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COMPREHENSIVE REVIEW OF ARTIFICIAL SKIN DEVELOPMENT: ELECTRONIC AND BIOENGINEERED APPROACHES

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Abstract

The rising need for skin substitutes in medical and cosmetic applications has sparked a surge in interest in the study of artificial skin. The goal of artificial skin research is to develop a material with the same structure and properties as human skin, including the ability to regulate temperature, sense touch, and provide protection from the elements. Artificial skin has been made using 3D printing, electrospinning, and tissue engineering, among other methods. To replicate human skin's structural and mechanical qualities, the most promising methods involve combining natural components like collagen, elastin, and hyaluronic acid with synthetic polymers to make a composite material. Recent breakthroughs in the field of artificial skin development have led to skin substitutes that may fuse with adjacent tissues, encourage cell proliferation, and speed up the healing process. These skin substitutes have a wide range of possible uses, from cosmetic ones like making prosthetics look more realistic to medical ones like treating burns, chronic wounds, and skin cancer. The field of artificial skin development has come a long way, but there are still obstacles to overcome, such as creating a material that can fully replicate the complex functions of human skin, increase the longevity and durability of artificial skin and make sure it is safe for human use. To continue expanding the development of artificial skin and bring it closer to practical usage, more research and collaboration between diverse sectors of science is required. The skin is a protective, self-healing, multipurpose organ that is considered "smart," and various types of artificial skins have been created with characteristics and functions that are like those of natural skin. This article talks about the creation of manufactured skin replacements, like electronic skins, and bioengineered skin replacements. Robots with this silly skin can also understand their surroundings more deeply and sensitively. The differences between the two types of skin are pointed out, and the effectiveness of both types of artificial skin is judged based on these differences. By using conventional silicon-based or flexible computing devices like memristive devices and synaptic transistors, which are used in the implementation of artificial skin perception, artificial skin can outperform human skin in terms of distributed, low-latency, and energy-efficient information processing. Future improvements in artificial skin perception will make it possible

to make next-generation intelligent electronic systems and gadgets for cutting-edge uses like robotic surgery, therapy, and prosthetics. In this review article, the previous year's artificial skin research is examined, and the significant advancements in the field are surveyed and retrospectively evaluated.

INTRODUCTION

The skin is the main organ and has three jobs: to protect, to control, and to feel [1]. Humanoid robots have made a lot of progress in the past few years, which has made the need for artificial skins grow. The main goals of artificial skins are to make it possible for people and robots to work together and to act as sensors to keep people and robots from getting hurt [2]. Human skin has a network of very sensitive receptors that can send signals to the brain about mechanical stimuli from the outside world. Putting this function into an artificial skin is interesting because it could lead to more advanced humanoid robots, biomedical prostheses, surgical electronic gloves, and wearable health monitoring devices. To be like human skin, artificial skin should be able to measure how mechanical stimuli like normal pressure, lateral strain, and flexion cause stress to be spread out in space. It should also be able to move things around, control grasps, and keep track of how the body moves. Second, skins that aren't real having to be able to stretch [3-26]. This makes sure they can cover any curved or moving surface, like the joints of a robot arm, and that they can withstand repeated and long-term mechanical deformation, like bending and twisting. Third, if artificial skin is going to be used a lot in our daily lives, it needs to be able to be used over a large area and be cheap to make [1]. Electronic skin (e-skin) is made by simulating human skin with flexible and stretchable electronics. It can create artificial sensations and do other things that regular electronics can't do [2]. Typical artificial skin needs to have a lot of sensors, like pressure sensors and temperature sensors, built into a flexible sheet-like structure. Using micromachining techniques, temperature and pressure sensor parts are put together in a random way on a flexible copper-PI sheet. By adding conductive polymer to inter-digital copper electrodes that have already been set up, tactile sensing elements can be made [27]. Artificial skin based on arrays of pressure sensors on a flexible substrate has made a lot of progress, with reports of increasing sensitivity, response speed, and resolution of tactile mapping. On the other hand, these pressure sensor arrays were not flexible like human skin. Instead, they could only show how pressure was spread out in space. To solve these problems, it is possible to make stretchable mechanical sensors with multiple mechanical force sensitivities by using materials that naturally stretch and designing new mechanical sensor architectures [1]. Tactile electronic skin, or "e-skin," could be used for a lot of different things, like prosthetic skin, wearable sensors, and health monitoring. On the other hand, many of the ways things are made today involve complicated steps or materials that are hard to find. On the other hand, you can make good capacitive tactile sensors for an e-skin by putting a microstructured dielectric elastomer layer between two conductive fabric electrodes. The fabric is easy to cut and bend into three-dimensional shapes, which makes it quick to try out different sensor configurations. The sensors that were made are very straight and don't change much over time [28]. Robosapiens are becoming more pervasive in everyday life. Physical human-robot connection is essential for safety and is advantageous for communication, social engagement, and collaborative work. They offer a unique method for designing and producing robot skin sensors with the mechanical properties of human skin and the capacity to precisely sense touch. Our artificial skin is composed of various silicone elastomers that imitate the layers of human skin and an embedded electrode matrix for mutual capacitance sensing [29]. So that they can feel what's going on around them, robots need smart skin. Smart skins that can measure things like location, pressure, temperature, and humidity have been suggested in the past to do the same things that human skin does. Thin-film

transistors, piezoresistive composite polymers, ionic conductors, silicon nanoribbons, Ge/Si nanowire arrays, carbon nanotubes, and even self-healing composites are all used to make smart skins flexible, stretchable, and able to do more than one thing. Still, smart skin needs to have better resolution and use less energy if it looks better and lasts longer. In older works, pixels-based digital technology was often used to make places look clear [30-56]. But with digital smart skins, increasing the resolution usually means adding more electrodes and sensing units. This raises the cost and makes it harder to remove electrodes, deal with signal interference, and process data. An analogue method is a whole new way to do things, especially when it comes to reducing the number of electrodes and sensing units. Smart skins could be portable and not need batteries if they had their own power source [57].

