FONDAZIONE ISTITUTO ITALIANO DI TECNOLOGIA

A TECHNOLOGY TEASER

SENSING MOISTURE LEVEL OF HUMAN SKIN

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ROBOTICS

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For this purpose, the Foundation:
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- develops innovative methods and know-how, in order to facilitate new high-level practices and positive competitive mechanisms in the field of national research;
- promotes and develops scientific and technological excellence, both directly, through its multi-disciplinary research laboratories, and indirectly, through a wide collaboration with national and international laboratories and research teams;
- carries out advanced training programs as a part of wider multi-disciplinary projects and programs;
- fosters a culture based on sharing and valuing results, to be used in order to improve production and for welfare-related purposes, both internally and in relation to the entire national research system;
- creates technological understanding about components, methods, processes and techniques to be used for the implementation and interconnection of innovative products and services, in strategic areas for the competitiveness of the national production system;
- pools research scientists operating in various research institutes and establishes cooperation agreements with high-level, specialized centers;
- promotes interactions between basic research and applied research facilities, encouraging experimental development;
- spreads transparent, merit-based selection mechanisms for research scientists and projects, in compliance with globally approved and established criteria.

CONTENTS

EXECUTIVE SUMMARY

The moisture level of human skin is a crucial parameter for several applications in cosmetic and medical fields. A remarkable number of products which affect the moisture level is available on the market (lotion creams, moisturizers…) and also the efficacy of some topical drugs can be different for differently levels of hydration of the skin.

However, despite the relevance of the topic, there are still open issues in the measurement of skin hydration. The existing devices are not reliable and sometimes even not affordable. The consumers can't verify the efficacy of their products and the lack of a solid measurement system make the validation of results more difficult for the companies. In this framework, IIT technology can carve out an important position.

This technology represents a unique chance for companies active in the cosmetic or medical skin care market. IIT assets appear well positioned for an out-licensing strategy, providing the licensee partner with the ability to take care of the late stage development, CE certification, scale-up and production process. The licensee should guarantee a high probability of market success based on consolidated marketing & distribution organization. A typical licensing strategy based on entry fee and subsequent royalties on net sales can be envisaged.

INTELLECTUAL PROPERTY

PCT International Application #	PCT/IB2011/051299 – 28th March 2011
Priority Application #	IT FI2010A000053 – 29th March 2010
Regional Patent Applications filed	**EP** 11716067.1, **US** 13/637347
Applicant	Fondazione Istituto Italiano di Tecnologia
Inventors	Virgilio Mattoli, Francesco Greco, Lucia Beccai, Paolo Dario
Title	Sensing Moisture Level Of Human Skin

Short Description

A human skin moisture measuring device comprising an interdigitated resistive sensor on a transparent support, an image sensing device, such as a video camera, a CCD device or a C-MOS device, and a lighting device. The device allows evaluating at the same time the moisture of skin and the real surface of skin in contact with the sensor; this last feature can be also used for studies on tactile perception.

IIT TECHNOLOGY

The human skin and the moisture level

The human skin is the covering of human body. It has several functions, such as protection against pathogens, regulation of water exchange with environment, insulation, temperature regulation and tactile sensation.

In order to accomplish these goals, the human skin has a complex structure. It is composed of many layers: the epidermis, the dermis and the subcutis or hypodermis (Fig. 1).

The **hypodermis** is the inner layer; its purpose is to attach the skin to underlying bone and muscle as well as supplying it with blood vessels and nerves. It consists of loose connective tissue, adipose tissue and elastin.

The **dermis** consists of epithelial tissue and cushions the body from stress and strain. It is tightly connected to the epidermis by a basement membrane. It also harbors many nerve endings that give the sense of touch and heat.

Finally the **epidermis** is the outer and thinner layer; it provides a barrier to infections from environmental pathogens and regulates the amount of water released from the body into the atmosphere.

