BioCosMe: Lip-based Cosmetics with Colorimetric Biosensors for Salivary Analysis using Deep Learning

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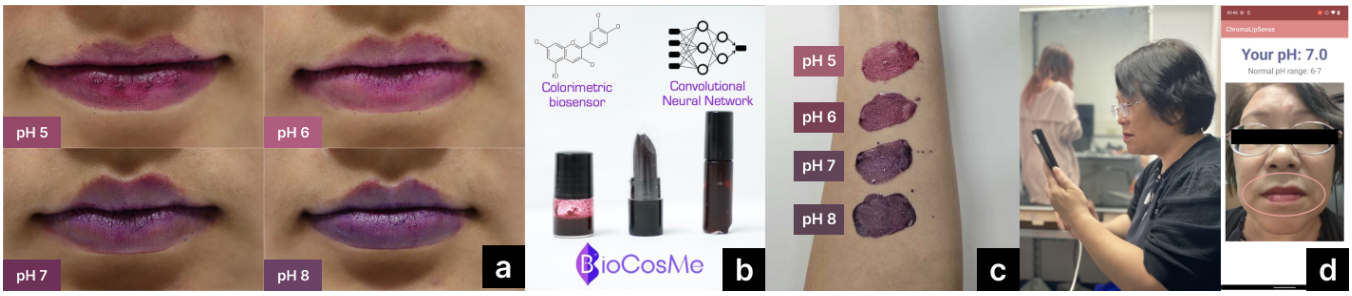


Figure 1: BioCosMe: a) Colorimetric demonstration across four pH levels; b) Three lip-based products; c) Technical evaluation of four pH levels on forearm; d) User checking pH value on mobile app.

Abstract

This paper introduces three lip-based product biosensors as novel form factors for health monitoring that display pH levels through color variation. Using the unique properties of lip—based products such as different colors, easy application and reapplication on lips, interaction with saliva, we aim to provide an always-available and non-invasive access to information typically obtained through lab analysis. This paper presents our skin-safe fabrication processes and technical evaluations of a lipstick, lip tint, and lip gloss. We created a mobile app with a Convolutional Neural Network (CNN) model to detect the pH levels. Our dataset involved six users, eight different lighting conditions, three cameras and seven pH levels. The results showed improved detection of pH variations compared to traditional methods. A user study with 11 participants was conducted to evaluate usability. This approach offers a convenient and unexplored form factor for monitoring biochemical information, blending self-expression with health awareness.

CCS Concepts

• **Human-centered computing** → **Human computer interaction (HCI)**; **Ubiquitous computing**.

Keywords

Lipstick, cosmetics, anthocyanin, colorimetric biosensors, biosensors, biocosmetic interface, deep learning, CNN, color detection

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1 Introduction

Measuring biofluids, such as saliva, blood, and sweat, is crucial for monitoring various health conditions through biosensors. Traditionally, biosensors have been used in medical devices and laboratory settings, but recent advances have led to their integration into everyday items. While transdermal sensors interacting with interstitial fluid are created in different forms such as patches with microneedles [15, 54] and permanent tattoos [58], they often present challenges related to invasiveness and tissue damage [50]. Non-invasive alternatives involve measuring sweat using skin-worn patches [13, 37, 62], temporal tattoos [3, 14, 16, 59], jewelry [31, 52, 66], and fabric [42, 71]. However, they can induce contact dermatitis, restricting their usability for analyte monitoring [35].

Saliva is an ideal medium for non-invasive biosensors due to its transparency, regenerative nature, and rich composition of crucial health-related information. Its composition includes enzymes, hormones, antibodies, and metabolic byproducts, providing diverse physiological data [40, 68]. That data can be exposed through colorimetric biosensors [63], whose colors chemically change to indicate specific analyte concentrations including pH [33], glucose [6, 8] and lactate [41]. It presents an easy collection process and direct correlation with the metabolism; however, its most common method of collecting saliva is in a container and applying it to a paper substrate is inconvenient for everyday use.