Researchers made it so that artificial skin could feel vibrations and forces, making it as sensitive and accurate as human hands. Because of this, robots can do delicate tasks without the help of humans. People get important information from tactile stimuli during social interactions, which helps them understand the interaction better. On the other hand, this process is affected not only by the basic qualities of touch, but also by the context of interaction and the people's cultures, beliefs, and feelings [58-75]. If a robot could understand the meaning of touch in the same way, it could make intuitive interactions between humans and robots much more successful in the future. The California Institute of Technology (Caltech) has made a new kind of artificial skin that lets robots feel temperature, pressure, and even dangerous chemicals with just a touch. This new skin technology is part of a robotic platform that has a robotic arm and sensors that can be attached to human skin. A machine-learning system that connects the two lets the human user control the robot with their own movements while getting feedback through their own skin. The sensors that let the fake skin know what's going on around it are built into the hydrogel. This review article covers the overview of the area of artificial skin [76-97]. The aim of this review paper is to summarize the work done over the last few decades regarding artificial skin. This review article sketches the issues that people faced, and the solution has been reviewed. We are reviewing different methods, including the biomechanics measurements, flexible tactile sensor system, multisensory paper skin, bioinspired mineral hydrogel, fast-adapting cutaneous mechanoreceptors and synergistic soft–hard segments design. Furthermore, we are reviewing types of equipment that has been used in the past decades, including liquid polymer, Pressure Sensor, Fabrication, Silicon rubber embedded with conductive liquid, Helical electrodes, etc. Summary of research papers on artificial skin published in different journals and conference papers shown in table 1.

A bibliometric analysis of published papers indexed by the Scopus database has been performed. Review these published records using the keywords "Artificial skin "from 2011 to 2022, as shown in fig.1. fig.1 (a) shows the yearly publications from 2011 to 2022, from 2018 to 2022 mainly focusing on electronic skin, and from 2011 to 2017 focusing on Bioengineered skin. Fig.1 (b) shows the journal and conference published papers, most of the papers have been published in the journal category. fig.1 (c) shows the country-wise publications, the papers have been published in the top five countries are the USA, China, Germany, UK, and Korea. Moreover, fig.1 (d) shows the publications by subject area.

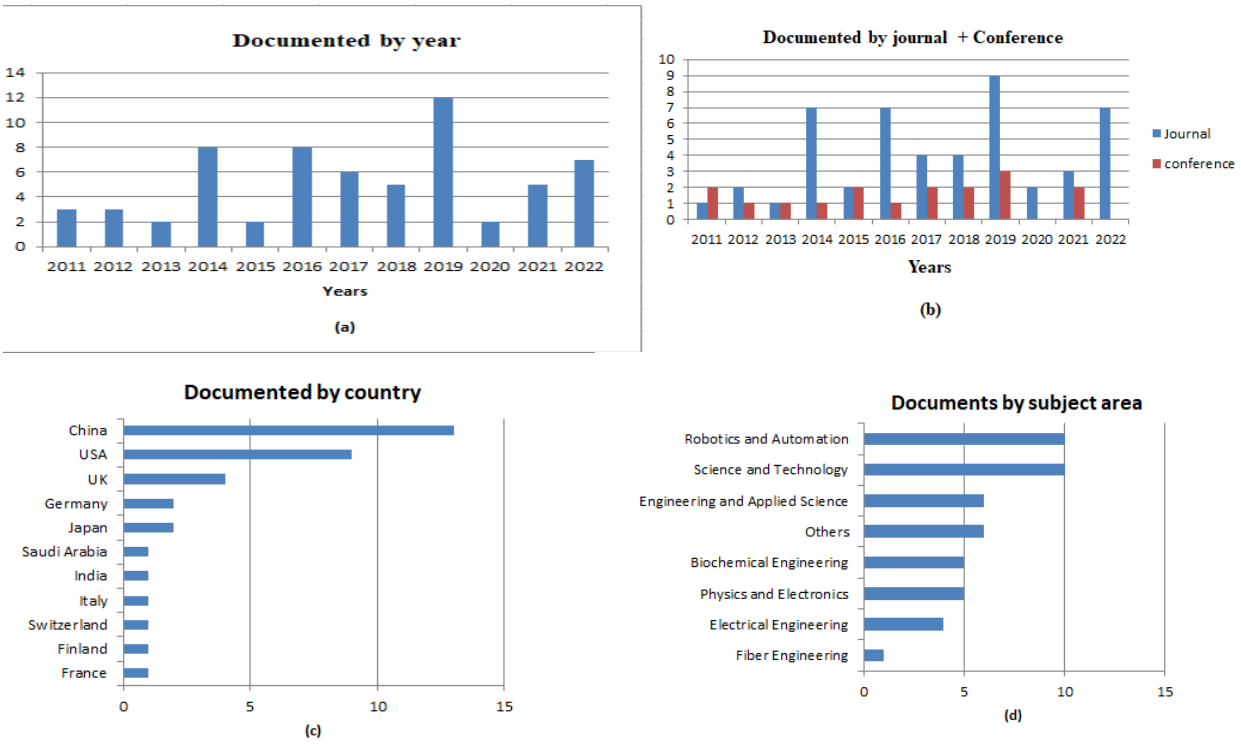


Figure 1: Review of the research work done for artificial skin development from 2011 to 2022, (a) year-wise publications from 2011 to 2022, focusing on electronic and bioengineered skin, (b) journal and conference published papers, (c) Country-wise publications, (d) subject area wise publications

This section introduced the artificial skin, the need of artificial skin in robotics, and year, country-by-country, and subject area-by-subject surveys on artificial skin. The rest of the article is organized as follows, Section-II presents a literature review of the article on artificial skin; Section-III describes artificial skin categories, and how we made artificial skin through different method, and brief information on methods and sensors.