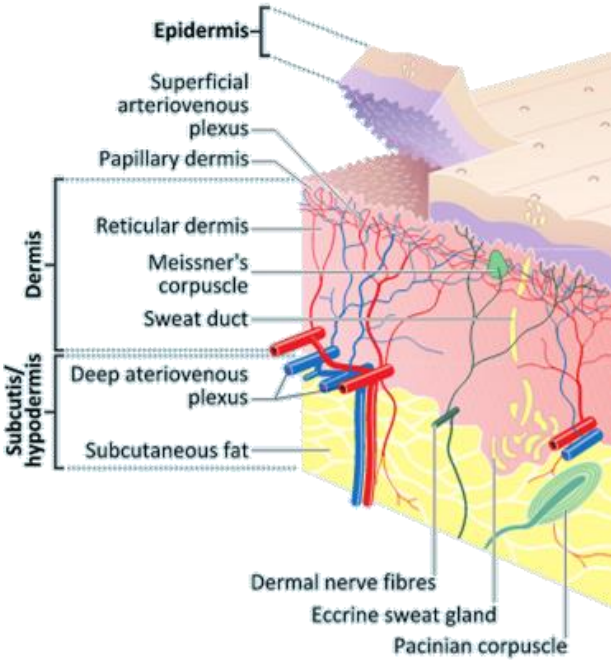

Figure 1. The three layers of the human skin.

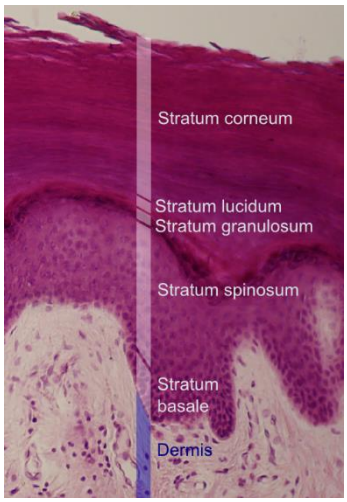

Figure 2. The layers of the epidermis.

The epidermis, in turn, is composed of different *strata* (Fig. 2). The *stratum corneum* (or horny layer) is the outer one: it consists of about 20 sheets of cells which cover, like a membrane, the entire human body.

The horny layer is the interface between the human body and the surrounding atmosphere. It contains a certain amount of water, which represents the humidity and moisture level of human skin.

Any instrument aiming at measuring the moisture level or human skin should have the ability to investigate the horny layer.

Skin hydration is a key measure for many purposes but existing instruments have a limited accuracy and precisions.

Applications

The diagnostic importance of the water content in the horny layer of the epidermis is well known. From a medical point of view, an adequate hydration has effect on the following points:

- **Biological activity**. Hydration is a symptom of normal biological activity. A low level may be a useful diagnostic signal for an ongoing alteration or even a disease.
- **Topical drugs efficacy**. The efficacy of drugs which are absorbed by the skin is affected by the moisture level.
- **Barrier property**. A good hydration generally increases the ability of the skin to protect the body.

Obviously, hydration is relevant also from a cosmetic point of view. For example:

- **Health**. A proper moisture level is considered healthy and associated to the idea of beauty.
- **Bodycare products**. Their efficacy is highly affected by hydration; in other cases, the product itself should be able to modify the hydration of the skin.

Medical and cosmetic purposes in certain situations overlap. For example, in the case of the skin of the scalp, the poor hydration leads to dandruff, with ensuing flare, irritation, itchiness and desquamations. This is medical condition but has evident side effects also for the external appearance and the self-confidence of the person.

For any of the above-mentioned applications, the measurement of the moisture level and its monitoring is a necessary and critical activity which therefore requires reliable instruments.

IIT Solution: the components

Most existing sensors have a sensitive element which has to be in contact with the skin and measures a physical quantity, for example the resistance or the capacity in a circuit, in order to derive the humidity according to known physics rules. IIT solution follows the same logic but allows to obtain more accurate results; the structure of the solution is reported in the picture below (Fig.3).

