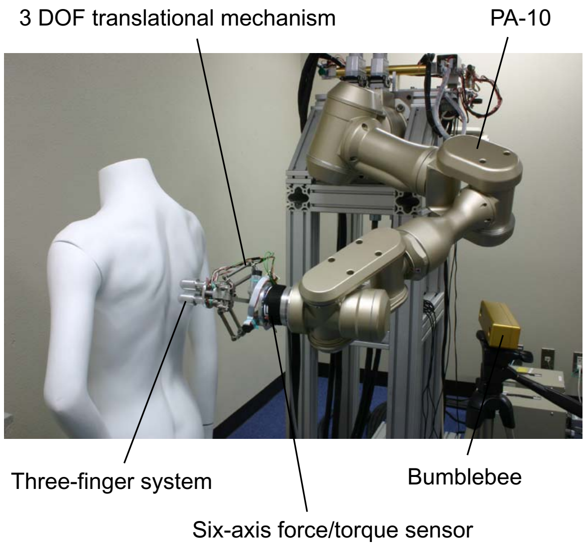

Fig. 1. Photo of the developed skincare robot.

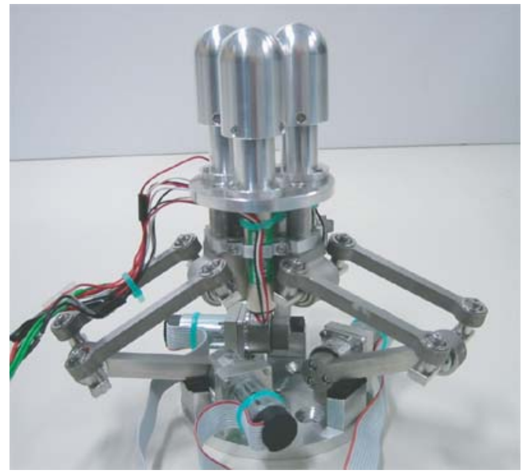

Fig. 2. Overview of the hand prototype.

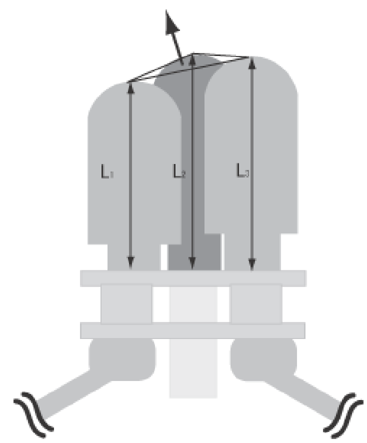

Fig. 3. Principle of the sensor.

use a laser range sensor. It provides accurate measurement, but is quite expensive. A low-price measurement system is preferable. Thereby, we should note that it is difficult for aged people to remain motionless during the treatment. Hence, small displacements of the body should be admitted. Furthermore, the robot should be able to handle several delicate places, like the backbone, with special care because these places are quite sensitive to pain. The robot should be able to produce fast motions without exerting a large force during the treatment.

To satisfy these requirements, the robot should first of all be robust against modeling errors. In such case, both a low-price, low-accuracy measurement system and motions of the patient can be admitted. Further on, a hand with small mass is desirable. This will improve physical safety and ensure fast motion ability. Another approach to ensuring physical safety is mechanical restriction of the workspace.

III. Experimental Setup

A. System Overview

An experimental setup is introduced to confirm the feasibility of our concept. Figure 1 shows the overall view of the experimental setup. The robot system is a macro-micro system. The micro part is employed for fine motions. It is a three-finger system, driven by a three-DOF parallel translational mechanism. The base of the parallel mechanism is attached to the hand of a seven-DOF Mitsubishi Heavy Industries PA-10 manipulator, which is used for gross motions. A stereo vision camera Bumblebee is employed to measure the shape of the body. Its accuracy is of the centimeter order, but the price is reasonable. A six-axis force/torque sensor is installed at the end-effector of the PA-10 arm to obtain experimental data. In other words, this sensor is not used for feedback control.

We would like to emphasize that the macro-micro system is just a possible approach, which we used to confirm the effectiveness of the developed robot skill. That is, we do not consider the macro-micro system as a necessary condition. A wire-driven system may ensure the same motion abilities, and may be preferable for safety reasons.