Lipstick, a widely utilized cosmetic, serves as an ideal substrate for biosensors due to its direct contact with saliva through lip gestures such as mouthwatering and lip smacking, and with food and drinks. Its portability, routine reapplication, and discreet nature make it well-suited for wearable biosensing devices. Additionally, the color variability inherent in lipsticks presents an opportunity to visually represent pH changes using anthocyanin [26, 43, 47], which transitions from pink to purple. The main contributions of this paper include:

BioCosMe as a Biocosmetic Interface: Creating 3 lip-based products as novel form factors for colorimetric biosensors, and introducing ***Biocosmetic Interface*** which combines cosmetics with biotechnology for health monitoring.

DIY Fabrication: Detailing a DIY process for biosensor lipstick, lip gloss, and lip tint with natural and skin-safe pigments and buffers for technical and user evaluations.

Machine Learning for On-Body Biosensors: Developing deep learning models and dataset for pH levels detection on lips.

Technical Evaluation and User Study: Technical evaluations show the biosensor efficacy and reversibility. User study conducted to understand usability of BioCosMe.

2 Related Works

2.1 Anthocyanin as pH biomarker in Saliva

This project uses pH biosensors as the proof of concept of lip-based cosmetics due to it has been widely study in the literature [5], availability of food-grade and skin-safe materials, and measurable concentration levels in saliva. For instance, pH is more alkaline in chronic gingivitis patients and more acidic in chronic periodontitis patients [2], it can provide metabolic, hormonal, and immunological aspects [9], has a relationship with stress levels [10], and changes on pH has been observerd in diabetic patients [48]. Another past research uses rosella flower extract as pH sensing in lip balm [53].

Other saliva-based biosensor projects include braceIO presented biochemical ligatures for dental braces that respond to pH, nitric oxide, and uric acid [55], Wearable Lab on Body showed a wearable on the cheek with a paper-based biochemical censor cartridge[40] and a 3D printed microfluidic device as a mountguard was created for detecting glucose and nitrate [12].

2.2 Color-Changing On-Skin Technologies

Color-changing skin technologies have been created for environmental monitoring and health diagnostics [38], leveraging the body's surface as an interactive display. EarthTones is a cosmetic-inspired wearable chemical sensing powder designed to detect and display harmful environmental factors through color change [18, 20]. Another environmental on-skin interface is ChromoSkin that integrates thermochromic pigments into makeup for dynamic color changes with temperature shifts [19]. Electrochromic films were used as displays on the skin[24, 65]. Dermal Abyss embeds biosensors in skin, replacing traditional tattoo ink to monitor real-time sodium, glucose, and pH levels [58]. Temporal tatoos were developed with colorimetric biosensors and microfluids [25]. However, makeup products, especially lip-based ones, have not typically been used to interact with saliva for monitoring health data.

2.3 Color Sensing Techniques

Colorimetric sensing relies on visual or instrument-based detection. Visual methods need large color changes for easy detection but can lead to human error. Instrument-based methods require specific lighting and spectrophotometers, which are time-consuming and need frequent calibration [1, 46]. Integrating machine learning with quantitative data extraction from images is a more efficient approach [51], but consistent detection still needs controlled lighting. A microfluidic colorimetric sensor improves accuracy with photos under 3000K to 6000K lighting [60]. However, maintaining consistent lighting for lip biosensors is more challenging than for sensors or test strips.

3 Fabricating Lips Products

The lip products are formulated using skin-safe, food-grade and cosmetic-grade materials [43]. Design considerations include the safety, commercial availability, and functionality of these biosensor and cosmetic materials. We also aim for consistency in material properties and color response across different pH levels, comparable to commercial products. Our goal is to achieve an optimal balance between effective biosensor functionality and desirable cosmetic qualities. The fabrication process and software could be downloaded from our repository[1]. The design considerations significantly influenced both the material selection and the fabrication process. We adhered to considerations common in biosensor [7, 39, 70] and cosmetic research [23, 61]. For the cosmetic aspect, priorities included safety with food-grade and skin-safe materials, performance in terms of longevity and ease of application or removal, and desirability concerning scent, color, and texture. For the biosensor aspect, efficacy was crucial for accurate results, quick color changes, and a

[1] https://github.com/InteractiveOrganismsLab/BioCosMe

pH range suitable for human saliva. Additionally, reversibility and reusability were essential for consistent accuracy and durability after multiple uses.

3.1 Form Factors

We implement biosensors into lip-based cosmetic products: 1) Lipstick: Wax-based cosmetic product that remains solid at room temperature; has a smooth, glossy finish when applied. 2) Lip Gloss: Viscous gel with a shiny gloss finish. 3) Lip tint: Water-based lip tint that dries to a natural finish.

