engineering proceedings

MDPI

Proceeding Paper

Textile Pressure Sensors: Innovations and Intellectual Property Landscape †

Massimo Barbieri [1,*] and Giuseppe Andreoni [2,3]

[1] Politecnico di Milano, Technology Transfer Office (TTO), Piazza Leonardo da Vinci 32, 20133 Milano, Italy
[2] Dipartimento di Design, Politecnico di Milano, Via Durando 10, 20158 Milano, Italy; giuseppe.andreoni@polimi.it
[3] Bioengineering Laboratory, Scientific Institute IRCCS «E. Medea», 23842 Bosisio Parini, Italy
* Correspondence: massimo.barbieri@polimi.it; Tel.: +39-02-2399-9233

† Presented at the 11th International Electronic Conference on Sensors and Applications (ECSA-11), 26–28 November 2024; Available online: https://sciforum.net/event/ecsa-11.

Abstract: Textile pressure sensors represent a recent field area of development within the field of wearable technology and smart textiles. The potential applications of these sensors are diverse, spanning healthcare, sports, and other domains. The objective of this paper is to provide a comprehensive analysis and benchmarking of the intellectual property rights (IPR) scenario for textile pressure sensors. Indeed, as the field progresses, it will be necessary to implement ongoing adaptations to IP strategies and legal frameworks in order to effectively address the emerging challenges and opportunities. A number of patent databases have been employed in order to evaluate the patent landscape pertaining to textile pressure sensors. This has involved the utilization of specific keywords.

Keywords: textile pressure sensors; wearable; patent landscape; intellectual property

Citation: Barbieri, M.; Andreoni, G. Textile Pressure Sensors: Innovations and Intellectual Property Landscape. *Eng. Proc.* **2024**, *82*, 37. https://doi.org/10.3390/ecsa-11-20512

Academic Editor: Stefano Mariani

Published: 26 November 2024

1. Introduction

The integration of functionalized fibers or fabrics within smart textiles enables the monitoring of a range of physiological parameters, including electrocardiogram (ECG), respiration, temperature, and moisture. In some cases, mechanical or electrical actuation can even be embedded with technical fabrics in the garments [1].

The multifunctionality of these textiles is particularly beneficial in healthcare, where they can be used for patient monitoring, in sports, where they can be employed for performance tracking, and in ergonomic studies, where they can be used to assess body posture and movement [2–7].

Textile pressure sensors represent a recent field area of development within the field of wearable technology and smart textiles. The potential applications of these sensors are diverse, spanning healthcare, sports, and other domains [8–10].

These sensors are integrated into fabrics, thereby enabling the detection of pressure changes through touch or body movement, thus providing a seamless interface between the user and the digital world. The research and development of textile pressure sensors is concerned with the interdisciplinary fields of material science, electronics, and design.

Textile pressure sensors are primarily developed using conductive fibers or yarns, which are woven into or coated upon fabrics [11].

The underlying electric principles are as follows: (1) the use of materials whose electrical resistance changes under pressure, or (2) the modification of the sensor geometry, which results in a change in electrical capacitance.

The aforementioned materials comprise conductive polymers, carbon nanotubes, and metallic nanoparticles in a deposited ink. The integration of these materials into textiles can be achieved through a variety of techniques including weaving, knitting, printing, and embroidery. This results in the production of flexible, durable, and washable sensors.

As the technology matures, the status of intellectual property (IP) rights assumes greater importance for stakeholders seeking to define an exploitation strategy for their innovations.

The objective of this paper is to provide a comprehensive analysis and benchmarking of the intellectual property rights (IPR) scenario for textile pressure sensors. Indeed, as the field progresses, it will be necessary to implement ongoing adaptations to IP strategies and legal frameworks in order to effectively address the emerging challenges and opportunities. A patent landscape is a specific type of patent search conducted to identify the most recent inventions or to study the evolution of a particular technology and provides an overview of patent activity. A patent landscape analysis (PLA) was carried out on textile pressure sensors, used in a variety of applications, including wearable electronics, healthcare monitoring, and smart textiles. This paper describes the methodology and the outcomes of this PLA.

2. Materials and Methods

This research is based on a "systematic" review in the most relevant patent databases in order to evaluate the patent landscape of textile pressure sensors in terms of materials, manufacturing processes, and sensing principles by exploring the sources through specific keywords [12]. Data were extracted from the following patent databases: Patentscope [13], Google Patents [14], Espacenet [15] and Orbit Intelligence [16]. The searches were conducted using keywords exclusively, across the Title, Abstract, Claims and Description search fields. Boolean and proximity operators were employed. The full details of all searches are provided in Appendix A.