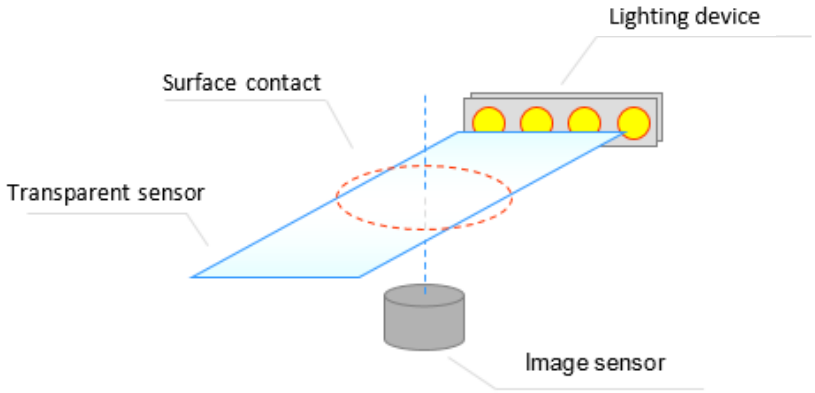

Figure 3. The main components of the system: transparent sensor, image sensor and lighting device.

Every component is briefly described below.

Transparent sensor

One of the main issue of existing moisture sensors is the impossibility to see the surface under analysis. The measure of the moisture level is highly dependent on the surface of the skin which is actually in contact with the sensor; this is one of the causes for the low accuracy of the existing devices.

A transparent sensor is a first necessary precaution for a different approach to this problem. The sensor has a substrate made of glass or quartz or other suitable transparent materials. Two interdigitated electrodes are inserted on the substrate. They are made of transparent and conductive material (such as Indium Tin Oxide). (Fig.4).

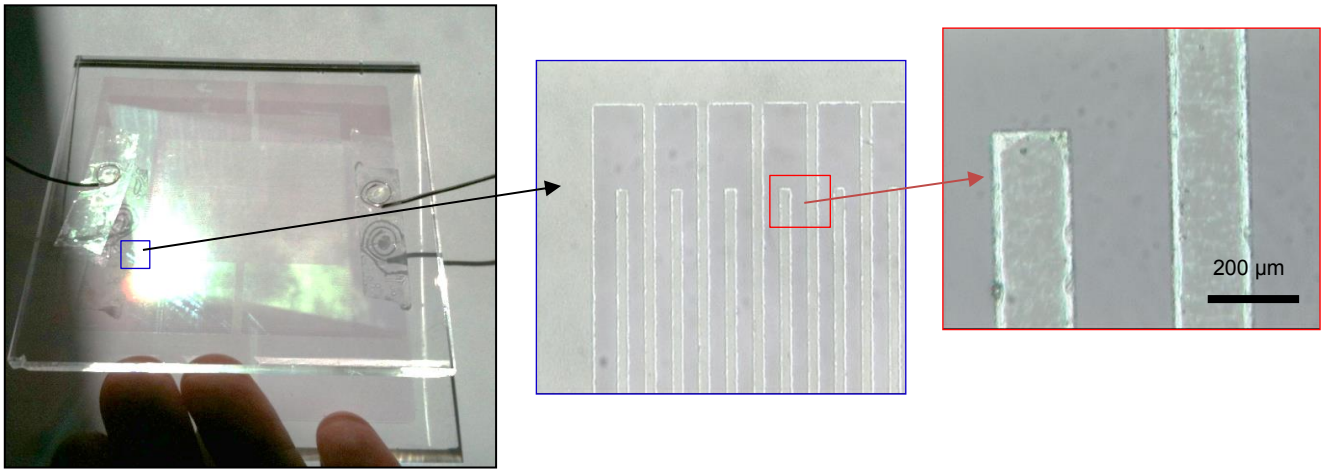

Figure 4. The transparent substrate and the interdigitated electrodes in the prototype. The total dimensions of the prototype are 100x100x5 mm, while the sensitive area of the device is 50x50 mm.