B. Special hand

In this section, a special hand, comprising a multifinger system in combination with a three-DOF translational parallel mechanism [6], is proposed to ensure ointment application. From observations of skills of nurses, it became clear that their motions depend on the target area. For example, the index finger is utilized for a small area, and two or three fingers are used for a relatively large area simultaneously. For a wide area, the palm of the hand is employed. In the special hand, we employ a simple three-finger system, thus avoiding the use of other heavy, multifunction mechanisms. The fingers are arranged on a circle of 35 mm diameter at equal intervals. The diameter of each finger is 25 mm and is larger than that of a human finger, to handle a wide area.

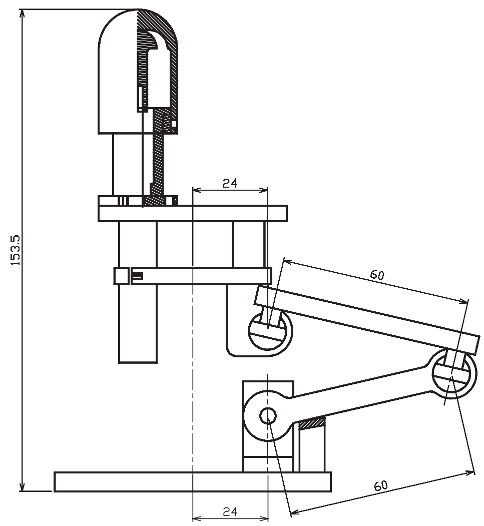

Fig. 4. Hand design details.

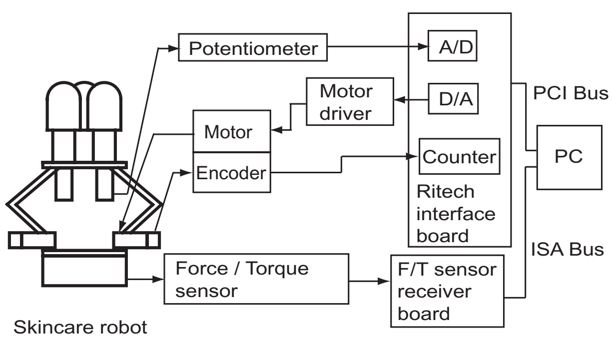

Fig. 5. Hardware architecture.

Fig. 2 shows the special hand. Its features are listed below.

- Three fingers
- Each finger includes a mechanical spring
- Hemispherical shape of the finger tips
- Light-weight finger tips
- Each finger includes a linear potentiometer to measure the length of the spring
- A modified Delta mechanism is employed for three-DOF translational motions

The special hand is designed to be highly compliant in order to ensure robustness against modeling errors. Each finger is equipped with a mechanical spring for compliance in the longitudinal direction. The spring constant is 0.29 N/mm, with finger tip stroke of 20 mm. On the other hand, the hemispherical shape of the finger tip improves adjustability to the body shape. Because of the specific combination light-weight finger tip – mechanical spring, the system is able to ensure fast response passively. In other words, skin treatment without excessive force can be expected. In addition, with the fingers it is possible to identify the contact plane by measuring the length of the three fingers. Figure 3 shows the principle. It is also possible to sense forces in the longitudinal

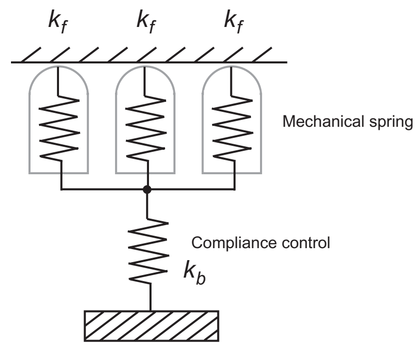

Fig. 6. Compliance model.

direction without an expensive force/torque sensor. As a result, force feedback control can be achieved just with the developed inner sensor.

Note, on the other hand, that it is difficult to ensure safe fast motions, similar to that of a nurse, by active control of the PA-10 arm only. Such motions can be achieved, though, with the three-DOF parallel mechanism. In addition, physical safety can be ensured by both the lightweight traveling plate of the mechanism and by the mechanical limitation of its workspace. The parallel mechanism has also the advantage fast motion capability, as required. A modified Delta mechanism [7] performing just three-DOF translational motions with constant orientation is employed. The constant orientation property is almost the same as that of the human hand. Details of the mechanism are shown in Fig. 4.