The dataset was crosschecked to exclude duplicates, records that were not within the scope of the search and irrelevant records.

The time range for the analysis was set to 20 years, i.e., the validity period of a patent. All documents were admitted to this review: granted patents or filed inventions still pending approval (application status).

3. Results and Discussion

The outcomes of the patent searches are presented in Table 1. The list of results from the four databases utilized in the search is provided in the Supplementary Materials (Dataset S1).

Table 1. List of the results obtained through the patent searches.

Database	Number of Documents Retrieved by Database Searching	Number of Documents Remaining After Screening
Patentscope	173	121
Google Patents	365	180
Espacenet	291	206
Orbit Intelligence	288	213

It can be observed that the number of results varies depending on the database, as each database is characterized by a distinct search engine. Additionally, the coverage of patent documents differs. Consequently, the subsequent analysis of data has been conducted on the results obtained by Orbit Intelligence, given its value-added data (concept extraction, key content, etc.), and the verification that this data extraction comprised the documents provided by the other databases. Thus, Orbit Intelligence was demonstrated to be the most complete patent source for this search.

The temporal analysis, as illustrated in Figure 1, highlights that up to 2009, the interest in this sector of innovation was very limited: very few publications or applications are shown. From 2010 to 2014, an increase in the trend is shown, even if it is moderate. Indeed, the number of patent filings shows a relevant change and increase from 2014 until 2021. Meanwhile, in 2022, the number of filings seemed to have reached a plateau or event to decrease. The data for 2023 and 2024 are not yet available, as patent applications are typically published 18 months after the initial filing.

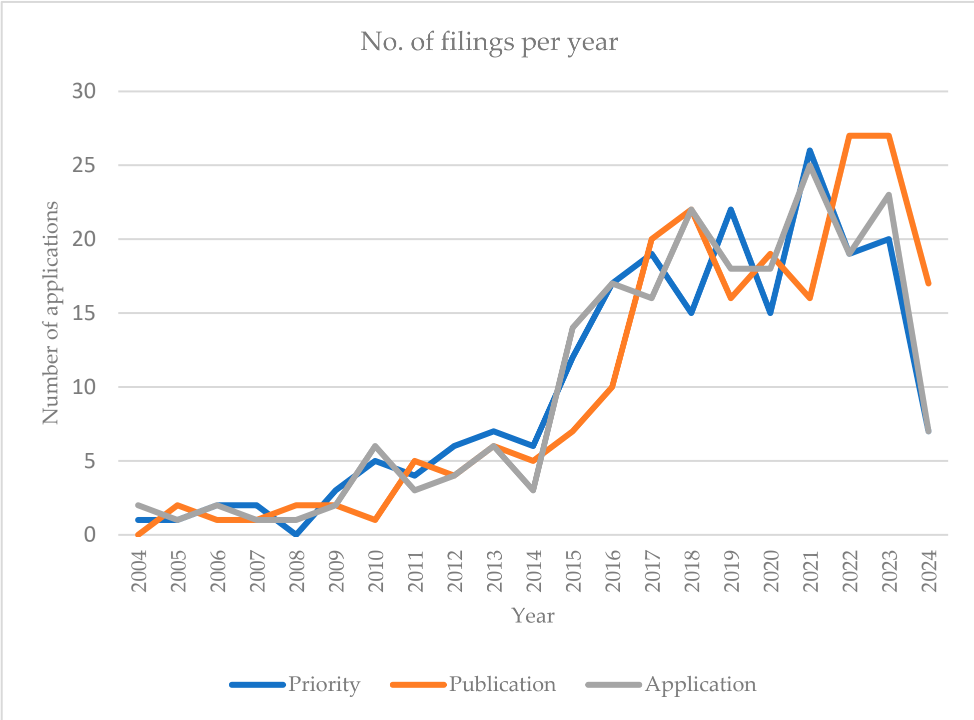

Figure 1. Number of filings over the past twenty years. In this figure, the priority, application and publication year are indicated.

The analysis of the successful examination reveals that 47.4% out of the received applications were granted, 26.3% are currently pending examination, 19.7% lapsed due to the non-payment of maintenance fees or the lack of a response to an Office Action, 5.2% were revoked by the Patent Office and 1.4% have expired.