The shape and the dimensions of the electrodes may vary as a function of the accuracy of the instruments.

Image sensor

The sensor has a superior and inferior surface; one of the surfaces is in contact with the skin; on the other side, an image sensor will scan and take pictures. The image sensor can be a videocamera, a CCD (Charge-Coupled Device) or CMOS (Complementary Metal–Oxide–Semiconductor) device. The image sensor is necessary to capture and measure the effective skin surface which is in contact with the sensor. This is possible thanks to the transparence of the sensor and to the lighting device.

Lighting device

The lighting source is LED type or equivalent. The light radiation should have a proper incidence over the plan of the sensor; the lighting device is used to accurately illuminate the part of skin actually in contact with the sensor so that the image sensor can measure the surface in contact.

IIT Solution: how it works

When a light radiation moves from one medium to another (e.g. from air to glass), it can have different behavior according to the angle of incidence and the refractive indices of the two media in which it moves.

- **Total internal reflection**. In this case the light is trapped in the sensor. The light can only escape from the borders, while no radiation can get out from the upper or the lower surface of the sensor (Fig.5)

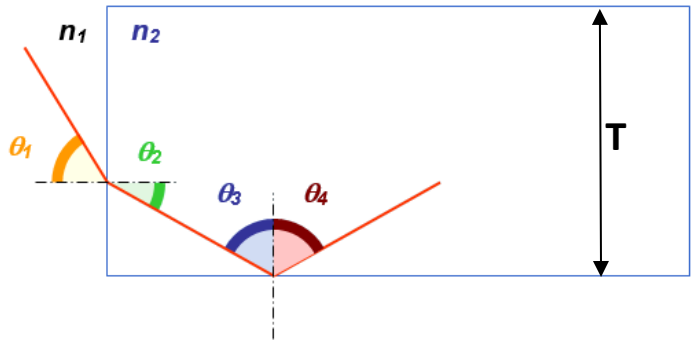

Figure 5. Picture not to scale. T is the thickness of the sensor, n_1 and n_2 are the refractive index of air and glass (respectively 1 and 1.5). Under a certain angle θ_1, the radiation is trapped in the sensor.

Total internal reflection can occur when the radiation refractive index is lower on the other side of the boundary and the incident angle is greater than a certain critical angle.
The reflective index of glass is higher than the reflective index of air: the radiation can get through the boundary when moving from air to glass (and its angle of incidence is changed from θ_1 to θ_2), but can't get out from the lower or upper surface because it is totally reflected by the boundary (Fig.6).

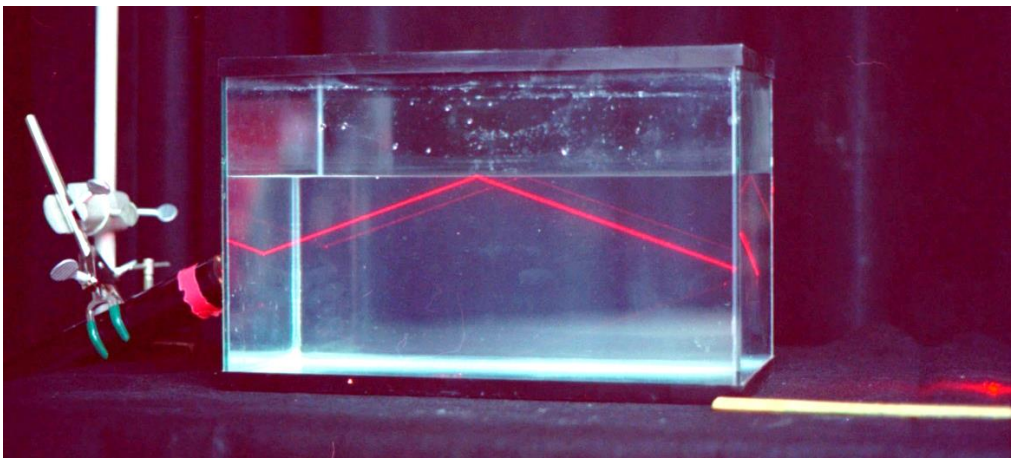

Figure 6. Total internal reflection when light tries to move from water (thicker) to air (lighter). The reflection occurs only for angle of incidence higher than a critical angle.