In this way, fast motion ability for fine motions is achieved by the light-weight passive compliance fingers, while large motions, beyond the finger stroke, are dealt with the parallel mechanism. Furthermore, larger motions, beyond the workspace of the parallel mechanism, are supported by the PA-10 arm. In this way, we designed a three stage architecture that satisfies all required motions.

C. Control System

RT-Linux is employed as OS in the controller. The control interface board is a PCI Ritech Interface Board. As motor drivers we used the TiTech drivers. Signals of the potentiometers are also captured by the Ritech Interface Board. Figure 5 shows the control system of the special hand.

D. Compliance Control

As we mentioned, each finger tip has passive mechanical compliance. However, it cannot handle motions with a stroke over 20 mm because of stroke limitation. Therefore, active compliance control in the longitudinal direction is introduced for the modified Delta mechanism. The linear potentiometers inside each finger are utilized to achieve the active compliance control. The distribution of the compliance is shown in Fig. 6, where, k_f is the stiffness of the spring, k_b is the stiffness of the active compliance controller. The overall

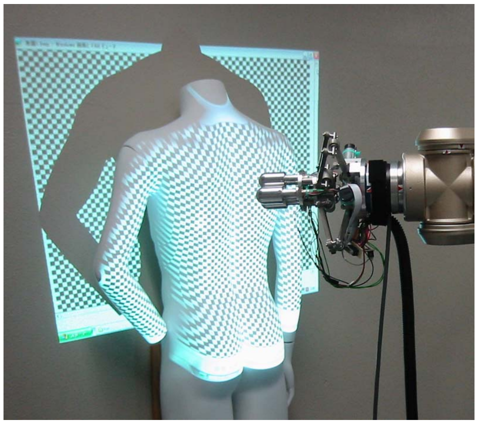

Fig. 7. A mannequin with projected visual pattern.

Fig. 8. Overview of measurements for nurse's skills.

stiffness can be written as follows:

$$k = \frac{3k_f k_b}{3k_f + k_b}. \tag{1}$$

It is clear that k cannot exceed k_b, but longer strokes can be obtained. Fast responses, which cannot be achieved by active control, are handled by the passive (mechanical) compliance. And the stroke limitation of the spring is eased by the active compliance control. In this way, both passive and active compliance complement each other. In addition to active control in the longitudinal direction, cyclic circular motion is performed in the orthogonal plane by using position control. The details will be addressed later.

IV. Measurement System

A. Measurement of Body Shape

A digital stereo vision system Bumblebee is employed to measure the body shape. To improve the accuracy, a white-and-black checkered pattern is projected by a PC projector as shown in Fig. 7. As a result, the errors become less than ± 10 mm. The measurement of body shape is performed only once, at the beginning of the skincare procedure.

B. Path Planning

To obtain reference data for skincare motion, we asked a qualified nurse to apply a hand cream to the surface of a force/torque sensor (see Fig. 8), in the usual way. The data obtained are shown in Fig. 9. The hand speed is relatively fast (over 200 mm/s), while the pressure is around 5 N. As already mentioned, motions of the nurse, however, depend on the target area. In addition, nurses may perform different type of motion even at the same target location. In case of a back, mainly reciprocating and rotational motions are utilized. In our system, rotational motions (ϕ 40 mm, 2 Hz) are employed by referring to the nurse motions in Fig. 9 as a first step.

On the other hand, we need to plan the path of the hand of the PA-10 arm based on data measured by the digital stereo vision system. However, it is difficult to create a path from more than 10,000 points with low-depth data. In addition,

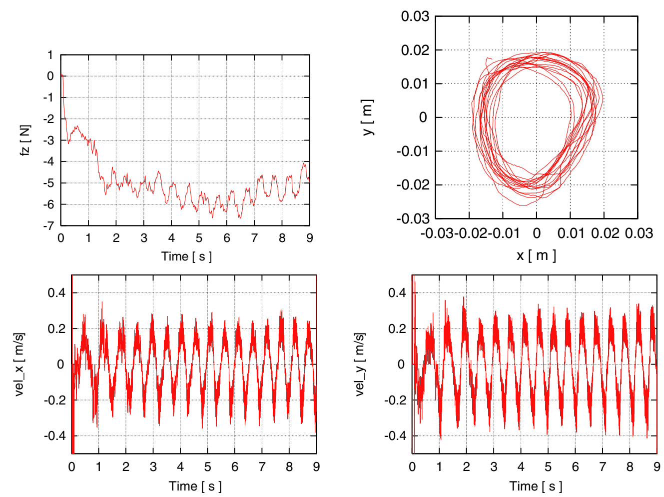

Fig. 9. Measurement results of nurse skills.