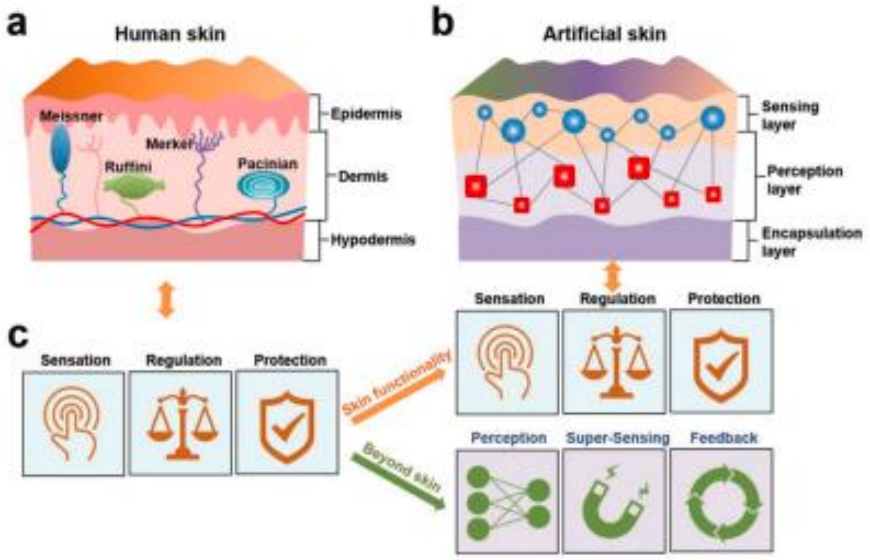
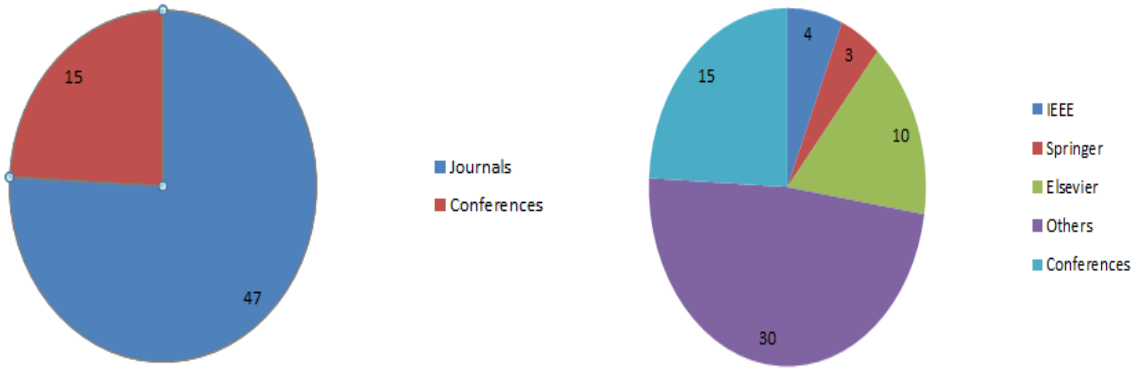


Figure 2. Human skin and artificial skin schematics courtesy from [2]

Table 1. Summary of research papers on artificial skin published in different journals and conference papers.

Years	IEEE	Springer	Elsevier	Other Journals	Conferences	Total
2011			[98]		[99, 100]	3
2012	[101]			[102]	[103]	3
2013				[104]	[105]	2
2014		[106]	[107, 108]	[109-112]	[113]	8
2015				[114]	[115]	2
2016		[116]		[1, 57, 117-120]	[121]	8
2017	[122]			[123-125]	[126, 127]	6
2018			[128]	[129-131]	[132]	5
2019	[28]			[133-140]	[141-143]	12
2020	[144]		[145]			2
2021		[146]		[2, 147]	[29] [148]	5
2022			[149-153]	[154, 155]		7
Total	4	3	10	30	15	63

Overview of research papers of artificial skin development published in different journal, conference and publisher wise, shown in figure 3.



(a) (b)

Figure.3 Overview of research papers of artificial skin development (a) journals and conference paper (b) published paper

Literature review

Humanoid robots are getting better quickly, which has increased the need for synthetic skins. The main goal of artificial skins is to make it possible for robots to interact with both people and their surroundings. They also keep people and robots safe by acting as sensors. This article plans, makes, and measures the flexible 8x8 temperatures and tactile sensing array that will be used as the artificial skin for robot social interaction, teamwork, and communication, but it is also important for safety. For real Human-Robot Interaction, they made an artificial skin sensor that looks like human skin. The interface is made up of a grid of conductive yarn and several layers of silicone. It is used to do mutual capacitance sensing with a high resolution and update rate. Human-robot interactions have a lot of problems when it comes to working together and being safe, but artificial skin can help. Their plan is to imitate the physical and sensory qualities of human skin[29]. The flexible sensor suggested has a simple design, is easy to make, works well mechanically, and can bend to fit curved surfaces. Their development board lets them make touch measurements that are accurate, repeatable, and don't change much over time. The results show that the sensor skin can detect forces up to 5N and touch over the whole surface with an accuracy of 0.5mm and a applications[27]. Parts of temperature and pressure sensors are put together in a random way on a flexible copper-PI film using micromachining. Touch sensing elements are made by adding conductive polymer to inter-digital copper electrodes that have already been made. The parts that measure temperature are separate chips called temperature sensor chips. Physical connection between people and robots is good for rate of 40Hz. They also showed that the sensor can be used on a curved surface without affecting its ability to read, which makes it easy to put on a robotic arm to help people interact with it in a natural and safe way. WiseSkin is a project that wants to make artificial skin so that people with prosthetic limbs can feel again. The tactile information transfer system is built on a wireless sensor network that has limits on adaptability, latency, energy, and reliability. The goal of this paper is to suggest a way for the WiseSkin wireless sensor network to talk to each other within these limits[127]. After looking at different ways to solve two of the most important problems in event-triggered low power systems, the tradeoff between energy and latency and simultaneous transmissions, the proposed design was chosen. Analytical models and testbed experiments were used to do the evaluation. Lastly, they suggest that simultaneous

