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Extensive Review on Humidity and Moisture on Skin Device Analysis

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Abstract:
Moisture and humidity influence the skin properties, particularly in the coefficient of friction (CF). In the process of dexterous manipulation, changing in skin hydration will trigger the mechanical properties of object interface and alter the required minimum force to slip any object on the surface. The moisture level of the skin can be obtained based on two principles either the principle of capacitance or conductance. However, there are only few studies reported on the device to measure skin moisture with limited information on the device capacity. On the other hand, currently available devices in the market are mostly manual reported, and it is difficult to find a complete research study on the device prior to marketing. Other devices that are familiar in the aforementioned fields are normally established based on the lab scale standard in comparison with the developed devices, which are not for universal use. For example home-based monitoring or personal skin care routine. Not to mention, the measurement varies from image sensor and many others. Therefore, in this study, the fundamental concept of a device based on pressure sensor was discussed. The information on the quantitative skill measurement was also provided. In the last part, all the devices that are related to moisture and humidity measurement were tabulated and their performances were highlighted.

Keywords: Moisture; Humidity; Skin device.

1. INTRODUCTION

To study dexterous manipulation, the mechanical properties of the skin are very important to master. These mechanical properties are strongly influenced by moisture and humidity of the skin, particularly in the coefficient of friction (CF). In the process of dexterous manipulation, changing in the skin hydration caused the mechanical properties of the object interface and altered the minimum force required to slip any objects on the surface (1, 2). Study by (3, 4) showed that scopolamine will increase prehensile force as a consequence of reducing the palmar sweating. Similar trend was also found in (5, 6). In the study, the variation in CF induced by different levels of skin hydration were detected in different behaviour of study manipulation.

The moisture level of the skin can be determined based on two principles which is capacitance or conductance. It is easy to understand the principle behind these two kinds of moisture methods. It is because a simple electrical model of the skin as a resistor is in line with a capacitor. The reason behind this situation is because the value of both components can be influenced by the water content of the skin. The architecture design of probe electrodes, the frequency of the current and the design of electric circuits can influence the resultant of this measurement principle (7, 8). For example, researchers (9, 10) studied on two commercial devices; Corneometer® (capacitance based) and the Skicon-200 (conductance based). From the study, the results showed that there is good correlation between the methods and lower sensitivity when the hydration is at lowest value (conductance based) and the same trend for capacitance based; the sensitivity test is lower when the hydration level is high. Other type of devices like SkinChip, the MoistureMeter, the Nova DPM 9003 and Dermalab also tested and compared (11–16).

However, up to the authors' knowledge, there are not many studies reported on the device to measure skin moisture and the information on the device capacity is also scarce. On the other hand, the devices that are currently available in the market are mostly reported only on the manual, not the completed research study of the device before they are marketed. Other devices that are familiar in the aforementioned fields are normally established based on the lab scale standard to compare with studied devices, not for universal perusal for example home-based monitoring or personal skin care routine. Not to mention, the measurement from image processing (fit in industry 4.0) and many other sensors are also limited.

Therefore, in this study, the basic concept of the device design based on pressure sensor, focusing on humidity and moisture skin analysis will be discussed. The mathematical equation on the quantitative measurement also provided. In

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the last parts, all the devices that are related to moisture and humidity measurement that are available in research and in the market will be tabulated and their performance also highlighted.

2. FUNDAMENTAL CONCEPT OF THE DEVICE BASED ON PRESSURE SENSOR

The most common methods to measure skin moisture content for humans is using Bioimpedance Analysis (BIA) and Capacitance method. The development of bio-impedance analysis techniques as a noninvasive, affordable, and secure tool for assessing hydration status has been the focus of recent study. The foundation of bio-electric impedance analysis (BIA) is the ability to simulate bodily tissue as an electrical circuit with capacitance and resistances. The BIA and capacitance methods are focused on the upper layer of skin that is stratum corneum (17). Figure 1 shows the layers of human skin in general.

