

Design and Implementation of a User-Driven System for Continuous Monitoring and Behavior Change Support in Skin Condition Improvement

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Abstract—Recent advancements in sensing technology have facilitated data-driven systems that promote behavioral change. This paper introduces a continuous monitoring system for tracking skin moisture and oil levels to improve skin condition. By analyzing subtle fluctuations in these parameters, the system generates personalized improvement strategies based on the collected data. The system provides personalized feedback to improve skin conditions and encourages effective behavior modifications.

Index Terms—Skin Condition Monitoring, Behavior Change Support, Sensing Data, Personalized Feedback System, User-Centered System Design

I. INTRODUCTION

Advancements in sensing technology have enabled real-time, personalized systems that promote behavior change through the analysis of user behavior and health data from wearable devices and smartphones. These systems provide automated advice and reminders, offering scalable solutions for behavior modification.

This study proposes a behavior change support system aimed at improving skin conditions. The system uses sensors to collect skin-related data and delivers personalized improvement strategies, addressing the challenge of managing skin quality fluctuations. Traditionally, skin improvement required expert consultations, incurring significant time and cost. The proposed system mitigates these burdens by enabling users to manage and improve their skin condition with ease.

This paper presents the design, implementation, and evaluation of the system, including results from user experiments validating its effectiveness. In this study, the effectiveness of the proposed system was evaluated with nine participants. While the sample size provided initial insights into system usability and impact, its limited scope presents challenges in generalizing the results. Future research will address this limitation by involving a larger, more diverse population, which will enable a more comprehensive evaluation of the system's efficacy.

II. RELATED WORK

This section reviews studies on behavior change using sensing data for personalized interventions.

A. Workstyle Improvement Support System

Tsuji et al. [1] developed a system that collects workplace behavior data via wearable sensors, tracking face-to-face interactions, body movements, and desk work focus. The system provides three types of feedback: behavior log visualization, workstyle diagnosis, and personalized workstyle advice.

Combining behavior measurement with personalized advice effectively improved workplace behaviors. This highlights the potential of wearable devices and data analysis in workplace behavior change systems.

B. Support System for Office Workers with Diabetes

Francesc et al. [2] investigated mobile health (mHealth) interventions for office workers with type 2 diabetes. Data on sedentary behavior, physical activity, and clinical metrics (e.g., HbA1c) were collected via questionnaires and sensors. The system provided real-time feedback, health guidance, and goal setting through a smartphone app.

The intervention reduced sedentary time, increased physical activity, and improved clinical outcomes. This demonstrates the effectiveness of mHealth interventions in driving behavior change, emphasizing the role of personalized, real-time feedback.

C. Positioning of This Research

Building on previous studies in workplace and health-related behavior change, this research applies similar principles to skin condition improvement. By using sensors to track skin data and providing personalized feedback, the study explores new opportunities in personalized healthcare. These findings may also inform the development of behavior change systems in other health and beauty-related domains.

III. PROPOSED SYSTEM

The proposed system provides personalized feedback to improve or maintain skin condition based on data from skin measurement devices. The key features of the system include:

- Continuous skin condition data collection and analysis
- Personalized feedback tailored to individual skin profiles

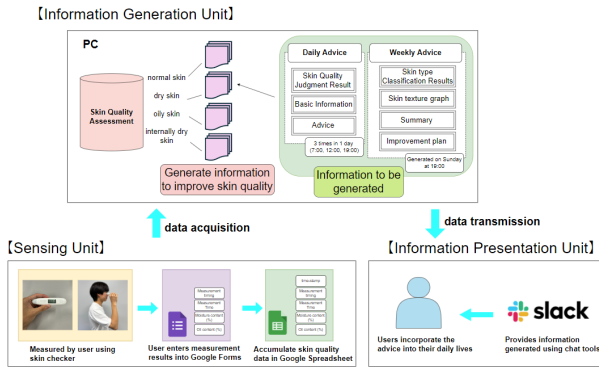


Fig. 1. System Configuration Diagram

- Encouragement of behavior change through effective information delivery

Users can refer to the provided information to make informed decisions for improving their skin care routines, thereby enhancing self-management and achieving sustainable skin improvements.