3.1.1 Lipstick. Our calibrated formula includes:

- Commercial Lipstick Base (33.3%): Ensures safety, intensity, texture, providing shape and spreadable texture.
- Cetyl Octanoate (8.3%): Contributes to adhesion, hydrophobicity, and texture, serving as a waterproofing agent, emollient, and texture enhancer.
- Non-Nano Titanium Dioxide (8.3%): Intensifies the color and provides hydrophobic properties, offering waterproofing and opacity to the lipstick.
- Skin Safe Primer Adhesive (8.3%): Serves purposes of adhesion, texture, and forms a film or barrier on the skin.
- Clear Silver Mica Powder (8.3%): Provides intensity, range, and color.
- Red Cabbage Powder (33.3%): Acts as a pH sensing coloring agent, this powder contributes to the range, color, and efficacy of the lipstick biosensor.

The fabrication process begins by heating all the ingredients until fully melted (175°F). The mixture is then magnetically stirred as the temperature is reduced to 165°F, and transparent silver mica powder and red cabbage powder are added. To ensure a smooth texture, it is mixed continuously for about 20 minutes, allowing for thorough blending and homogeneity. Upon reaching the target temperature, typically maintained for 5 minutes, the formula is poured into silicone molds to create bullet-shaped lipsticks. These molds are pre-chilled at 35°F and are immediately chilled again after pouring to preserve the desired final texture. After 10 minutes, the lipsticks are removed from the molds and inserted into lipstick containers for further chilling for 15 minutes before being stored at room temperature until usage.

3.1.2 Lip Gloss. The pH-sensitive lip gloss fabrication follows a similar process than our lipstick biosensor (detailed above) with minor adjustments in the proportions to achieve its liquid and gel-like consistency feature. Our calibrated formula includes: Lip Gloss Base (33.3%), Cetyl Octanoate (8.3%), Non-Nano Titanium Dioxide (8.3%), Skin Safe Primer Adhesive (8.3%), Clear Silver Mica Powder (8.3%), Red Cabbage Powder (33.3%).

The lip gloss fabrication process begins by heating the specified portions of each ingredient until fully melted, typically reaching 175°F. The mixture is then magnetically mixed until completely melted. Subsequently, the temperature is reduced to 165°F, and transparent silver mica powder and red cabbage powder are added while it is continuously mixed for about 20 minutes, allowing for thorough blending and homogeneity. We then blend the lip gloss without heat till it reaches below 130°F to pour into the lip gloss containers. The lip glosses are then chilled at 50°F for approximately 15 minutes before being stored at room temperature until usage.

3.1.3 Lip tint. We blend common cosmetic lip tint ingredients to create a product that delivers color and retains biosensing abilities. Our calibrated formula includes: 30 g Red Cabbage Powder, 8 g Clear Silver Mica Powder, 200 mL Deionized Water, 80 mL Vegetable Glycerin, 5 mL Phenoxyethanol, 3 mL Polysorbate 80.

The procedure begins by mixing 80 g of cold water, from the total 280 g, with the chosen powder (red cabbage) gradually until well combined. Following this, glycerin is added to the mixture and thoroughly mixed in. While this mixture is blended for about 5 minutes at 165°F, additional water is gradually added until the mixture reaches a thickness similar to room-temperature olive oil. The mixture is blended without heat until it reaches below 120°F to safely add Phenoxyethanol and Polysorbate 80. Finally, an additional 10 minutes of blending will ensure texture and consistency. The lip tint is stored in a small 5 ml bottle for application. To apply the lip tint, a lip brush is used, ensuring that the lips are dry and free of lip balm or other oil-based products.

4 Biosensor Evaluations

4.1 Artificial Saliva pH Buffer Solutions

To evaluate the color changing properties of all biosensors, we subject them to tests of pH 5, 5.5, 6, 6.5, 7, 7.5, and 8, matching pH values typical of human saliva in normal and abnormal conditions [10, 36]. We fabricated pH buffer solutions with artificial saliva and food safe acid and base materials[29, 72]. Our artificial saliva ratio involves 0.085 g of sodium chloride, 0.12 g of potassium chloride, 0.02 g of calcium chloride, and 0.005 g of magnesium chloride for every 100 g of deionized water. To alter the solutions to desired pH levels, we used sodium dihydrogen phosphate dihydrate (H2NaO4P) and acetic acid (C2H4O2). Each solution is mixed with a magnetic stirrer at 75°F. The solutions are then each checked with an industry digital pH meter to ensure accuracy.