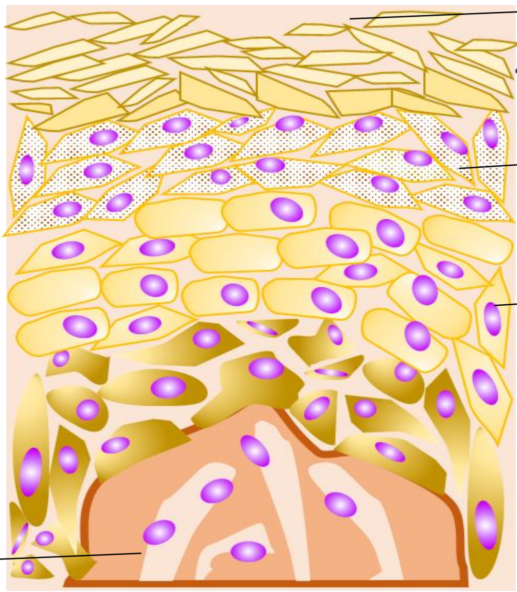

Figure 1. Layers of human skin.

The stratum corneum is the upper layer of the skin (18). As the upper, it mostly consists of dead skin cells that can be slough off and replaced by the layer below them. Keratin was known as the protein responsible to work out to replace those dead skin cells. Keratin has a function to prevent the water evaporation and to absorb the water into skin. Therefore, the hydration of the skin can be measured through this stratum corneum layer. This is important to prevent dry skin. On top of the stratum corneum, which is the horizontal layer is the dead skin, and the body will secrete the oils through that layer. The oils in stratum corneum will be used to protect the body from foreign invaders such as allergens (18–21).

2.1 Bioimpedence Analysis (BIA) Method

Bioimpedence analysis (BIA) method is a method that is normally used to estimate body composition, for example body fat or total body water. The concept of BIA is applying an electrical impedence or hostility to the electric current through the body tissue. A total of 50KHz current is typically supplied to the skin. This method can estimate the amount of water (moisture) on the stratum corneum of top skin and also the amount of oils in the skin (22–34). Towards this versatile application is that commercialized BIA skin moisture sensor in cosmetics. The device is normally designed in small size and the tip of the device consists of a transducer. This transducer is present in the form of two protruding metal electrode rods. When the electric supplies from the device, the quantitative measure can be obtained, representing the quantity of water content in the body (17, 35). Despite versatile applications, using BIA can spot many advantages. These include the consistency of the results obtained, simple method, cheaper and also easy to fabricate. However, there are also some drawbacks of BIA. Compared to other devices for measuring body composition, this method can be considered as not accurate. It is not eligible to refer as gold standard. Even though attempts have been made by multiple electrodes to increase the frequencies, BIA still cannot use as reference method to compare with others (35).

2.2 Capacitance Method

Compared to the BIA method, the capacitance method is a method that is specifically applied to measure skin moisture. Normally, this method will have two parallel plates that are capable of holding the charge. In between the designed plates, there is electrical flow. Every edge of the plates there will be ‘scatterfield effect’ objectively. The charge between the plates was controlled by the capacitor. Any materials that are greater than 1 with a relative static permittivity can concentrate electrostatic lines of flux as effective dielectrics and water is considered as dielectrics (35, 36). Therefore, in the concept of capacitance method, increasing the quantity of water in the skin is parallel to increase in capacitance. The transducer in this method was called an ‘interdigital capacitor’ (IDC). The interdigital capacitor (IDC) is basically a thin strip of copper

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designed with small distances to utilize the scatterfield effect. This copper strip is normally fabricated on a printed circuit board (PCB) laminate. An example of IDC is depicted in Figure 2.

The sensitivity of the sensor is increased as the distance in between the interdigital decreases. This sensitivity also can be influenced by different types of metals used. For example, commercial devices named Corneometer® use thin gold strips as their sensor instead of copper strips. Building an IDC on a PCB is preferable as it can be fabricated on a PCB milling machine. This machine has some advantages as they can remove the unwanted copper and leave the copper shape as Figure 2. The squares in the picture have a function to attach the leads. In general, the basic concept of capacitance method is depicted in Figure 3. The scatterfield on the top will penetrate the stratum corneum layer of the skin when the IDC touches the skin. The penetration depth is parallel to the distance between the strips. As the strip is closed, the depth of penetration is higher. The corneometer® is the gold standard device for analysis (37).