- **Refraction**. In this case the radiation can escape from the lower or upper surface. However, a medium thicker than air is necessary. Water, having refractive index n_3 =1.33, can be this medium.

Refraction describes the behavior of light radiation when the skin approaches the sensor. The water in the horny level work as thicker medium and the light can escape from the lower or upper surface (Fig.7)

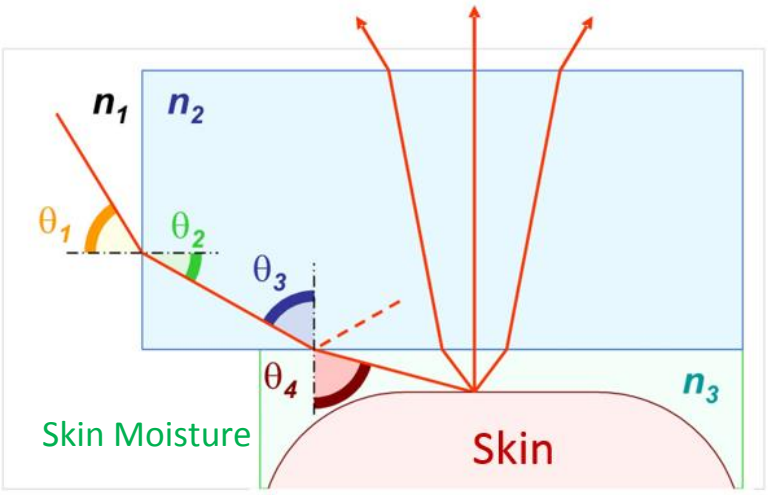

Figure 7. The skin moisture can cause the refraction of light radiation for certain angles of incidence.

As a consequence, the skin in contact with the sensor is illuminated by the lighting device and the actual surface in contact can be calculated through the image sensor.

Most moisture sensors measure the resistance in the circuit to calculate the humidity and don't consider the surface which is actually in contact. However, this resistance is highly affected by the actual size of this surface and can bring to very different results.
Since IIT solution allows to calculate the size of the contact area, it is possible to correct and *normalize* the resistance before calculating the humidity. The normalized value of the resistance is independent from the size of the contact area and lead to a more accurate and precise value of humidity.

MARKET ANALYSIS

Figure 8. Group of commercial pictures from the web.

Nowadays skin moisture is strongly related to the ideas of beauty and health. Marketing campaigns promote this association of ideas through commercials and pictures in which comfort, beauty, happiness and hydration are recurring concepts (Fig.8).

A technique to measure skin moisture has necessarily the skin care market as its first reference. By 2019, **global skin care will be a $131 billion market, from $121 billion in 2013**. This equates to $20 billion in total skin care market growth. North American skin care sales are set to grow $1.3 billion, from $15.3 to $16.7 billion by 2019.

These numbers lead to an estimated 3.5% global CAGR in the period 2014-2019.
The skin care market can be divided into several segments; facial treatments represent the first segment holding more than half market .