Figure 2 illustrates the five countries with the highest number of filed and published applications. China leads the ranking, with 109 priority applications, followed by the USA (37) and South Korea (19). Notably, the PCT procedure is a popular choice among applicants, with 39 applications.

The filing of a single international patent application under the Patent Cooperation Treaty (PCT) allows applicants to simultaneously seek protection for an invention in 157 countries.

The Patent Cooperation Treaty (PCT) does not function as a granting system, as there is no such thing as a "worldwide patent". Rather, the PCT establishes a procedure for postponing the entry into the national phases.

This is usually employed when the applicant is uncertain as to the optimal geographical scope for extending the patent.

Table 2 presents a list of the most cited applications. It should be noted that half of these have expired, been deemed to be withdrawn or terminated before grant. Those highlighted in green are the ones where the patent family is still in force.

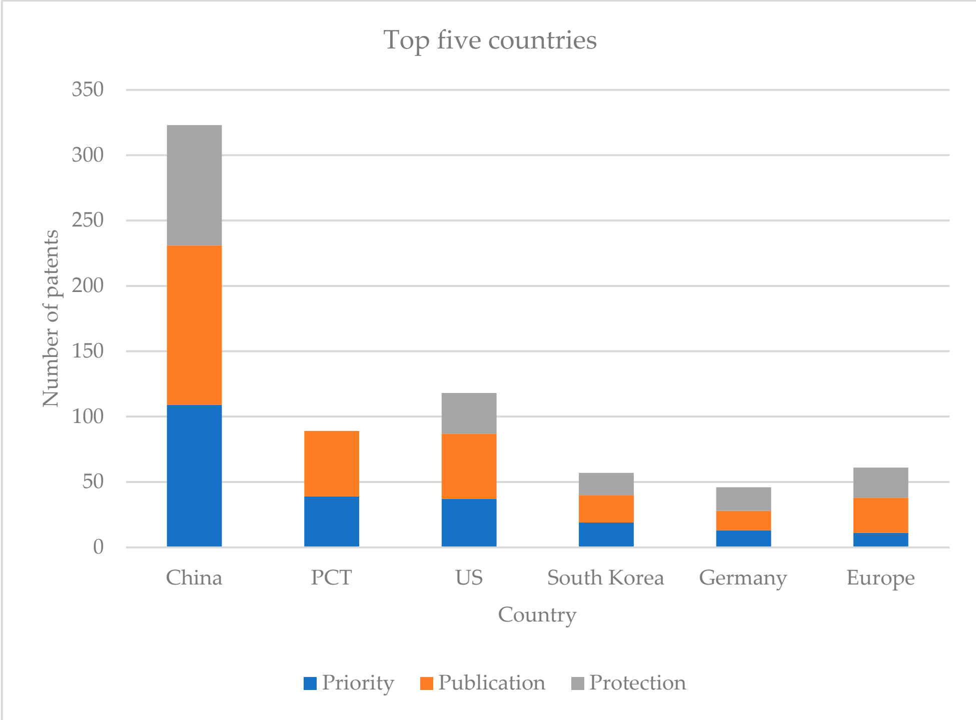

Figure 2. Number of filings per country or international application (PCT).

Table 2. List of the most cited patents/patent applications.

Title of Patent/Application	Application No.	Priority Date	Forward Citations	Geographic Scope of Protection
Conductive pressure sensitive textile	WO200175778	2000	13	13
Textile pressure sensor	GB2443208	2006	8	1
Pressure sensor	WO2007059971	2005	6	4
Textile pressure sensor	WO2013120624	2012	6	4
Pressure sensor	WO9960357	1999	5	1
Fabric-based pressure sensor arrays, including intersecting elongated conductive strips on opposite sides of a textile sheet	US11617537	2011	4	1
Tactile pressure sensor	WO0026627A1	1998	4	1
Textile capacitive pressure sensor	WO2005121729	2004	4	1
Sensors, interfaces and sensor systems for data collection and integrated remote monitoring of conditions at or near body surfaces	US20150177080	2015	3	12
Resistance-type pressure distribution fabric sensor	CN107144379	2017	2	1

In addition to the number of forward citations, it is also important to consider the geographic scope of protection, which indicates the number of countries in which the patent application has been filed and granted.

Figure 3 shows the distribution of the primary concepts or applications for the analyzed results, allowing for the rapid identification of the most frequently occurring concepts. This can be interesting as a source of inspiration for new developments or the identification of protected technologies in a novel field.