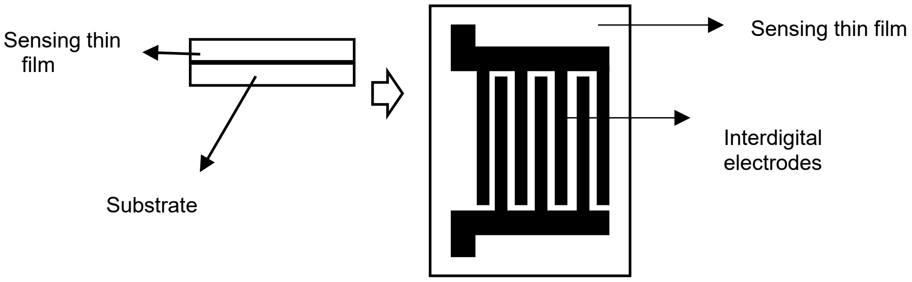

Figure 2. The structure of simple IDC.

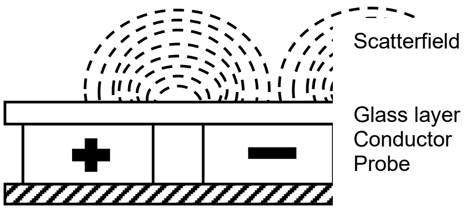

Figure 3. Illustration on scatterfield effect of IDC.

Compared to both methods, the BIA method has advantages over the capacitance method in terms of costing as the cost for the capacitance method (taking into consideration the cost of Corneometer ®) is $5200USD and £1,450.00 in 2024 (38) and the price for the probe alone is $2800. Many researchers could not afford the price and the only supplier for the device is Courage-Khazaka Electronic. However, the capacitance method is more accurate than the BIA method.

2.3 Modules to Ensemble the Device

There are basic modules used to ensemble the device for humidity and moisture analysis. These include a transducer, capacitance for measuring the circuit, signal processor, Analog-to-Digital Converter (ADC), microcontroller and the display. The transducer that is used in the device is called IDC, which functions to convert the quantity of skin moisture into capacitance (35). Meanwhile, the circuit that will be used to measure this capacitance will have raw signal to integrate the signal into ADC. This ADC then will be connected to a microcontroller to control the display. The display will show the results either in the form of LED or LCD screen. In short, the module is depicted in Figure 4 and description in Table 1.

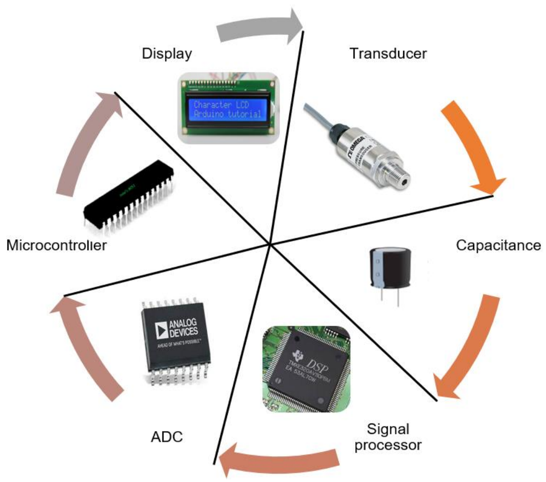

Figure 4. Basic skin moisture device modules.

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Table 1. Description of different modules.