the data noise is relatively large. Therefore, the measured area is divided into small segments with 60 mm height and 10 mm width. The center of each segment is defined as a representative point, having a depth value calculated as the average of the depth values of all points in the segment. The path in the z–y plane is planned to connect the representative points, while the depth data (x axis) is interpolated by a spline function, as shown in Fig. 10. The graph depends on a base coordinate system Σ_B in Fig. 11.

V. Experiments with Humans

Experiments on a human's back were performed with the developed experimental setup. One of the coauthors of this work was employed as the subject (at the age of 24 years). We should note that the condition of his skin was different from that of an aged person. Nevertheless, at the present moment, our focus is just on the physical interaction between the robot and a real human body. Later we intend to address the specific problems related to the type of skin under treatment.

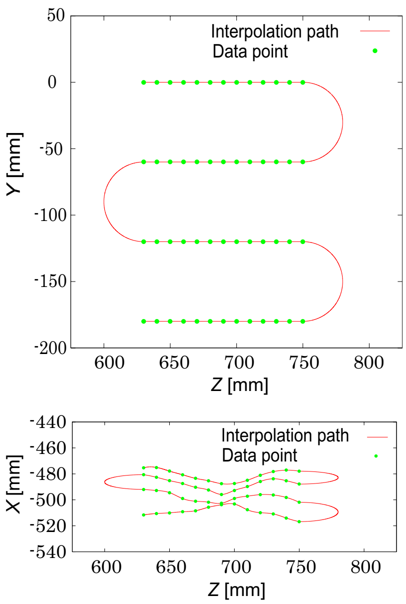

Fig. 10. Planned path for execution on a mannequin.

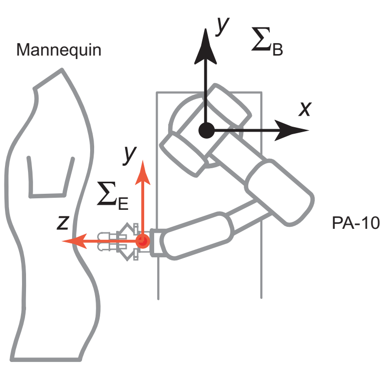

Fig. 11. Coordinate systems.

The overall setup is shown in Fig. 12. An ointment (glycerin) is roughly distributed in advance on the back, as shown in the left photo of Fig. 13. The PA-10 arm moves along the planned trajectory with constant orientation under position control. In addition, the modified Delta mechanism employs active compliance control in the longitudinal direction of the fingers (z axis of the Σ_E). In the $x-y$ plane, position control ensures cyclic rotational motions.

The right photo in Fig. 13 shows the result of the ointment application task. It is seen that the ointment has been finely distributed on the back. Figure 14 shows force data on the Σ_E from the six-axis force-torque sensor. It is apparent that no excessive forces or moments appear during the task. The 10 N force in the z direction is acceptable, because the subject did not experience any painful sensation. Oscillations in the data depend on the cyclic motions of the modified Delta mechanism. The variance is also acceptable. Figure 15 shows position data for the modified Delta mechanism. It can be seen that the active compliance control works well,

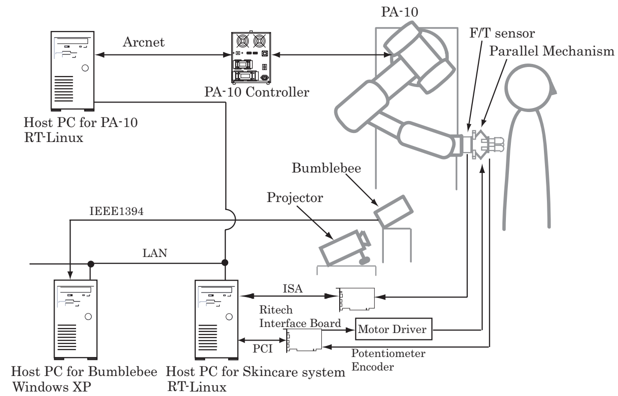

Fig. 12. Integrated system.