transmissions be used in multi-hop wireless sensor networks that are driven by events and have random traffic spikes. The main reason for the decision is that it uses less energy than other ways to avoid collisions. This is a general principle that can be used in many kinds of Cyber Physical Systems. The design and production of soft artificial skin with an array of soft strain sensors for detecting different hand gestures by measuring the joint movements of five finger joints[115]. The proposed skin was made of a hyperelastic elastomer with tiny channels that were filled with an ionic liquid and a liquid metal. The liquid metal microchannels were used to connect the sensors to an external control circuit, while the ionic liquid microchannels were used to detect changes in the sensing material's mechanical strain. Flexible conductive threads were used to connect the two liquid conductors so that the different liquids wouldn't mix. A USB cable connected the skin device to a computer. A microcontroller instrumentation circuit connected the skin device to a computer so that the 3-D hand movements could be shown on a screen. Summary of research papers on artificial skin shown in table 2.

Table 2. Summary of research papers on artificial skin

References	Methods	Datasets/Equipments	Evaluation Measures	Limitations/Issues
(2016)[1]	A stretchable artificial skin made of electronic fabric	Elastic thread+ Nylon fiber+ polyurethane fiber+ sliver electrode+ piezoresistive rubber+ sensor electrode+ stretchable electronic fabric+ Mechanical stimuli sensor unit	2D Mapping	Several mechanical force sensitivities for a single sensor unit have been shown, but a sensor array that can stretch and map multiple forces has not been shown to work.
(2016)[57]	Smart Skin that runs on its own batteries	Silicon nanoribbons+ polymers+ conductors	1.9mm resolution	Improving smart skin perception and standby time demands increasing resolution and conserving energy.
(2015)[115]	Microfluidic Strain Sensing Incorporation	Soft joint strain sensor+ Ionic liquid microchannels+ softwires	2-D plane	Also, if the gadget is going to be used for a long time or as a way to send gesture commands, it should be as unobtrusive as possible.
(2011)[98]	Flexible tactile sensor array with helical electrodes	Conductive polymer+ PDMS+Tactile sensing element+ upper spiral electrodes+ polymer substrate	70% twisted	In order to fabricate sensing elements, intricate micromachining procedures are necessary.
(2011)[99]	Photolithography process	Silicon rubber embedded with conductive liquid-filled Microchannels+ Twelve-key keypad+ fabrication+ 700 microns	A microchannel with dimensions of 20 microns in height and 200 microns in width requires a pressure of around 100 kPa	Pressure sensing technique may be low.

			to induce a 5% voltage change.	
(2011)[100]	Multi-Modal Sensing Capability Embedded Use of Liquid Conductors	Helical electrodes+ hyperelastic strain sensors+ pressure sensors+ embedded microchannels	3D printed molds	Reduced channel width may lead to more compact skins.
(2012)[101]	Embedded Microchannels+ Liquid Conductors	Strain Sensor+ Pressure Sensor+ Fabrication	3D printed molds	Reduced channel size could result in more compact and sensitive skin.
(2012)[102]	Tactile assessments and friction assessments	High speed video camera+ Glass plate+ Fixed base	Friction force is 0.46+0.30 N	The stress is not efficiently measured
(2012)[103]	Flexible Tactile Sensor System	liquid polymer+ silicon rubber+ carbon black silicone rubber	3-D tactile sensor	We can increase the flexibility and sensing power
(2013)[104]	Scanning circuit	temperature sensor+ Pressure sensor+ copper polyimide substrate	6% carbon black (CB), 12% carbon fiber (CF)	The difference in height between the pressure and temperature sensor arrays can prevent cross-sensor interference.
(2013)[105]	Biomechanical Evaluations	Hyperelastic Strain Sensor+ EMG sensor	maximum error less than 8%	Improved sensor attachment to the base layer reduces hysteresis and improves angle tracking.
(2014)[106]	EIT-based Sensitive Skin	Rubber+ Soft Suede+ Stand	90% precision for both emotions and social communications	There was no significant correlation between the gender or country of origin of the touch transmitter and the accuracy of touch classification.
(2014)[107]	Slip using sensors	PVDF Film+ strain Gause	Compressive elastic modulus is 11.8 N/cm2	The network wouldn't be trained unless an error occurred. This indicates that once a network has been taught, it can be difficult to adapt to a new circumstance.
(2014)[108]	Temperature sensor with enhanced printing	Temperature sensor+ flexible substrate	Poly Ethylene Naphtalate (PEN) with a thickness of 125 mm	Due to the low glass transition temperature, it might be challenging to integrate these materials onto flexible substrates.
(2014)[109]	multi-sensory	Strain sensor+ pressure sensor+ temperature sensor	artificial skin stretched 20%	Limited stretchability