A. System Configuration

The system consists of three main components:

- 1) **Sensing Unit:** Collects skin condition data
- 2) **Information Generation Unit:** Analyzes and stores the collected data, generating relevant feedback
- 3) **Information Presentation Unit:** Displays personalized recommendations to users

These components provide continuous support for skin care behavior changes in Fig. 1.

To enhance understanding of the system’s functionality, visual aids were included to clarify the roles of each component. For example, the Sensing Unit diagram illustrates the specific parameters measured, while the Information Generation Unit flowchart demonstrates the decision tree logic used for skin condition classification.

1) *Sensing Unit:* We use the Skin Checker provided by Good Skin Laboratory [3] to measure moisture, oil, elasticity, and skin tone. The device uses bioelectrical impedance analysis (BIA) to assess moisture and oil levels by emitting a weak current through the skin. The device’s specifications include a 12 cm length, 40 g weight, and a battery life of 2.5 years with two daily measurements.

In this study, participants used the Skin Checker three times a day—upon waking, before lunch, and before bed—and recorded the results in a Google Form. These entries were saved to a Google Spreadsheet for further analysis. The measurement area was the under-eye region, where skin is thinner and more sensitive (Fig. 3).

The contents of the Google Form questionnaire are shown in I, where participants record the time of measurement, measurement timing, moisture level, and oil level. The data recorded in the Google Form is stored in a Google Spreadsheet, as shown in II.



Fig. 2. Skin Condition Sensor



Fig. 3. Measurement Site

B. Information Generation Unit

In the Information Generation Unit, the system classifies the user’s skin condition into one of four categories based on the data collected and stored by the Sensing Unit, and generates daily and weekly advice aimed at improving or maintaining skin condition.

Daily advice is generated three times a day at 7:00, 12:00, and 19:00, and consists of the following three types of information:

- 1) User’s skin condition classification based on skin data

TABLE I
QUESTIONNAIRE CONTENT

No.	Questionnaire Content
1	When was the measurement taken?
2	What time was the measurement taken?
3	What is your skin moisture level?
4	What is your skin oil level?

TABLE II
DATA STORED IN SPREADSHEETS

Timestamp	Measurement Timing	Measurement Time	Moisture (%)	Oil (%)
2024/06/17 6:33:14	After waking up	5:55:00	48	47
2024/06/17 11:01:45	Before lunch	11:00:00	62	41
2024/06/17 23:06:51	Before going to bed	23:00:00	55	47
2024/06/18 6:58:30	After waking up	5:55:00	40	50
2024/06/18 11:34:43	Before lunch	11:30:00	46	47
2024/06/18 23:25:21	Before going to bed	23:20:00	55	48

TABLE III
SCIENTIFIC METHODS FOR DETERMINING SKIN CONDITION

Skin Type	Moisture (%)	Oil (%)	Skin Condition Details
Normal Skin	35 or higher	Less than 47	Balanced moisture and oil levels, healthy skin with minimal issues
Dry Skin	Less than 35	Less than 47	Lacks moisture, prone to roughness and itching
Oily Skin	35 or higher	47 or higher	Excess sebum production, prone to shine, enlarged pores, and acne
Combination Dry Skin	Less than 35	47 or higher	Lacks moisture but has excess sebum, prone to roughness and acne

TABLE IV
GENERATED INFORMATION 1

Moisture (%)	Oil (%)	Skin Condition Result
35 or higher	Less than 47	Your skin condition as of 11:00 on July 1, 2024, is Normal.
Less than 35	Less than 47	Your skin condition as of 11:00 on July 1, 2024, is Dry Skin.
35 or higher	47 or higher	Your skin condition as of 11:00 on July 1, 2024, is Oily Skin.
Less than 35	47 or higher	Your skin condition as of 11:00 on July 1, 2024, is Combination Dry Skin.

(hereafter referred to as Generated Information 1)

- 2) Basic information and advice on skin condition (hereafter referred to as Generated Information 2)

Weekly advice is generated on Sundays at 19:00, and consists of the following four types of information:

- 1) User's skin condition classification based on the past week's data (hereafter referred to as Generated Information 3)
- 2) Skin condition graph plotted using the past week's skin data (hereafter referred to as Generated Information 4)
- 3) Trends in skin moisture and oil levels over the past week (hereafter referred to as Generated Information 5)
- 4) Improvement suggestions based on the past week's skin data to improve or maintain skin condition (hereafter referred to as Generated Information 6)

The classification follows the scientific method by Shiseido Co., Ltd. [4], in III.