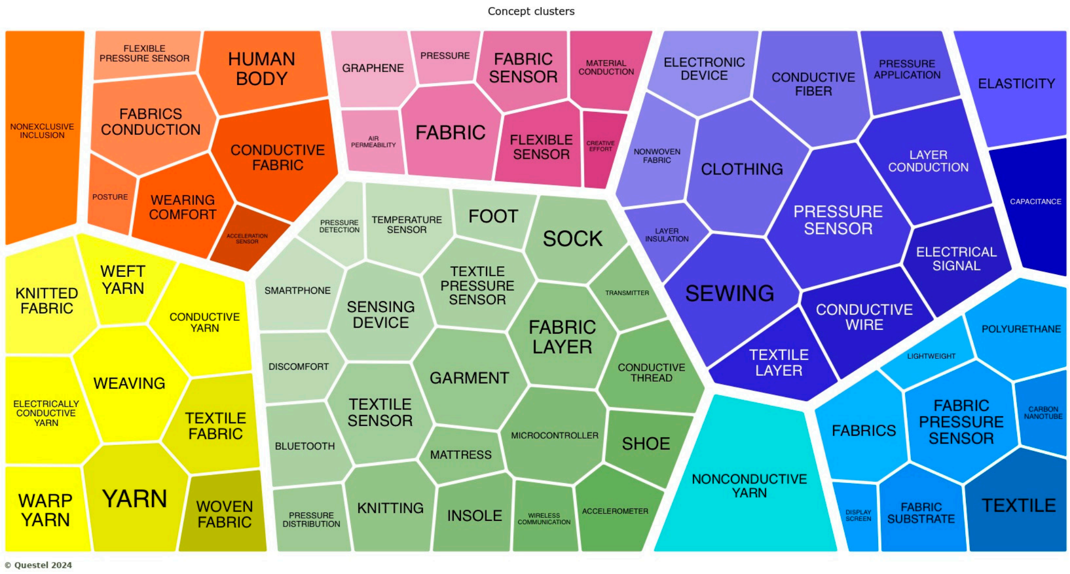

Figure 3. Concept clusters.

The documents retrieved by the search are categorized into the following top three subclasses: (1) G01L (measuring force, stress, torque, work, mechanical power and efficiency or fluid pressure), (2) A61B (diagnosis) and (3) D10B (indexing scheme associated with the subclasses of Section D relating to textiles and the chemical composition of fibrous materials).

The textile-based sensors use different sensing mechanisms: piezoresistive (79 results), piezocapacitive (46), piezoelectric (43) and triboelectric (9).

In terms of materials used in force sensors, carbon allotropes are in first place: graphene (32 results), carbon black (26) and carbon nanotubes (14).

Other materials mentioned are PEDOT (17), polyaniline (12), MXenes (7) and Ti_3C2T_x (2).

In patent application No. CN115790920A (filed in 2022 and published in 2024), the conductive material comprises at least one of carbon black, carbon nanotubes, carbon fibers, conductive graphite, graphene, gold powder, silver powder and nickel powder [17].

Patent application No. CN115752827 (filed in 2022 and published in 2024) claims a stretchable array flexible fabric pressure sensor characterized by the non-conductive fibers including at least one out of cotton, viscose, nylon, or polyester fibers; the material of the conductive layer should have at least one selected from carbon black, graphene, carbon nanotubes, polyaniline, PEDOT/PSS, silver nanoparticles and copper nanoparticles [18].

Patent application No. CN118482842A (filed and published in 2024) describes a method of fabricating a MXene fabric pressure sensor [19].

The fabric pressure sensor claimed in patent application No. CN117848556A (filed and published in 2024) is based on a liquid material (a gallium–indium alloy in an n-decanol solution) [20].

The pressure sensor claimed in patent application No. WO2015/014950 (filed in 2014) comprises a conductive polymer which is one of the following: poly(3,4-ethylenedioxythiophene) poly(styrene sulfonate (PEDOT:PSS), poly(4-(2,3-dihydrothieno[3,4-b]-[1,4]dioxin-2-yl-methoxy)-butanesulfonic acid) (PEDOT- S) or PEDOT:tosylate [21].

The resistive pressure sensor described in utility model no. CN206504812U is characterized by the first and the second conductive layers being a carbon black–silicon rubber composite layer [22].