(2014)[110]	Carbon Nanotube FET Sensor Circuit.	silicon nanowire FET+ Artificial Skin Sensor	32 nm carbon nanotube FET (CNFET)	Avoid device leakage current.
(2014)[111]	Remote Handshaking	Resistance wire+ Urethane gel+ Urethane sponge	(F(2,22)= 7.675, p<.01)	Lack of illusion prevents teleconferencing from replacing face-to-face meetings.
(2014)[112]	Silver Electrode Printing+ Temperature Sensor Printing+ Strain Sensor Printing	Temperature sensor+ strain sensor+ polyester film	3* 3-pixel array on an 8* 8 cm^2 substrate	The proposed method does not use vacuum deposition or optical lithography to produce metal and sensor patterns.
(2014)[113]	wireless sensor nodes that use very little power	ultra-low power (ULP) sensor+ force sensor	A modern prosthetic hand with dexterity has a battery that can hold 14.8 Wh.	Even though there are myoelectric prostheses that work and are very flexible, not many amputees use them.
(2015)[114]	All-carbon multimodal skin sensors that can pick up both mechanical and biological stimuli at the same time	elastic carbon nanotube (CNT) fabrics+ Ecoflex	With high accuracy, CNT microyarn sensor skin could pick up changes in humidity in the range of 48 to 75% RH.	But because it is hard to put together individual CNTs, their use in the economy as a whole has been limited.
(2016)[116]	Printed organic transistor circuit	Polymer	3D electronics	There is less stretchability
(2016)[118]	Multisensory paper skin	Temperature Sensors+ Humidity Sensor+ PH Sensor+ Multifunctional Force Sensor+ Paper Skin	3D antennas, 3D touchscreens	This paper's skin technology is less flexible and able to stretch.
(2016)[119]	Learning to link what you see and what you feel	Real life Objects	3D space around the skin surface	The presented architecture may not be possible because it needs a lot of processing power and memory.
(2016)[120]	The neural basis of how hard a natural or artificial touch feels	ANN	75% accuracy	But the neural factors that determine the size of a touch haven't been figured out for sure yet.
(2016)[121]	RFID Skin Made of Fabric	Fabric+ temperature sensor	The double metalized nylon conductive fabric is 100 m thick.	We need to improve fabrication process

(2017)[123]	Mineral hydrogel based on bio-inspiration as a self-healing	alginate mineral hydrogel+ hydrogel-based capacitive sensor	Pressure sensitivity of up to 1 kPa so that a light finger touch is possible	Lack the ability to heal them and have poor face-to-face contact.
(2017)[126]	Delicate Surgical Manipulation	pneumatic soft robotic gripper	3D-printed	This way of making things can be used to make very thin soft actuators and soft actuators in many different shapes that can be used in many different ways.
(2018)[129]	Cutaneous Mechanoreceptors That Change Quickly	biological somatosensory system+ Artificial mechanoreceptor cutaneous sensor+ pressure sensitive systems	0.21 volts per kilopascal at static pressure	Because a pressure sensor's mechanism is limited by a single type of signal or a limited set of material properties, it is based on a local interpretation.
(2018)[130]	Turboelectric proximity and pressure-sensing skins that are self-powered, very stretchable, and very sensitive	Ecoflex 00-30 with Ag flakes as a upper turboelectric robotic skin+ Ecoflex 00-30 with molded pneumatic chambers+ Ecoflex 00-30 with embedded paper+ Ecoflex 00-30 with bottom turboelectric pressure-sensing skin	The tribo-skins keep their sensing functionality even after being stretched to 100% strain.	Their huge potential is severely limited by the fact that they don't have the right electronics for sensing, interacting, and feedback control on their deformed bodies.
(2019)[133]	Fibers that conduct electricity and a high-elastic spacer fabric	Conductive fabric+ Electrostatic spinning + 3D penetrated fabric+ Pressure sensor+ Wireless passive sensor	3D penetrated fabric	This skin has not the ability of self-healing.
(2019)[135]	Touch screens that are built into the skin and work wirelessly	Electronics + Silicone C+ PI+ Cu+ Clothes + Silicone B+ Actuators+ Silicone A	The comparable strains for a 145-degree bend remain below the elastic limit (0.3%).	The system can work better if the mechanical action at the skin interface is made stronger.
(2020)[145]	Artificial skin made of engineered silk protein hydrogel	silk hydrogel+ piezoelectric devices	We can harvest energies ranging between 6.2 and 0.9 μW/cm^2	Only about 20% of the EG-skins that are made can be bent, folded, and stretched.
(2021)[147]	Synergistic soft–hard segments design	Self- healing elastomer	self-healing ability with 93% efficiency	PCL self-healing elastomers, on the other hand, are good at being compatible with cells but

				have a higher Young's modulus and less flexibility.
(2015)[156]	A Soft Pneumatic Actuator	silicone rubber+ fibers	3D printed molds	With two sensors built into the actuator, a proprioception mechanism can be used to control bending more precisely and get a better idea of how well a grasp will work.
(2015)[157]	multi-modal artificial skin	Proximity Sensor	Cell input voltage is 3.0–5.5 V	It is hard for other senses to make up for the lack of artificial skin.

Categories and Methods:

Artificial skin

There are two categories of artificial skin, electronic skin (e- skin) and Bioengineered skin.

3.1.1 Electronic skin

Electronic parts are used to mimic the way skin works in artificial skins. Consider using capacitive or piezoresistive parts to make the same response as a mechanoreceptor. In reverse, temperature sensors have replaced thermo receptors in the skin. Putting these sensors in a grid makes it possible to recognize where something is. These devices could be a way to give skins some functionality again. To manufacture synthetic skins as flexible as human skin, soft substrates such as silicone rubber are employed to fulfill the skin's mechanical requirements. On the other hand, sensors can be built from a variety of materials, from silicon-based electronics to nanostructures of conductive polymers. These are gaining popularity because they are more adaptable. [158] Since review papers on the development of electronic sensing skins have already been written, we will only talk about the most important points here.