The details of the generated information are explained below.

In Generated Information 1, the user's skin condition is determined based on the latest moisture and oil levels stored in the spreadsheet, using a decision tree created according to the skin classification method mentioned above. The conditions for the decision tree and the generated skin condition classification results are shown in IV. This information is designed to allow users to quickly recognize their skin condition upon receiving the provided information.

In Generated Information 2, basic information and advice regarding the user's skin condition, based on the results from Generated Information 1, are provided. An example of the generated information is shown in V.

TABLE V
GENERATED INFORMATION 2

Basic Information	Advice
Oily skin can be caused by a high intake of sugar and fats, which increases sebum production. A balanced diet is important for maintaining healthy skin.	For breakfast, incorporate low-fat, high-protein foods. Egg whites, oatmeal, and fruits are good choices. Adding yogurt and berries can help provide antioxidants and support skin health.

TABLE VI
GENERATED INFORMATION 3

Most Frequent Skin Type	Classification Result
Normal Skin	Your skin is classified as Normal.
Dry Skin	Your skin is classified as Dry Skin.
Oily Skin	Your skin is classified as Oily Skin.
Combination Dry Skin	Your skin is classified as Combination Dry Skin.

The basic information and advice are stored in an Excel file, and information appropriate to the skin condition is randomly selected.

In Generated Information 3, the percentage of each skin condition over the past week is calculated based on the data stored in the spreadsheet, and the most frequent skin condition is identified. The generated classification result is shown in VI. This information is designed to allow users to quickly recognize their skin classification when receiving the provided information.

In Generated Information 4, a skin condition graph is generated using the past week's skin data stored in the spreadsheet. The vertical axis represents moisture levels, the horizontal axis represents oil levels, and the user's skin data is plotted as red dots. The background of the graph is shaded blue to represent the range for normal skin, distinguishing it from other skin conditions. The generated skin condition graph is shown in Fig. 4.

In Generated Information 5, the trends in skin moisture and oil levels over the past week are analyzed based on the data stored in the spreadsheet. The generated information includes the following five items: (1) the range and average value of moisture levels over the past week, along with an evaluation, (2) the range and average value of oil levels over the past week, along with an evaluation, (3) the average moisture and oil levels after waking up, along with an evaluation, (4) the average moisture and oil levels before lunch, along with an evaluation, and (5) the average moisture and oil levels before going to bed, along with an evaluation. An example of the generated information is shown in VII.

In Generated Information 6, suggestions for improving or maintaining skin condition based on the past week's data are provided. An example of the generated suggestions is shown in VIII.

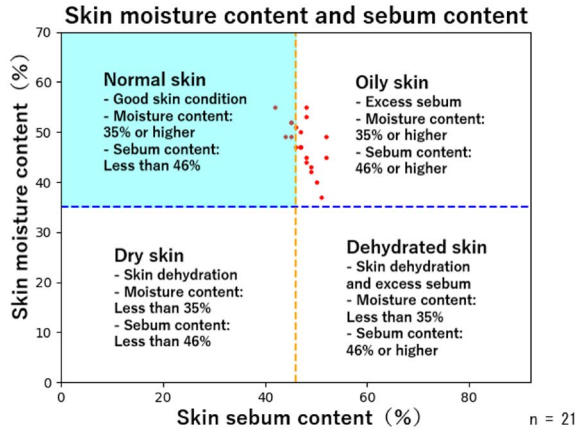


Fig. 4. Generated Information 4

TABLE VII
GENERATED INFORMATION 5

No.	Details
1	Moisture levels range from 37% to 55%, with an average of 47.6%. The overall trend shows an ideal moisture level.
2	Oil levels range from 42% to 52%, with an average of 47.4%. The overall trend shows higher oil levels.
3	After waking up, moisture levels decrease (average: 44.1%) and oil levels increase (average: 48.9%).
4	Before lunch, moisture levels decrease (average: 46.4%) and oil levels increase (average: 47.6%).
5	Before going to bed, moisture levels increase (average: 52.1%) and oil levels decrease (average: 45.9%).