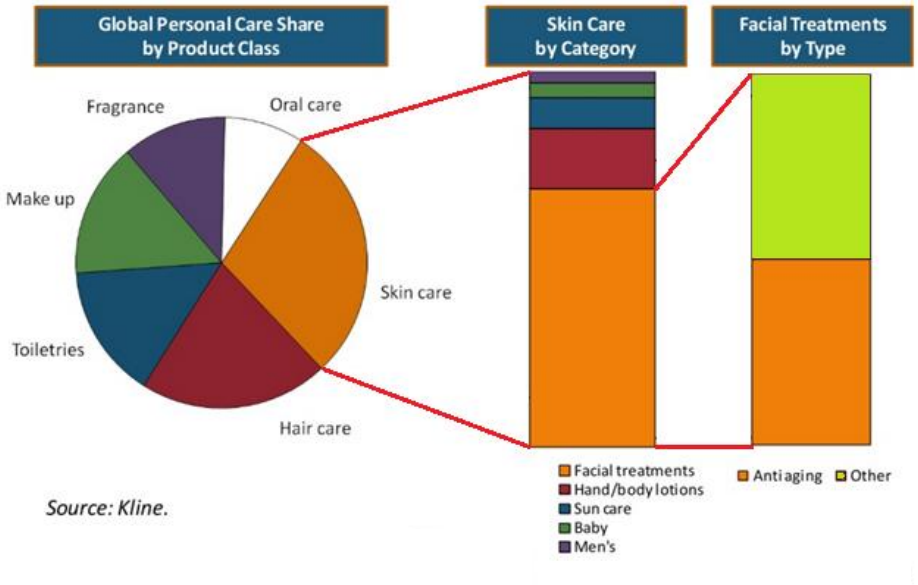

Figure 9. Classification of skin care market by category and product type.

Anti-aging creams are the leading product of this segment, which includes also moisturizers (Fig.9). In general, all products for facial treatments are expected to provide the user with a moisturizing effect, even when their main functionality is different.
The main factors pushing the growth of the sector are listed below:

- New markets are available: China and Far East are expected to sustain the growth next years. However new markets are not only geographic; for instance, the skin care for men is an emerging and promising market.

- Increasing willingness to spend money on luxury/premium products, which are generally expensive. Actually, *premium market* is estimated up to 42 billion in 2019, with a growth twice as much as *mass market* (*Euromonitor International, SPARK Convention 2015*).

The best way for beauty products to justify a price premium is through proven effectiveness. The effectiveness can be proved only through accurate and impartial measurement systems. From this point of view, an increase of the demand for devices and techniques to measure skin moisture has to be expected.

Although being the most important, skin care market is not the only market which is affected by the skin moisture sensors. Moreover, the end-user, for instance the person interested in knowing the own skin moisture level, is not the only potential customer. An equally important share of market is represented by companies and institutions, operating research and development activities in a similar field. A non-conclusive list of potential company or institution profile interested in this technology is reported below:

- **Pharmaceutical industry**. The effects of drugs and topical medication can be investigated with more precision.
- **Animal health**. Skin properties are important signals for the health of animals.
- **Academic reaserch**. Accurate measurement instruments are necessary in order to validate scientific outcome.
- **Industrial research**. Companies can validate the efficacy of their products more easily.

About the pharma industry, more than 90% of topical skin medications sold in the EU5 countries (France, Germany, Italy, Spain and United Kingdom) have semi-solid formulations, such as lotions, creams, ointments, gels, pastes or foams. The remaining share is evenly split into liquids and powders.
Dermatology drug market will have an estimate volume of $37.8 billion in 2026 at a CAGR equal to 3.2%. Atopic Dermatitis and Acne Vulgaris make up an important share of this market (Fig.10).

Disease	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	CAGR (%)
Acne Vulgaris	2.714	3.994	4.593	4.866	5.272	5.272	5.883	6.260	6.772	7.346	7,5
Atopic Dermatitis	3.765	2.714	2.782	2.810	2.868	-	-	-	-	-	3,88

Figure 10. Market Size (USD Million). Data refer only to US, France, Germany, Italy, Spain and UK.

However, moisture level skin may affect the efficacy of topical medications in several fields, even outside dermatology. GlobalData reports more than 800 topical products with cutaneous or transdermal route of administration. These products are obviously used in dermatology (21%), but also in the treatment of the central nervous system (45%) and some infectious diseases (14%) (Fig.11).