4.2 Technical Evaluation

We test each biosensor with each of the seven pH levels mentioned on a forearm, and take photos of the results with seven different lighting conditions. For this test, we used pH solutions at 10 mM H2NaO4P. To ensure consistency of testing, we used the same person's forearm to evaluate all three products and all pH levels.

Lip Stick To begin testing, we clean the participant's forearm with alcohol. We then place a square stencil on the cleaned area of a human forearm and apply the lipstick to the designated area. Next, 0.25 mL of the pH solution is dropped onto the lipstick with a pipette. The results are photographed in all lighting conditions. The area is then cleaned with make up remover and wiped dry to be ready for the next test. This process is repeated for all pH levels.

Lip Gloss The process for lip gloss is similar to that for lipstick, with camera angles adjusted to minimize glare from the glossy surface, ensuring accurate color representation in photos.

Lip Tint Given the lower pigmentation of the tint compared to the other products, we applied two layers for each test. After applying the first layer with a stencil, we allowed it to dry for approximately one minute before applying the second layer. The

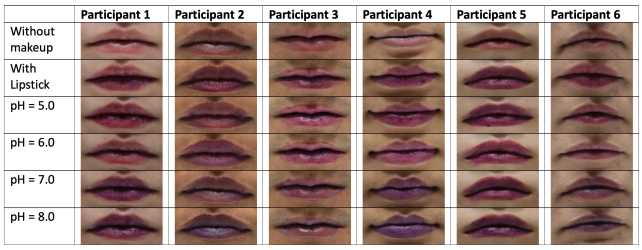


Figure 2: Participants lips: without makeup, with BioCosMe, and with BioCosMe in Four pH solutions.

biosensor was then tested and photographed following the same protocol used for the lipstick.

4.3 Reversibility and Re-usability

To test the color reversibility of the biosensor, the ability to produce accurate results after prior usage, we subject the biosensors to two series of the artificial saliva pH buffer solutions of varied base and acid concentrations. The first series of buffer solutions contain around 10 mM of sodium dihydrogen phosphate dihydrate (H2NaO4P) and the second around 100 mM. As we test multiple times using the same biosensor, in this series of testing, we not only test the reversibility of the biosensor, but also the re-usability, referring to how many times the biosensor can be used before physically deteriorating. For each biosensor, we performed 7 tests in series using pH levels 5, 6, 7, and 8 from both concentrations. We first subject the biosensor to the 10 mM series (5 to 8). Then, using the 100 mM concentration solutions (7-5). The results for lipstick and lip gloss showed that the products were able to product accurate results and lasted through all seven rounds of repeated testing.

5 Software Implementation

5.1 Biosensor Color Detection and CNN

Models. Our framework includes three models: two supervised machine learning models commonly used in colorimetric biosensors: Random Forest (RF) [21] and SVM [22, 34, 51], and CNN [11, 67].

Datasets. We created our own dataset that includes 2304 images. Six participants (five females, one male) participated in the data collection. They were healthy individuals without skin allergies and had previous experience with cosmetics. Images were captured in the Color Lab at the California Lighting Center (UC Davis). Eight color temperatures are used, each with specified illuminance levels and color rendering indices (CRI): 2200K, 2700K, 3000K, 3500K, 4000K, 5000K, 5700K, and 6500K. Three camera devices were used: Canon EOS R, Pixel 6 smartphone and the Iphone 15 pro smartphone. The testing setup placed the cameras directly in front of the subject, who rested their chin on an optometry lifting chin bracket. To represent saliva with different pH values, seven solutions were prepared with 5, 6, 7, and 8 pH levels. Figure 2 presents a sample of our dataset with lips without makeup, with BioCosMe, and after applying different pH solutions. Figure 3 showcases lips with BioCosMe on pH 8 under all the lighting conditions.