Other materials mentioned in the scientific literature, such as transition metal sulfides (TDMs), metal–organic frameworks (MOFs), black phosphorous, antimonene or $SnO_x/SnCl_2$, were not found in the results set.

Finally, the type of clothing to which the pressure sensors are attached is worth mentioning.

Garments (48 results) are the most commonly cited, followed by shoes (32), socks (19) and gloves (14).

4. Conclusions

Textile pressure sensors can be used in a variety of applications, including wearable electronics, healthcare monitoring, and smart textiles. This is an interesting and wide market, so the IPR in this sector could be strategic. The PLA that was carried out on textile pressure sensors confirmed a good number of interesting applications in the last 20 years (213 in total, selected through the Orbit Intelligence platform, which showed the best performance among the available sources) with a positive trend in the number of patent applications until 2021. About half of the applications were then successfully granted.

Most of the priority patent applications (and utility models) were filed in China.

In addition, PLA has shown an increase in the use of piezoresistive materials.

These materials change their electrical resistance in response to applied pressure. Carbon-based materials (e.g., graphene, carbon black and carbon nanotubes) or conductive polymers such as polypyrrole are often used because of their high sensitivity and flexibility.

Some solutions indicating capacitive pressure sensors were also claimed.

In capacitive pressure sensors, two conductive layers are separated by a dielectric material. When pressure is applied, the distance between the layers changes, modifying the capacitance. The dielectric materials used can be silicone rubber or other flexible polymers.

Piezoelectric materials that generate a voltage when mechanically stressed were also found in the dataset. Common piezoelectric materials used in textile pressure sensors include polyvinylidene fluoride (PVDF) and its copolymers. These are often coated onto fibers or incorporated into layers within the textile.

Current activity in the field still emerges from the PLA, but a possible plateau or even a decreasing trend seems to start. This could be due to the following reasons: (a) the change in paradigm, for example moving towards Internet of Things solutions that are less embedded, less seamless, but somehow easier to be integrated into systems, or (b) the limits of the available materials or (c) the limited economic impact for textile pressure sensor exploitation.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/ecsa-11-20512/s1, Dataset S1: Database results list.

Author Contributions: Conceptualization, M.B. and G.A.; methodology, M.B.; data curation, M.B.; writing—original draft preparation, M.B.; writing—review and editing, G.A.; supervision, G.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are available in this manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

This appendix provides a list of the search queries that were used to retrieve the patent data.

Patentscope

EN_ALLTXT:(“textile pressure sensor*”) OR (EN_ALLTXT:(“fabric pressure sensor*”)) OR (EN_ALLTXT:(“knitted pressure sensor*”)) OR (EN_ALLTXT:(“textile pressure”)ˆ3 and EN_ALLTXT:(sensor*) OR (EN_ALLTXT:(“knitted pressure”)ˆ3 and EN_ALLTXT:(sensor*)) OR (EN_ALLTXT:(“fabric pressure”)ˆ3 and EN_ALLTXT:(sensor*)))

Google Patents

TAC=(“textile pressure sensor”) OR (“fabric pressure sensor”) OR (“knitted pressure sensor”)

Espacenet

(ctxt = “textile pressure sensor?” OR ctxt=(“textile” prox/distance<3 “pressure sensor?”)) OR (ctxt = “fabric pressure sensor?” OR ctxt=(“fabric” prox/distance<3 “pressure sensor?”)) OR (ctxt = “knitted pressure sensor?” OR ctxt=(“knitted” prox/distance<3 “pressure sensor?”))

Orbit Intelligence

Search Step	Results	Query
1	21	(TEXTILE PRESSURE SENSOR)/TI/AB/CLMS/ICLM
2	52	(FABRIC PRESSURE SENSOR)/TI/AB/CLMS/ICLM
3	0	(KNITTED PRESSURE SENSOR)/TI/AB/CLMS/ICLM
4	87	(TEXTILE PRESSURE SENSOR)/TI/AB/CLMS/DESC/ODES/ICLM
5	130	(FABRIC PRESSURE SENSOR)/TI/AB/CLMS/DESC/ODES/ICLM
6	206	1 OR 2 OR 4 OR 5
7	59	(TEXTILE PRESSURE SENSOR)/KEYW/TI/AB
8	134	(FABRIC PRESSURE SENSOR)/KEYW/TI/AB
9	1	(KNITTED PRESSURE SENSOR)/KEYW/TI/AB
10	288	6 OR 7 OR 8 OR 9

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