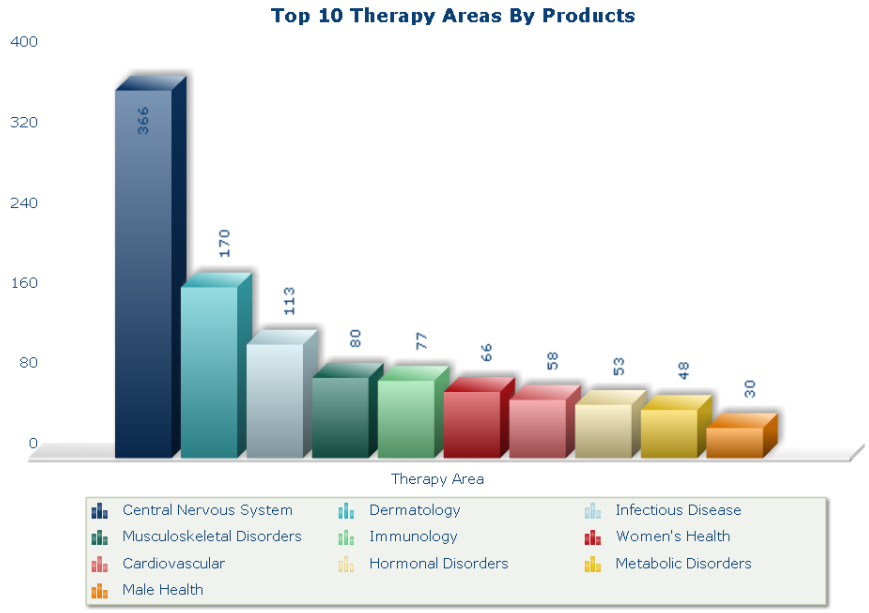

Figure 11. Topical products (cutaneous and transdermal) grouped by therapy. Central nervous system represents the first field of application, while dermatology is the second.

Main sources

https://www.linkedin.com/pulse/how-consumers-shop-anti-aging-skin-care-market-trends-michelle-skelly
http://www.slideshare.net/klinegroup/kline-global-beauty-exchange-2014-vf-31754861
http://drug-dev.com/Main/Back-Issues/TOPICAL-TRENDS-Trends-in-Skin-Medication-Dispensin-620.aspx
https://www.pharmaetrack.com/ (GlobalData)

COMPETITIVE SCENARIO

A great variety of sensors for skin moisture is available on the market. They can be grouped in four categories:

- Resistive sensors
- Capacity sensors
- Optical sensors
- Trans epidermal water loss (TEWL)

Even if the technique is different, the measurement strategy is the same: a sensitive "head" is in contact with the skin (Fig.12).

In the first three devices, the degree of the skin moisture determines a variation of an electrical measurement circuit comprised in the head or a variation in the overall refractive index (in case of optical measurements).

Figure 12. The electrical circuit is visible on the top of the sensitive head. (Neon SK-5D, commonly sold on Amazon)

The fourth and last category is slightly different.

Figure 13. The chamber of the TEWL sensor.

The TEWL measures the evaporation over a certain period in a chamber which has to be applied on the skin (Fig.13)

Skin moisture can be calculated according to the increase of relative humidity inside the chamber due to the evaporation of the water in the horny layer.
These devices are not common because of their overall dimensions: even though the chamber can be small, the central unit is generally larger, resulting in a not portal device.

These solutions are not accurate or precise for the following reasons:

1) Measurements are highly dependent on the size of contact area.
2) Skin elasticity, the pressure while applied to the sensitive head and the natural irregularity of the skin contribute to the uncertainty of the contact area.

As a consequence, measurements are generally not consistent and hardly reproducible.
Moreover, there is a third drawback:

3) It is not generally possible to access to the contact area during the measurement.

This excludes a certain number of applications that could be of considerable scientific interest (and thus industrial interest), such as, for example, the study of the dynamics and perception of the touch in correlation to the degree of skin moisture.