Modules	Description
Transducer	- Two types of transducers for the device; two metal rod electrodes or an IDC. - In the BIA method, two rod electrodes were used to determine the moisture. - In the capacitance method, IDC will be implanted. Not many companies are using IDCs approach since the difficulty of finding IDC is crucial. Instead, the price to get individual item is also very expensive. - Students can design the proposed IDC using an IEEE milling machine or the IDC can be ordered from a local electronic supplier (whether in the form of a new shape proposed or suggested by the supplier).
Capacitance measuring circuit	- *tau* = R×C, where “R” represents the equivalent resistance of the circuit and “C” is the capacitance of the IDC (35). - Allow the IDC to be charged by battery or any other way like through USB and it will discharge through the circuit’s resistance. - The time for the IDC to fall to 0.707 times its maximum value is from time constant (*tau*). - Controlled by a microcontroller. - The discharged voltage is normally will be collected in ADC and the digital output of ADC with combination of timer will help microcontroller determine the discharge time.
Signal processing	- 98.80 microsecond. - One method of signal processing is equivalent to the signal used in ADC. - Frequency of 10MHz. - A microsecond timer will be used to time the duty cycle of the signal. Meanwhile, this duty cycle is equal to the test capacitance used to produce the signal. - Oscilloscope is used to test satisfactory accuracy of sample signal at 10 MHz aforementioned frequency. - Very sensitive and extra care should be taken to preserve accurate measurement data here.
Microcontroller	- To display numerical results. - Example of microcontroller that is normally used for research is AVR Butterfly microcontroller kit. This controller is complete with an ADC converter and LCD screen. - Required two normal 1.5 V AA batteries in order to function. - Preparing separated ADC and LCD screens normally resulted in tedious work and the cost was also higher compared to this completed kit. Instead, this kit can be programmed in both C and assembly. Full code is available in the C programme.

2.4 Optical Method to Measure Skin Hydration

Apart from using BIA and capacitance methods, skin hydration also can be measured through optical fibre-based devices. The method relies on the change in refractive index value through water content measurement. They provided a fibre-optic probe to be pressed on the skin and when the light is effectively reflected the walls of cladding. If the refractive index (η_{core}) is higher than the skin (η_{skin}), the reflected light will be higher and vice versa. Example of a fibre-optic probe is depicted in Figure 5 (39-40).

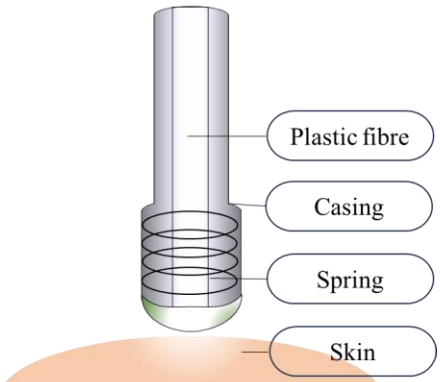

Figure 5. Basic design of fibre-optic probe.

3. QUANTITATIVE MEASUREMENT OF DEVICE SENSOR

3.1 Bioimpedance Model

In circuit, 0 volts represents 0 pF and 10 volts is equal to 100 pF. This means that 0 to 10 V scales is equal to 10 pF-1 nF scales of capacitance. The circuit normally relied on a special chip called 74C14 Hex Schmitt Trigger. The circuit will work successfully by charging the test capacitance to 70% of its maximum value. The 120k resistor and 2k2 diode will be combined with this chip’s internal oscillator work to divide the charged time to 100 units. This means 100 pF capacitor will take 100 units time of charge (1 pF capacitor = 1 unit of time to charge, 45 pF capacitor = 45 units time to charge to 70% aforementioned its maximum value). 1 unit of time is equal to 1.012 μs. The remaining charging test capacitance (23 units of time will not be charged to 77 pF capacitor). 77% of duty cycle is considered high and balanced 23% of duty cycle is considered low. The high signal of the cycle is equal to 10.15 V and the low is equal to 8.859 V. Therefore, 12 V battery or battery life is used to cover the circuit [A]. However, in order to obtain a low-pass filter of DC signal, the first order low-pass filter is used. This filter is implemented to the resistor of 1 MΩ and 1 μF capacitor to give an effective cut-off frequency of approximately 0.16 Hz cut-off frequency. The equation here is $2\pi F = 1/RC$, where F here represents the value of cut-off frequency.

3.2 Optical Parameters

To attain optimal/desired bio-optical results, computational studies are essential for comprehending the impact of both non-optical (such as tissue layer thickness) and optical input factors (such as wavelength, beam size, etc) (41). In recent years, optical technologies have revolutionized medical diagnosis, surgery, as well as treatment, and the medical device sector offers optical technology a plethora of opportunities. The greatest technological area in medicine is optical fields, which include endoscopy, microscopy, robotics, lasers, optical surgery, and ophthalmic optics (42). These disciplines account for $73 billion of the global market. Considering the size of this industry, it is expected that advances in optical fiber technology will result in thinner and smaller fibers; increased use of noninvasive imaging techniques like optical coherence tomography (OCT) and higher resolution imaging; and increased accuracy and use of laser-based therapeutics (42). Most medical specialties use optical devices, which are not limited to microscopes. They also include ophthalmoscopes, otoscopes, endoscopes, colonoscopes, surgical microscopes, and imaging equipment used in robotically assisted surgery (42–43).