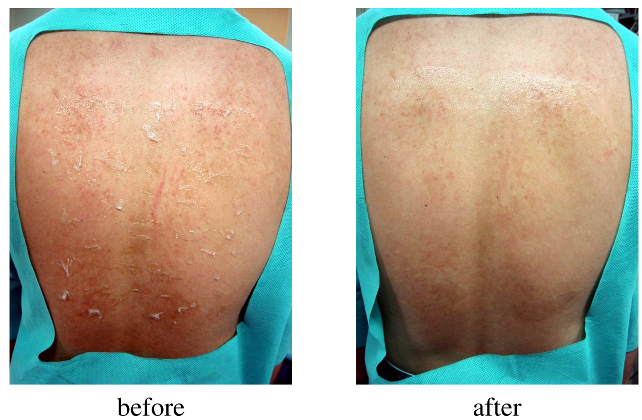

Fig. 13. Result of the experiment.

successfully adapting the motion of the special hand to the varying body shape.

VI. Conclusions

A skincare robot, which is able to apply ointment to the back instead of a nurse is proposed, and relevant technologies are discussed. A novel special hand is designed and an integrated experimental setup, including a measurement system for body shape, is also developed. The performance of the experimental robot has been confirmed by applying ointment to the back of a human. The smoothness of the distribution and the lack of excessive forces show that this specific task can be handled by a robot. Performing more sophisticated skincare skills with real aged persons is our next goal.

We believe also that significant improvements can be achieved with a wire-driven system, instead of the present macro-micro type robot. A possible concept design is shown in Fig. 16. The special hand, to be used to apply the ointment, is driven by the parallel wires. In this way, the requirements for small mass and for restricting the workspace can be satisfied. The parallel wire-driven system can also ensure the required fast motions. The measurement system is located on the top.

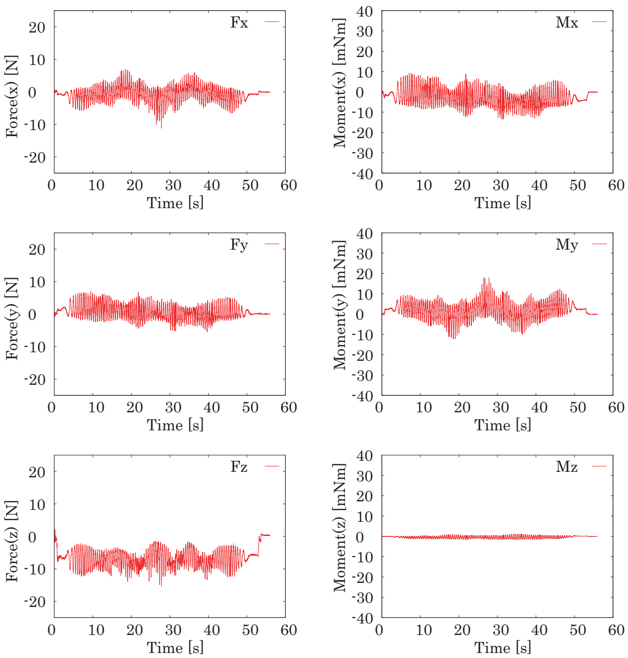

Fig. 14. Experimental results.

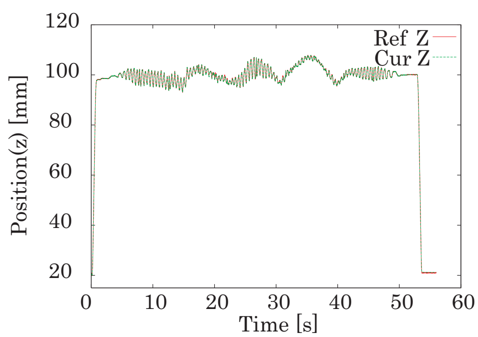

Fig. 15. z position of the traveling plate.

VII. ACKNOWLEDGMENTS

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Fig. 16. Concept design of the skincare robot.

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