IIT solution allows to overcome these issues: although the measurement of the humidity is still based on the variation of the resistance in a circuit, this measurement is corrected according to the contact area, which can be calculated thanks to the particular design of the sensor, to the lighting device and the image sensor. Furthermore, the sensor is completely transparent and does not prevent the access to the contact area.

Key players and major companies in the sector of sensors for skin moisture

- Delfin Technologies (Finland, http://www.delfintech.com/)
- Dermotrico (Italia, http://www.microcamera.com/)
- Schaller GmbH (Austria, http://www.humimeter.com/it/)
- Courage+Khazaka electronic GmbH (Germany, http://www.courage-khazaka.de/)
- IONTO Health & Beauty GmbH (Germany, http://www.ionto.de/en/)

Key players and major companies in the sector of cosmetic and/or clinical skin care in Italy

- Ales Group Italia (http://www.alesgroupe.com/)
- Artsana (http://www.artsana.com/)
- Bioderma (http://www.bioderma.it/)
- Biodue (http://www.biodue.com)
- Chefaro Pharma Italia (http://www.chefaro.it)
- Difa – Cooper (http://www.difacooper.com/)
- Fidia Farmaceutici (http://www.fidiapharma.com/it/)
- General Topics (http://www.general-topics.com/)
- Idi Farmaceutici (http://www.idifarmaceutici.com/)
- Istituto Ganassini (http://www.ganassinicorporate.com/it/)
- L'Oréal Italia (http://www.loreal.it)
- Mediolanum Farmaceutici (http://www.mediolanum-farma.it/)
- Pierre-Fabre (http://www.pierre-fabre.it/)
- Rottapharm (http://www.rottapharm.com)
- S.I.R.P.E.A. (http://www.sirpea.com/)
- Unilever Italia (https://www.unilever.it/)
- Valetudo (http://www.valetudo-lab.it/)

Subset of players and major companies in the sector of cosmetic and/or clinical skin care in the world

- Aquaglycolic (http://www.aquaglycolic.com/)
- Bioelements (http://www.bioelements.com/)
- Biotherm (France, http://www.biotherm.fr/)
- Caudalie (France, http://fr.caudalie.com/)

- Clé de Peau Beauté (Japan, http://www.cledepeaubeaute.com/)
- Clarins (France, http://www.clarins.fr/)
- Cosmedix (USA, http://www.cosmedix.com/)
- DERMAdoctor Specialist Skin Care (USA, http://www.dermadoctor.com/)
- Dermalogica (USA, http://www.dermalogica.com/)
- DHC Skincare (USA, http://www.dhccare.com/)
- Elemis (UK, http://www.elemis.com/)
- EmerginC (USA, http://www.emerginc.com/)
- Jan Marini (USA, https://www.janmarini.com/)
- Kiehl's (USA, http://www.kiehls.it/)
- Lancome (France, http://www.lancome.fr/)
- La Roche-Posay (France, http://www.larocheposay.it/)
- Lifeline Skin Care (USA, http://www.lifelineskincare.com)
- Minasolve (France, http://www.minasolve.com/)
- Natura Bisse (Spain, https://www.naturabisse.com/en)
- Neutrogena (USA, http://www.neutrogena.com/)
- Obagi Medical Products (USA, http://www.obagi.com/)
- Olay (USA, http://www.olay.com/en-us)
- PCA Skin (USA, http://www.pcaskin.com/)
- Perricone MD (USA, http://www.perriconemd.it)
- Peter Thomas Roth (USA, https://www.peterthomasroth.com/)
- Ren Skincare (UK, http://www.renskincare.com/)
- Revision Skincare (USA, http://www.revisionskincare.com/)
- Shiseido (Japan, http://www.shiseido.it/)
- SkinCeuticals (USA, http://www.skinceuticals.it/)
- SkinMedica (USA, https://www.skinmedica.com/)
- Tatcha Skincare (USA, https://www.tatcha.com/)
- Vichy (France, http://www.vichy.it/)

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