4. DEVICE APPLICATIONS ON SKIN MOISTURE AND HUMIDITY MEASUREMENT

The list of skin moisture and humidity that is available in the market with different companies manufactured is tabulated in Table 2. These are a few examples of the device. The device is applied using BIA and capacitance methods. The devices are for skin moisture analysis. There is also nano mist spray that can be used to control the moisture of human skin. The concept of the device is almost the same to all where they are designed with two metal balls or copper electrodes and also the use of gold strips to measure the moisture on the top of skin. Some of them might show the results on the LCD screen and some other types may be connected to smartphones and the skin condition can be monitored through the smartphone's screen. All the devices can read the skin condition within a few seconds. The device is designed with battery connection and also the use of USB cable to connect with other facilities or also can be battery life. All the devices mostly originated in China and the price offered is below $100 per unit. From the authors research, the standard reference devices that are normally compared for lab scale and the device that is under study are tabulated in Table 3 and 4, respectively. For standard devices (Table 3), it is used as a control to compare with research devices meanwhile the devices that are under progress and still need provision and extensive study are in Table 4.

Table 2. Moisture devices that are available in the market.

Devices	Properties	References
MiLi Pure Skin Moisture Detector White	- Metal balls - In 5s processing - Mobile apps - Screen results - Battery - Bluetooth - Real time - Skin's moisture level and tips for skin dryness - MiLi - China - $59.90	(44)
H20 Beauty MiLi Pure II Skin Moisture Detector White	- Metal balls - In s processing - Mobile apps - Screen results - Battery - Bluetooth - Real time - Skin's moisture level and tips for skin hydration - MiLi - China - $40	(45)
Digital LCD facial bia skin analyser salon spa home handheld face water skin moisture	- Probe - In s processing	(46)

Devices	Properties	References
	- Digital - Battery - Real time - Moisture, oil, softness - Kedida - China - $7.41	
Digital LCD skin moisture oil analyser detector face care professional set	- Probe - In 5s processing - Digital - Battery - Real time - Skin's moisture & skin routine - Riuty - $15.99	(47)
Skin care tools moisture meter LCD digital facial skin face moisture analyser	- Copper probe - In s processing - Digital - Battery - Real time - Moisture, skin type, oil - Sonew - China - $19.97	(48)
Digital LCD display personal skin moisture analyser skin care tool	- Probe - In s processing - Digital - Battery - Real time - Moisture, oil - Salmue - China - $16.77	(49)
GYLJJ facial nano mist skin moisture detector portable mini beauty	- In s processing - USB - Real time - Digital - Moisture, all skin type - Ninth aveneu - UK - $15.98	(50)
Nano mist sprayer with skin moisture tester	- In s processing - USB - Real time - Digital - Moisture, all skin type - Youyiun - China - $33.10	(51)
LCD digital moisture	- Probe - In s processing - Battery - Real time - Digital - Moisture, oil, softness - CheyiN - China - $19.02	(52)
Real bubee skin moisture tester	- Probe - In 5s processing - Battery - Real time - Digital - Moisture, oil, - RealBubee	(53)

Devices	Properties	References
	- China - $70.30	
Skin moisture tester	- Probe - In s processing - Battery - Real time - Digital - Moisture, oil, - Mior - China - ₱1,100.00 PHP	(54)
Portable digital LCD face bia skin detector monitor	- Biosensor - In s processing - Battery - Real time - Digital - Humidity - Model XM-0291 - China - $8-12	(55)

Table 3. Standard reference devices in the lab.