C. Information Presentation Unit

The system implements the information provision functions for both daily and weekly advice, as described in the previous section. To deliver the information, we utilized the communication chat tool Slack [5]. A dedicated channel was created for each participant, where the generated information is provided by a bot named "Skin Doctor."

The details of the information provision functionality are as follows.

Daily advice is automatically delivered three times a day at 7:00, 12:00, and 19:00. Since this feature is intended for daily use, a simple and easy-to-read design was adopted. An example of the actual presentation of daily advice is shown in Fig. 5.

Weekly advice is automatically delivered on Sundays at 19:00. Since the amount of information is more substantial, readability was improved by dividing the content into para-

TABLE VIII
GENERATED INFORMATION 6

No.	Details
1	The results show higher oil levels, indicating an oily skin type. It is important to remove excess sebum. Use gentle cleansers and wash your face twice a day. Using toners and sebum-control skincare products is also recommended.

Skin Type Doctor
Hello!

We are delivering information for improving and maintaining your skin condition. 🚨
At 11:30 on 2024/07/06, your skin type was **oily skin**.

Basic Information
Oily skin is influenced by the content of your meals. High-fat and high-sugar meals promote the secretion of sebum, which can lead to acne and pimples.

Advice
For lunch, aim to balance your intake of vegetables and whole grains, and make sure to consume a good balance of proteins, such as salad, grilled chicken, and whole grains. Also, consuming omega-3 fatty acids can help suppress

⚠️ Be careful when using skincare products related to the advice above. Please use caution and check if any abnormal reactions appear on your skin after using the recommended products. If you experience redness, itching, irritation, swelling, or any abnormalities such as blackheads, discontinue use.

Fig. 5. Daily Advice

TABLE IX
PARTICIPANT ATTRIBUTES

Participant No.	Age	Gender	Skin Type
1	23	Male	Dry Skin
2	22	Male	Oily Skin
3	21	Male	Oily Skin
4	21	Male	Oily Skin
5	21	Male	Unknown
6	22	Male	Combination Dry Skin
7	21	Female	Unknown
8	21	Male	Oily Skin
9	21	Female	Normal Skin

graphs and sections, as well as utilizing bold text and icons. An example of the actual presentation of weekly advice is shown in Fig. 6.

IV. DEMONSTRATION EXPERIMENT

This section describes the demonstration experiment conducted using the proposed system.

A. Overview of the Demonstration Experiment

This experiment aimed to collect skin condition data and evaluate its impact on behavior change. Additionally, the usability of the collected data and generated information was evaluated. Through interviews conducted before and after the experiment, the effectiveness and impact of the proposed system on skin improvement were assessed. To verify the impact of information provided by the proposed system on behavior change, the experiment was divided into two phases: Period A, during which the system was not used, and Period B, during which the system was used to improve skin condition. Period A was conducted from June 17, 2024, to June 23, 2024, and Period B was conducted from June 24, 2024, to July 7, 2024, for a total duration of 21 days.

B. Participant Attributes

Nine participants in their 20s were involved in IX.

C. Experimental Method

This section describes the methodology used in the demonstration experiment.



Skin Type Doctor

We will provide information on your skin condition, improvements, and maintenance methods based on one week's worth of data! ★

The data you submitted showed a percentage of *21/21 - 100.0%*

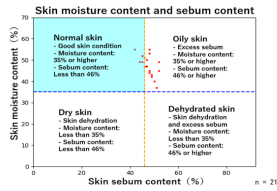
Please continue sending us more data, as it helps improve our analysis and advice.

We hope you can keep collaborating with us!

🔔 Skin Type Classification

Based on the analysis of the submitted data, your skin type is classified as "normal-oily". Below are your skin graph, summary, and improvement suggestions.