Pressure measurement using piezo-resistivity

Resistance fluctuations in piezoresistive sensors indicate strain. Changing contact resistance between materials is one way. This method creates a pressure-responsive polypyrrole (PPy) hydrogel array of hollow-spheres[159]. This made it possible to measure pressures lower than 1 Pa, and it also showed that an artificial skin made of coaxial electrode fibers could respond to strains of up to 100%[1]. Using nanoscale crack junctions that look like zippers to change resistance with mechanical strain has been shown to be able to detect small pressures of 5 Pa and vibrations with amplitudes of about 10 nm[160]. In the same way, layers of interlocking polyurethane nanofibers have been used to sense pressure, shear, and torsion over 10,000 cycles. [161]. Gold nanowires have also been put into arrayed piezoresistive skins, which are sensitive enough to detect pulses[162].

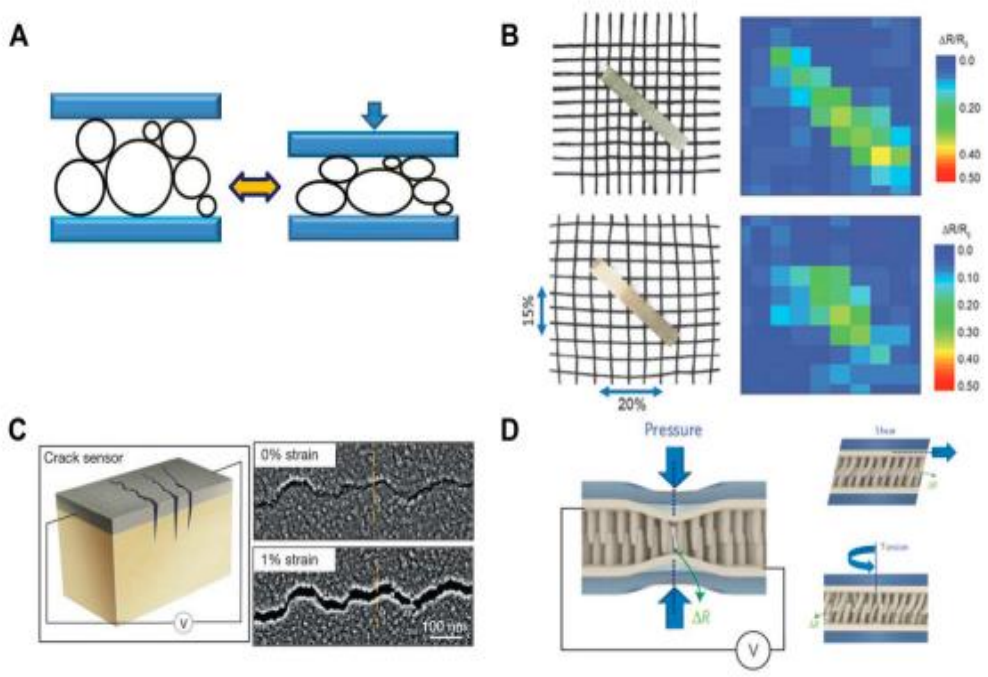


Figure.4 Artificial skins with piezoresistive properties courtesy from[1].

Table 3. Summary of research papers on pressure measurement using piezo-resistivity

References	Methods	Datasets/Equipments	Limitations/Issues
(2016)[1]	Stretchable Electronic Skin	Elastic thread+ Nylon fiber+ polyurethane fiber+ sliver electrode+ piezoresistive rubber+ sensor electrode+ stretchable electronic fabric+ Mechanical stimuli sensor unit	Different mechanical force sensitivities have been established for a single sensor unit, however a stretchy sensor array with multiple force mapping qualities has not been achieved
(2015)[163]	Surface-modified piezoresistive	piezoresistive nanocomposite flexible pressure sensors	We can increase the sensitivity
(2018)[164]	Touchpoint-tailored ultra-sensitive piezoresistive	piezoresistive pressure sensors	a low threshold for detection (0.36 Pa)

Pressure detection via capacitance

C = R0A/d is the formula for capacitive sensors. C, R, and 0 represent capacitance, relative static permittivity of the material between the plates, electric constant, area, and distance, respectively.[165]. These devices were sensitive enough to pick up venous pulses in the jugular vein[166]. Thin film polymer transistors made 15 times more sensitive, so they could now pick up the radical artery pulse wave[167]. The Artificial skin could hold up to 150% of its original size, and it was very clear.