Data Pre-processing. We preprocess the images by cropping the lips and resizing them to a resolution of 128x128 pixels, resulting

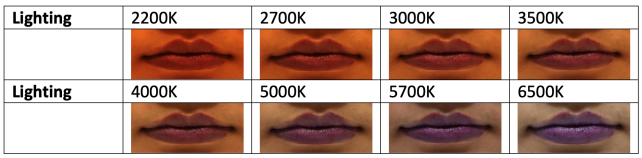


Figure 3: P4 lips with same pH in 8 lighting conditions.

in a total of 2304 images. For the RF, and SVM models, the medium RGB color values of the 128x128 pixels are calculated and used as inputs. For the CNN model, the entire cropped 128x128 pixel image is utilized as input. To enhance the model's ability to generalize to unseen data, we randomly divide the dataset into three subsets: 70% for training, 20% for validation, and 10% for testing.

Training Details. For the training of the RF and SVM, we used a grid search approach to determine the optimal set of hyperparameters. For the Random Forest model, we configured the parameters as follows: $n_estimators = 150, max_depth = 9, max_leaf_nodes = 6$. For the Support Vector Machine, we used the Gaussian Radial Basis Function (RBF) as the kernel function, with $\gamma = 0.001$.

For the CNN model, we utilized the default pre-trained weights from ResNet18. After experimenting with various configurations, we decided to freeze the first 14 layers and train the remaining layers along with a single fully-connected layer for 100 epochs. Model weights were selected based on cross-validation performance. We applied data augmentation techniques to the training set, including random flipping and cropping of images. During the training of the CNN model, we set the learning rate to 0.001 and the batch size to 16. The Cross Entropy loss function was chosen, and the Stochastic Gradient Descent (SGD) optimizer was used to update the model's weights and biases during training.

5.2 Evaluation

Table 1 presents the overall results of the RF, SVM and CNN models. We report classification metrics including precision, recall, and F1-score on the test set. These metrics provide a detailed understanding of each model's performance and its ability to correctly classify pH values based on color changes in the biosensor lipstick.

Model	Recall	Precision	F1
SM	0.23	0.31	0.26
RF	0.39	0.39	0.38
SVM	0.41	0.41	0.39
CNN	0.92	0.92	**0.92**

Table 1: Performance metrics of different models.

We compare the machine learning models with a standard method (SM) for biosensor analysis as described by [64]. This method involves comparing the readout color extracted from the images with the reference color of the biosensor lipstick. We calculate the CIE color distance between the readout color and the reference colors corresponding to the four pH values. The pH value associated with the shortest color distance is selected for detection.

Among the evaluated models, the CNN achieved an F1-score of 0.92, significantly outperforming the RF and SVM models, which

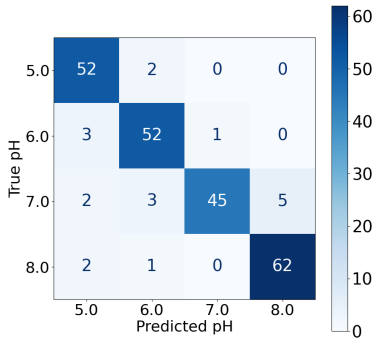


Figure 4: CNN model's test confusion matrix.

scored 0.38 and 0.39, respectively. The standard method demonstrated the lowest performance as it does not utilize any machine learning techniques. The lower scores for RF and SVM can be attributed to their inability to accurately assess the overall image color. In contrast, the superior performance of the CNN can be ascribed to the use of a pre-trained model, which leverages valuable information from extensive image datasets, allowing it to capture intricate details in images more effectively.

We tested the performance across various pH levels using a confusion matrix. As shown in Figure 4, while the CNN model performed well, it exhibited few misclassifications at all pH levels. We conducted a Leave-One-Participant-Out (LOPO) test, which achieved an average accuracy of 37%. Future works can use other biosensors with a wider color range between concentrations and expand the adaptation to that range with more than six participants.

5.3 Mobile application

A mobile application detects the pH level of the biosensor lipstick by capturing images from lips with the applied lipstick using the front camera. It extracts the readout color from the captured image and transmits it to a server for further processing. On the server side, a ResNet-18-based CNN architecture is utilized to analyze the color data and accurately classify the pH level. The ResNet-18 model, pre-trained on a large dataset, is fine-tuned to enhance its performance on our specific dataset.