🔔 Skin Graph



🔔 Summary

- Water content fluctuates between 37% and 55%, with an average of 47.67%. This indicates that your overall water content is within a reasonable range.
- Oil content fluctuates between 36% and 62%, with an average of 49.26%, suggesting a tendency towards higher oil content.
- Changes over time:
 - Water content has decreased (average: 44.1%) and oil content has increased (average: 49.48%).
 - Participants with dry skin: Water content has decreased (average: 44.46%), oil content has increased (average: 47.99%).
 - Participants with normal skin: Water content has decreased (average: 49.52%), oil content has decreased (average: 45.95%).

🔔 Suggestions for Improvement

- Enhance your skincare routine**
The increase in oil production may be due to excess sebum secretion. You may want to consider reducing the use of oil-based products and cleansing twice a day. Consider using sebum-control skincare products as well.
- Ensure proper hydration**
As you have a tendency towards higher oil content, balancing water and oil levels is crucial. Drinking about 1.5-2L of water daily will help maintain proper skin hydration and may improve overall skin texture.
- Improve dietary habits**
Based on the high oil content in your skin, we suggest a well-balanced diet, avoiding too many high-sugar and high-fat foods. Adding vitamin-rich foods, such as green leafy vegetables, and consuming omega-3 fatty acids may help keep your skin healthy.
- Quit smoking**
Smoking has a detrimental effect on skin health, accelerating aging and causing wrinkles and dullness. Quitting smoking will positively impact your skin's appearance.
- Manage stress**
Stress from daily activities may be contributing to your skin condition. Try to alleviate stress through relaxation techniques, and ensure you are getting enough sleep to maintain hormonal balance.
- Ensure adequate sleep**
Based on the sleep data, poor sleep quality can negatively affect skin health. Aim for 7-8 hours of good-quality sleep every night, as this will support healthy skin regeneration.
- Humidify your environment**
Keeping the humidity level around 22°C and using a humidifier can help prevent skin from drying out. Ensuring a comfortable living environment will support skin health.
- Control room humidity**
Keeping room humidity around 40-60% is ideal. A humidifier or other moisture control methods can help prevent your skin from becoming too dry.
- Protect your skin from UV rays**
Protecting your skin from UV rays by using sunscreen or staying out of direct sunlight can prevent further damage. Sunscreen will also help prevent the formation of spots and wrinkles.

Fig. 6. Weekly Advice

1) *Intervention Method:* In the proposed system, participants were asked to use the skin checker three times a day (after waking up, before lunch, and before going to bed). The participants recorded their measurement results in a Google Form, which collected the skin condition data. Information was provided to the participants through dedicated channels in a Slack workspace created for the experiment. Each participant received information three times a day (at 7:00, 12:00, and 19:00) in their designated Slack channel.

2) *Pre-Experiment and Post-Experiment Questionnaires:* To verify whether the proposed system induced behavior change related to skin improvement, both pre-experiment and post-experiment questionnaires were conducted. Google Forms was used for the questionnaires. The pre-experiment ques-

TABLE X
PERCENTAGE OF NORMAL SKIN IN PERIOD A AND PERIOD B

Participant No.	Normal Skin (%) in Period A	Normal Skin (%) in Period B	Difference (%)
1	88.24	81.82	-6.42
2	12.5	55.56	43.06
3	11.11	28.57	17.46
4	31.58	17.07	-14.51
5	30	61.76	31.76
6	0	4.65	4.65
7	80	33.33	-46.67
8	6.25	21.21	14.96
9	19.05	30.77	11.72

tionnaire gathered participant attributes, their skin condition, lifestyle habits, and interest in skin improvement. The post-experiment questionnaire assessed whether behavior change occurred as a result of the proposed system and evaluated participants' experience using the system.

V. EVALUATION

This section evaluates whether the proposed system contributed to improving the skin condition of participants through the demonstration experiment.

A. System Evaluation

This subsection compares the percentage of normal skin in Period A and B in X.

Six participants showed an increase in the percentage of normal skin from Period A to Period B, while three participants showed a decrease.

B. Questionnaire Evaluation

This subsection describes the results of the questionnaire conducted with the nine participants after the demonstration experiment.

1) *Behavior Change Induced by the System:* This section evaluates whether the system induced behavior change aimed at improving skin condition. Questions 1, 4, 7, 13, 16, 19, 22, and 25 of the post-experiment questionnaire investigated whether the information provided led to behavior change. Responses were binary ("Yes" or "No"), with "Yes" indicating behavior change. XI lists the questions.