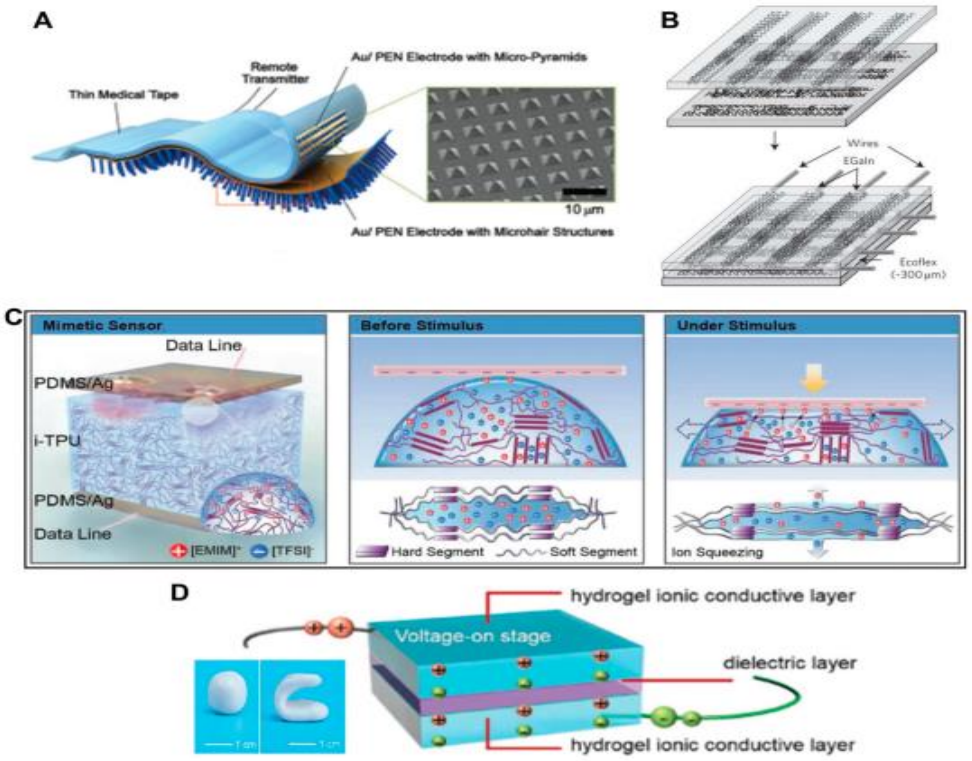


Figure.5 Artificial skins capable of capacitive sensing courtesy from[1].

Table 4. Summary of research paper on pressure detection via capacitance

References	Methods	Datasets/Equipments	Limitations/Issues
(2020)[168]	Touch mode pressure sensing	pressure sensor	The linear range of the sensor is going to be increased in order to demonstrate applications with a higher degree of precision.
(2017)[123]	Bio-Inspired Mineral Hydrogel Skin for Sensitive Pressure Detection	hydrogel sensor	Also, flexible and/or stretchable materials are not enough for bio mimicry and medical applications.
(2022)[169]	self-healable hydrogel artificial skin	A mechanical capacitive sensor based on the SHARK	The reported hydrogels did not have a lot of elasticity and heal quickly.

Detecting temperature variations

They talked about a temperature sensor array made of polyaniline nanofibers that had been electrochemically polymerized on poly (ethylene terephthalate) (PET) films. [170]. This substance acted like a thermistor and was very sensitive to temperature changes[171]. When an active matrix design and a deformable silicone rubber substrate were added to the skin, the skin's spatial resolution and performance became more stable, and it could handle strains of up to 50%. Even though the impurities that are added during synthesis are very dangerous, pure polyaniline is not cytotoxic in vitro and does not cause skin irritation[172].

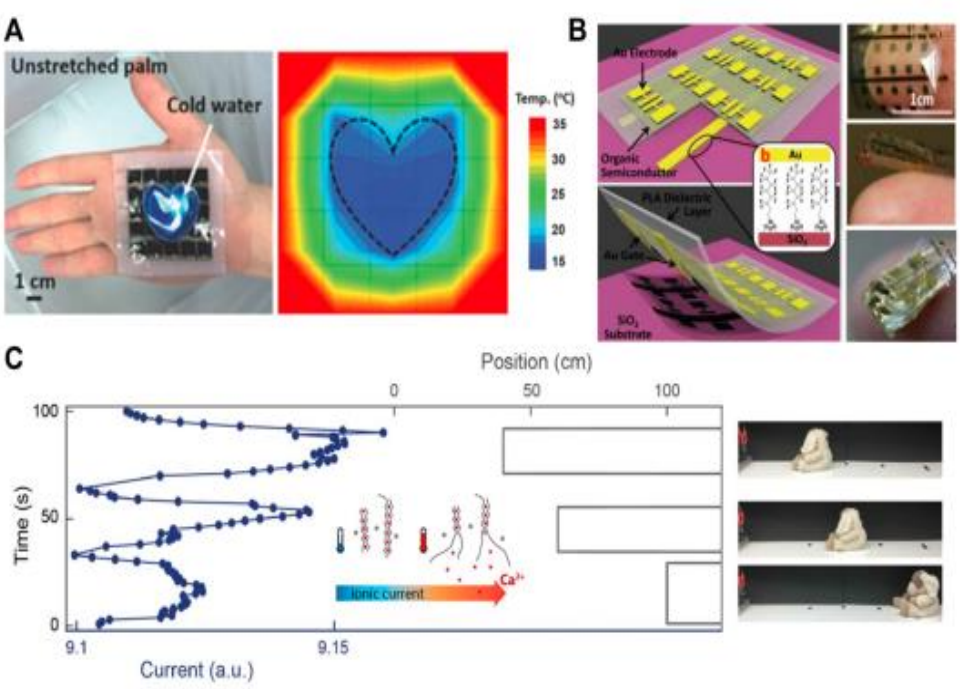


Figure.6 Artificial skin with thermal sensing courtesy from[1].

Table 5. Summary of research papers on Detecting temperature variation

References	Methods	Datasets/Equipments	Limitations/Issues
(2014)[112]	Full-Printed Flexible Fingerprint-like Three-Axis Tactile	Temperature sensor	But because it's hard to make devices on flexible substrates, flexible devices can only feel force in one direction
(2015)[173]	Arrays that measure temperature for artificial skin	Temperature sensor	Beyond room temperature, they have very limited thermal sensitivity, making them more practical.
(2015)[174]	Changing the shape of the base for an artificial skin	Temperature sensor	Furthermore, changing the design may improve selectivity even more.

3.1.2 Bioengineered skin

The first generation of artificial skins used to treat wounds led to the next step, which are bioengineered skins. This study goes beyond what has been done before by using new microstructures and materials to help cells stick together and grow so that tissues can heal. Progress in tissue engineering and the discovery of stem cells have made these changes happen faster. We'll look at how these advanced bioengineering technologies have changed in this section.

Restoring bioengineered skin function

As important as getting the injured area to heal is getting the artificial skin to work again. The use of skin colour is one way to deal with this problem[175]. Their main goal has been to make the next generation of tissue-engineered skin that looks like real skin. To make tissue-engineered skin, these researchers took biopsies of human foreskin and took out keratinocytes, melanocytes, and dermal fibroblasts[176].