Devices	Method	Suppliers	Origin
Corneometer® CM825	Capacitance based	Courage+Khazaka electronic GmbH	Germany
Skicon-200	Conductance based	I.B.S. Co. Ltd	Japan
SkinChip	Capacitance based	L'Oreal	America
MoistureMeter	Capacitance based	Delphin Technologies Ltd	Finland
Nova DPM 9003	Resistance	Nova	USA
Dermalab	Ultrasound	Cortex technology	Denmark
Dermal Torque Meter®	Torsion	Dia-Stron	UK
Twistometer®	Torsion	Dia-Stron	UK

Table 4. Ongoing research for devices.

Proposed devices	Method	Performance	References
Portable Skin Analyzers	Conductance-based	Sensitivity of 0.0068 (%/s)/(g/m2/h) and a linearity of 99.63%, conductance with a sensitivity of 1.02 μS/μS and a linearity of 99.36%, and hardness with a sensitivity of 0.98 Shore 00/Shore 00 and a linearity of 99.85%,	(56-59)
Ballpoint pen like pressure sensor	Capacitance-based	Detect the force applied in all the directions	(60-67)
Mobile application design	Mobile Apps-based	Prototype of the mobile application	(68-72)
Image-based Skin Analysis	Computational modelling-based	Varied appearance of the skin with changes in illumination and viewing directions	(73-84)
Super flexible sensor skin	Sensor-based	The temperature coefficient of resistance (TCR) reaches 0.4%/°C, the resistance change versus applied force was around 0.3%/KG	(85-89)

5. CONCLUSION

Moisture and humidity of human skin can be obtained through bioimpedence (BIA) method, capacitance method and also optical method. Bioimpedence and capacitance methods are dependent on the copper electrode that was designed on the top of the device to measure the moisture and humidity based on electric flow through the human skin. The difference between both methods is depending on the cost of probes, the sensitivity and also the accuracy of measurement. The usual technique for applying the methodologies and detailed information on skin classification can be obtained from earlier research (90). The gold standard of the device is Corneometer ®. Meanwhile, the optical-based method is designed with plastic fibre in the middle of the device that can be attached on top of the human skin. The concept is based on the refractive index of water content. Another method that is also applied in the cosmetics application is the spectroscopy method and many others. The calculation of the electric flow can be obtained through different circuit designs. A big concern of the designed device is on their sensitivity and accuracy of the measurement and also the period of life for the device to function optimally. After some period, the device normally displays inaccurate measurement of skin analysis due to their sensitivity that slowly loss throughout the time. However, as time goes by, it parallels to the technology available in the next generation. The invention will always be improved from time to time. It raises the bar for our way of life and makes knowledge instantly comprehensible. It can help gadgets communicate with each other over the internet. This application will be used by this design to enhance the current skin health monitoring system. Among the variables that will be tracked as part of this experiment are body temperature, pulse rate, as well as blood oxygen content that may play a part in influencing the skin moisture and humidity.

The readings can then be seen and used as needed by saving them in a comma-separated values (CSV) file. This can guarantee users' face skin health regardless of weather etc. Recent technical breakthroughs have led to an increase in the popularity of artificial intelligence (AI). The suggested study aims to investigate the notions of computer vision and neural network classification to ascertain an individual's skin health and conditions. By integrating many information sources into decision-making processes, advanced machine learning techniques have facilitated the integration of multimodal healthcare data and enabled the development of methodologies that closely resemble clinical practice. When evaluating a patient's condition and choosing the best course of therapy, clinicians frequently take into account a variety of data sources, utilizing the extra context and information that this method provides. For instance, doctors can contextualize their evaluations of medical imaging within the larger clinical picture by using the patient's demographic information, medical history, laboratory results, and vital signs. As a result, a growing amount of AI research in the healthcare industry has concentrated on using multimodal data to improve overall performance and more closely mimic physicians' methods (91). With the aid of cutting-edge technology, it is simpler for dermatologists or skin specialists to evaluate the skin appearance of the patient.

AUTHORSHIP CONTRIBUTION STATEMENT

Nurul Asmak Md Lazim: conceptualization, methodology, validation, writing – review & editing; Siti Hamidah Mohd Setapar: writing – original draft.

DATA AVAILABILITY

Data are available within the article.

DECLARATION OF COMPETING INTEREST

The authors declare there is no conflict of interest.

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