6 User Study

A user study was conducted to evaluate the use of lip-based products as a substrate for biosensors. The study focused on color detection accuracy, comfort, color visibility, usability, and mobile application usage by questionnaires and interviews. Eleven English speaking participants were recruited through advertisements and word of mouth, each receiving a $15 Amazon gift card upon completion of the 1-hour study. They identified as female, and their ages range from 18 to 53 (Mean = 30, STD = 10). The participants had 2 to 30 years of lip cosmetic usage experience (Mean = 11.5, STD = 7.9). Two participants reported using lip products every few months, seven used them weekly, and two used them daily.

6.1 Procedure

We began by briefing participants on the project and study process and obtaining their consent. They completed a demographic questionnaire on their past use of lip products and use of health-related technology. Each participant provided a saliva sample, which we tested with a commercial saliva pH test strip and a digital pH meter to establish a baseline for comparison with our biosensor. We provided our single-use lip products, mirrors, applicators, and makeup removers as needed. We ensured that they removed previous products and dried their lips between tests, moisturizing to their satisfaction before continuing.

Participants applied the lipstick and used the app to read their pH, comparing it with previous saliva sample results. They applied pH solutions (5 and 8) to simulate lip licking, collected data using the app, and observed color changes with a mirror. After evaluating the lipstick and app, they applied lip gloss, wetted their lips with saliva to observe color changes, then applied lip tint, waited 3 minutes to dry, and wetted their lips again to see the color changes. Finally, participants completed a post-questionnaire using a 7-Likert scale from (1 least favorable and 7 most favorable) and participated in an open-ended interview about their experience.

6.2 Findings

Through both the questionnaire and the interview, the participants responded mostly positively. All eleven participants rated the overall system favorably, averaging 6 out of 7 (STD = 1).

6.2.1 Lip Cosmetic. In evaluating the lip products as cosmetics, all responses indicated that they were at least comparable to commercial lip products. The general comfort level was rated above neutral (Mean = 4.6, Median = 5, STD = 1.7). Four participants found commercial lipsticks more comfortable, while the remaining seven preferred our biosensor lipstick. This aligns with interview responses, which indicated that our biosensor lipsticks were similar to commercial products.

Participants showed interest in various types of cosmetics. The preferences followed in this order: lip gloss, nail polish, lipstick, lip stain, temporary tattoos, blush, cream or lotion, henna, eye shadow, mascara, eyeliner, eyebrow pencil, foundation, and body glitter.

Participants were asked to evaluate our products based on our fabrication design considerations such as scent, longevity, texture, color (hue), color intensity (opacity), finish, and moisturizing properties. The least well-received factor was texture, with ratings below other criteria (Mean = 3.64, Median = 3, STD = 1.55). This is attributed to the biosensor reagent's low solubility in lipstick ingredients. Opinions on color and scent were split, reflecting personal preferences. All criteria had a standard deviation under 1.6, except those related to personal preferences "scent" (STD = 1.9) and "texture" (STD = 2.06). During interviews, four participants (P2, P8, P9, P11) strongly enjoyed the scent, while two (P4, P7) strongly disliked it. Similarly, for color (hue), P1 and P4 rated it 1 out of 7, but P3, P9, and P11 rated it 7. P11 specifically stated, "The color is very pretty; I would wear it just for that. On top of that, it also helps track pH."

6.2.2 Biosensor. All participants agreed that the color change properties of the colorimetric biosensors were noticeable by human eyes. The biosensors were deemed to be effective in response to lip wetting and artificial saliva. The efficacy of color change obtained the

highest score with both median and mode of 7 (Mean = 5.8, STD = 1.5). Compared to test strips and digital pH meters, the participants rated the convenience of the lipstick biosensor favorably as well (Mean = 5.4, STD = 1.66). The confidence of using the lipstick biosensor for pH measurements averaged 5.09 (STD = 1.08).

6.2.3 Privacy. We included questions on privacy concerns due to the publicly visible nature of the lip product biosensors and general privacy concerns with an app that takes photos. The results were surprising in that few of the participants indicated much concerns. In the interview, the participants explained that it is not strictly due to the potential exposure of their saliva pH values as they didn't associate the color as a biodata.

Few participants stated that it would be reassuring to have others help them notice if issues arise, or that they would like to help others track their health. For example, P2 stated *"it would be useful for others to help you see if you have an issue, like if one day I came in with blue lips, my friend could point it out before I even knew."* P11 stated that *"I wish my grandma used lipsticks, so I could help her track her health. Or may be I will have my mom use it."*

6.2.4 Application. The participants stated that the app was easy to use, some even brought up that they "liked how the app is straightforward" during the interview (P3, P4, P6, P7, P9, P10). They appreciated the history view that show their results, without saving photographs for privacy concerns.