In terms of behavior change, 66.7% of participants reported changes in skincare behavior, 88.9% in hydration, 33.3% in diet, 22.2% in stress management, 44.4% in sleep, 44.4% in room temperature, 0% in humidity, and 55.6% in UV protection.

2) *System Usability:* This section evaluates the system's usability. Questions 29, 31, 33 to 35 of the post-experiment questionnaire investigated whether the content and frequency of the information provided were appropriate. Question 35 used a 5-point Likert scale, where higher values indicated greater perceived usefulness of the system for improving skin condition. XII lists the questions.

The post-experiment survey revealed that 88.9% of participants found the weekly advice helpful in improving their skincare routines, and 66.7% reported that daily advice encouraged

TABLE XI
POST-EXPERIMENT QUESTIONNAIRE 1

Question No.	Question
1	Did your awareness or behavior regarding skincare change?
4	Did your awareness or behavior regarding hydration change?
7	Did your awareness or behavior regarding diet change?
13	Did your awareness or behavior regarding stress management change?
16	Did your awareness or behavior regarding sleep change?
19	Did your awareness or behavior regarding room temperature change?
22	Did your awareness or behavior regarding humidity change?
25	Did your awareness or behavior regarding UV protection change?

TABLE XII
POST-EXPERIMENT QUESTIONNAIRE 2

Question No.	Question
29	Did the daily advice help you recognize and take actions to improve your skin condition?
31	Did the weekly advice help you recognize and take actions to improve your skin condition?
33	Was the frequency of daily advice (7:00, 12:00, 19:00) appropriate?
34	Was the frequency of weekly advice appropriate?
35	Do you think this support system is useful for improving your skin condition?

actionable behavior changes. Specific feedback included comments such as, 'The system made it easy to monitor changes in skin condition, motivating me to adjust my habits.' However, some participants suggested increasing the specificity of the weekly advice to better support behavior change.

Regarding the information provided, 66.7% of participants reported that the daily advice helped them improve their skin condition, and 88.9% reported that the weekly advice was helpful. In terms of the frequency of information, 66.7% found the daily advice frequency appropriate, and 88.9% found the weekly advice frequency appropriate. Furthermore, 88.9% of participants rated the system's usefulness for improving skin condition as 4 or 5 on a 5-point scale.

VI. DISCUSSION

This section evaluates the system's impact on skin improvement and behavior change.

A. Skin Improvement

The demonstration experiment showed that six out of nine participants increased their percentage of normal skin, indicating the system effectively supports skin improvement by providing actionable feedback. Users were able to make informed decisions based on their skin condition data, leading to better skincare routines.

However, three participants experienced a decline in normal skin. Post-experiment surveys suggested that improved sleep habits contributed to better skin outcomes, while those with worsened skin did not achieve improvements in sleep. A correlation between poor sleep quality and skin condition was observed, suggesting the system could benefit from incorporating enhanced sleep-related feedback, such as daily and weekly sleep metrics.

Although limited by a small sample size, the study highlights the system's potential, warranting larger-scale studies for validation.

B. Behavior Change

All participants made efforts to improve their skin condition, demonstrating the system's effectiveness in driving behavior change. Notably, eight out of nine participants reported positive changes in hydration habits, emphasizing the impact of hydration-related information. The success in promoting behavior change can be attributed to the system's clear, actionable feedback, which helped users adjust their routines. For example, specific advice on water intake timing and quantity made it easier for users to modify their behavior.

VII. CONCLUSION

This study developed a behavior change support system aimed at improving skin condition through data collection, personalized feedback, and user engagement. The system utilized a skin measurement device to track skin condition metrics and generate tailored recommendations.

The demonstration experiment results showed that six out of nine participants improved their skin condition, and all participants made efforts to adjust their behaviors. These outcomes suggest that the proposed system is effective in promoting skin improvement and encouraging positive behavior change.

Future work will focus on scaling the system for a broader audience by conducting studies with diverse demographics, including various age groups and skin types. Enhancing advice granularity and integrating feedback will improve usability.

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