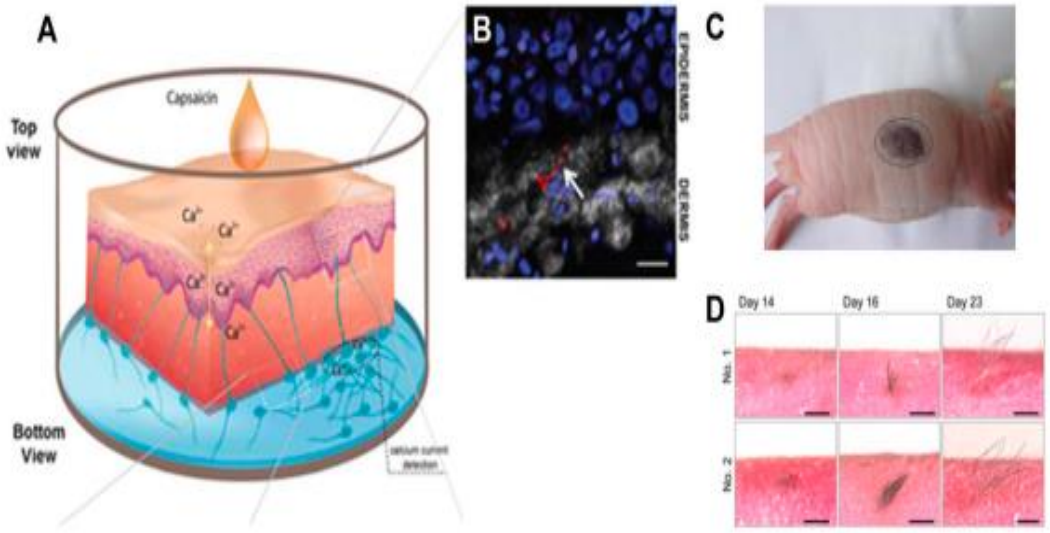


Figure.7 Bioengineered skin re-functionalization courtesy from [1].

Table 5.Summary of research papers on Bioengineered skin re-functionalization

References	Methods	Datasets/Equipments	Limitations/Issues
(2019)[177]	Skin tissue engineering	3D skin bioprinting	This may potentially lead to significantly improved in vitro models of human skin disorders.
(2017)[178]	Skin tissue engineering	3D polymeric matrix	Even though 3D-printed grafts have a sophisticated tissue architecture, bio-printed skin does not develop skin appendages.
(2018)**[179]**	skin tissue engineering	3D functional scaffolds	The principal drawbacks of currently available bioengineered skin are difficulty integrating with the wound bed, lack of vascularization, scarring, and constricted healed tissue.
(2010)**[180]**	Tissue scaffolds for the healing of skin wounds	Collagen-Based Matrices	Although potential hazards and benefits of composite scaffolds must be further explored in clinical trials, it is acceptable that they offer a new major approach for wound therapy.

Current Challenges

The study of artificial skin, which attempts to mimic human skin's structure and performance, is a complex one. Although artificial skin development has come a long way, it still faces numerous obstacles before it can be employed in medical settings. Challenges in creating synthetic skin include:

1. First, it attempts to mimic the intricacy of the human skin, which consists of many different layers and types of cells. Understanding the physiology and biology of human skin is essential for successfully recreating it in artificial skin.
2. Second, mechanical qualities must be achieved that allow artificial skin to perform as intended. These mechanical attributes include elasticity, strength, and flexibility. It is challenging to create materials with similar qualities.
3. Making sure it's biocompatible: Synthetic skin can't trigger an immune response or be rejected by the human body. It is difficult to create materials that are both functional and compatible with the body's natural tissues.

4. Human skin delivers a variety of sensory feedback, including touch, pressure, and temperature, which is essential for the functioning of the nervous system. Recreating these feelings in synthetic skin is challenging, but essential for a functional replacement.
5. Durability: Synthetic skin needs to be sturdy enough to last for years while still performing its intended purpose. The skin is continually exposed to environmental variables that might cause damage, making durability difficult to achieve.
6. Developing artificial skin that is both affordable and scalable presents a significant research and development challenge. Artificial skin can be difficult and costly to mass make because of the high cost of the materials and procedures involved in its creation.
7. Seventh, the time and money needed to gain regulatory approval before releasing artificial skin to the public.

Conclusion

Recent advances in synthetic skin research have demonstrated promising results for treating a variety of medical and aesthetic conditions. The advent of artificial skin has the potential to revolutionize wound care by offering a more secure and efficient replacement for current methods. Artificial skin has showed promise in treating a variety of skin ailments, including wounds, burns, and inherited skin illnesses. The advancement of artificial skin has also facilitated the development of more functional and mobile prosthetics and robotics. Researchers are making great gains in the production of artificial skin, but there are still obstacles to be addressed, such as identifying the right combination of materials to generate skin-like texture and durability. Artificial skin has the potential to change healthcare and improve the quality of life for many individuals if research and development are funded and supported. The review provides information about the state-of-the-art and previous advancement in Artificial skin. 89 articles have been studied about artificial skin. Electronic parts are used to make artificial skins work like real skin. Various methodologies, such as Sensing pressure through piezo-resistivity, sensing pressure through capacitance and Sensing temperature changes, etc., are explored in this review. Bioengineered skin is also talked about, as well as how it goes through different stages of development, such as Growing the matrix, functionalizing bioengineered skin, and restoring the function of bioengineered skin. The first generation of artificial skins used to treat wounds led to the next step, which are bioengineered skins. Future improvements in artificial skin perception will make it possible to make smart electronic systems and gadgets for cutting-edge uses like robotic surgery, therapy, and prosthetics.

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