7 Limitations and Future Works

Expound Cosmetics. As suggested by some participants, the current color may not suit everyone's preferences. Future work will modify the formula to include a wider range of pigments and reduce the amount of biosensor color reagent. This will help achieve a balance between accurate detection through our model and a variety of colors that lip cosmetic users may prefer, and will camuflage the color to reduce the chance to associate to a health data.

Our products were mentioned in the top 4 of the preferences list. This supported our fabrications of current products as well as promising future products. Most participants felt that some cosmetics, such as foundation—which is typically matched to the skin tone—were unsuitable for color-changing biosensors. Based on our study's results, we will explore incorporating biosensors into various other desired cosmetic forms such as nail polish and blush.

Potential Applications. By exploring additional biomarkers, we aim to expand the applications of our prototype. During the user studies, glucose monitoring was frequently mentioned for diabetic monitoring. Many participants (P1, P2, P3, P6, P7, P8, P10, P11) expressed interest in using the biosensor lipstick for monitoring sugar intake or saliva glucose levels. A lipstick capable of detecting salivary glucose offers a non-invasive option for diabetic patients, with glucose levels ranging from 1.0 mg/dL to 20 mg/dL [45]. Moreover, illnesses often require monitoring multiple analytes; for instance, lower pH levels have been detected in diabetic patients [49].

Monitoring hormonal fluctuations using hormone-sensitive compounds like hCG facilitates menstrual cycle tracking and hormonal imbalance management, a potential that a few participants from our user study mentioned (P1, P2, P10), while cortisol-sensitive colorimetric biosensors in lip products enable stress management by assessing salivary cortisol levels [17, 32].

Salivary chloride concentrations can indicate electrolyte balance and renal function, aiding in the detection of dehydration and metabolic disorders, thus serving for hydration status and electrolyte balance monitoring [4, 28]. Salivary biomarkers also indicate nutritional deficiencies in vitamins and minerals, allowing individuals to address dietary imbalances and optimize nutritional intake for adequate nutrient absorption and metabolism [27].

Salivary nitrite levels reflect physiological processes such as dietary nitrate intake and nitric oxide (NO_2-) metabolism, offering insights into cardiovascular health and inflammation [44, 69]. Furthermore, integrating colorimetric biosensors sensitive to skin health indicators like lead (Pb) and cadmium (Cd) supports monitoring skin conditions, including irritations, allergic reactions, or the presence of toxic elements in sensitive areas like the lips [30].

Limitations. Even with the promising results, this project has several limitations. Future works must conduct in-the-wild studies to detect durability on lips, reversibility, speed of change, interactions with food and beverages. However, we envision the product being reapplied after eating or drinking, similar to common lip products. Additionally, a larger dataset could improve the LOPO test results. We also recognize that our dataset does not include every skin tone, which could lead to higher errors. Considering frameworks like Monk Skin Tone can support more equitable datasets and generative AI to expand our dataset with several skin tones.

8 Conclusion

This paper introduces BioCosMe, a novel approach to colorimetric biosensors through lip-based products: lipstick, lip gloss, and lip tint. These products represent new form factors for integrating biosensors into everyday cosmetics. We presented our DIY fabrication process for these biosensors, utilizing natural skin-safe materials to ensure both technical reliability and user safety. Our work implements a CNN model and our own dataset for pH level detection on lips in different lighting conditions, demonstrating the application of ML techniques to on-body chemical biosensing. Technical evaluations confirm the efficacy and reversibility of the biosensors. A 11-participants user study provides insights into the usability of BioCosMe, highlighting its potential as a practical and user-friendly solution for real-time health monitoring. Previous research has explored Beauty Technology [56, 57] that merges cosmetics with electronics. We introduce a novel subfield in Human-Computer Interaction (HCI) known as ***Biocosmetic Interface,*** which integrates cosmetics with biotechnology for health monitoring. This approach transforms the body surface into a dynamic display of biochemical reactions. It aims to enable the development of new *biocosmetic interfaces* that utilize beauty products to access typically unexplored bodily compartments, such as bodily fluids.

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