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A Review of Patent Technologies on Smart Diapers

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Abstract

Driven by both global population aging and the rise of intelligent parenting concepts, smart diapers have become a critical entry point for personal health monitoring. Their core technologies directly influence caregiving efficiency and user well-being. This paper conducts a comprehensive review of global patents related to smart diapers and innovatively analyzes the progress in three major technological pathways: sensing technology innovations, energy and structural design, and intelligent systems for health management. Current technological development is undergoing a transformation from single-function wetness alerts to multidimensional physiological monitoring systems. With breakthroughs in sensing technologies and system architectures, product performance and commercialization feasibility have been significantly enhanced. The paper identifies core directions for future technological breakthroughs and provides new insights and references for R&D and industrial development in relevant fields.

Keywords

Smart diapers; sensing technology; reusable design; self-powered systems; health management.

1. RESEARCH BACKGROUND AND OBJECTIVES

According to data from China's seventh national census, the country is experiencing a rapid acceleration of population aging, with the proportion of elderly and disabled individuals continuously increasing. This trend presents an urgent demand for high-quality and efficient long-term care services [1]. Meanwhile, new-generation parents are increasingly embracing evidence-based parenting concepts, showing a strong preference for maternal and infant products that provide quantifiable data and intelligent feedback. This shift has fostered the emergence of a massive smart eldercare and intelligent maternity market [2].

As a core caregiving product for both infants and disabled adults, traditional diapers have inherent limitations in terms of real-time responsiveness and health monitoring. Focusing on the technological progress of smart diapers, this paper systematically reviews and analyzes key global patents to deeply examine the breakthroughs and limitations of mainstream technological approaches. The aim is to offer valuable references for R&D decision-making and industrial layout planning in related sectors.

2. PATENT ANALYSIS

2.1. Patent Application Trends

From the annual changes in patent applications, the development of smart diaper technology can be divided into three distinct stages:

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Early Exploration Stage (Before 2015): Prior to 2015, the global number of patent applications related to smart diapers remained relatively low and fluctuated significantly. Although there were small peaks in 2009 and 2014, the field was generally in an exploratory phase centered around proof-of-concept. Patents from this period mainly focused on the basic function of wetness detection using elementary sensing technologies, without large-scale R&D investments or established technological roadmaps.

Rapid Growth Period (2015–2018): Starting in 2015, with the maturation of the Internet of Things (IoT), low-power Bluetooth, and the widespread adoption of mobile internet, smart diaper R&D entered a fast lane. The number of patent filings steadily increased and reached historic highs in 2017 and 2018. During this period, innovation extended beyond simple wetness detection to include comfort, cost-effectiveness, and multifunctionality. Reusable designs and wireless connectivity became mainstream features.

Fluctuation and Integration Phase (2019–Present): Following the peak in 2018, patent applications entered a stage characterized by both fluctuation and technological integration. There was a slight decline in applications in 2019 and 2020, followed by a strong rebound in 2021 and 2022. These fluctuations reflect a dynamic adjustment within the industry, as companies face technological bottlenecks and explore new growth points. In this phase, basic wetness alerts have become standard, while patent focus has shifted to higher-level features such as data analytics, health management, and multi-scenario applications.

2.2. Major Source Countries and Applicants

China's mainland holds a dominant position in the global patent landscape for smart diapers. With a cumulative total of 221 patent applications, it significantly outpaces South Korea, the United States, the World Intellectual Property Organization (WIPO), and Taiwan, China. This disparity clearly indicates that China's mainland is not only the largest potential consumer market for this product but also the world's most vital hub for technological innovation and industrial momentum.

Since 2016, patent application activity in China's mainland has consistently led the global trend. Notably, in the key growth years of 2018, 2021, and 2022, the majority of patent increases came from China. In contrast, while South Korea and the United States maintain steady R&D investment, their annual application volumes remain relatively modest.

2.3. Interpretation of Technical Pathways

2.3.1 Innovation in Sensing Technologies: From "Wetness" to "Health"

(1) Diversification of Sensing Methods:

Resistive/Capacitive Sensing: This is the most fundamental and widely applied technique. By embedding two or more conductive ink lines or interdigitated electrodes inside the diaper, signals are triggered through the conductivity of urine or changes in dielectric constant. For example, Monit's patent WO2022181852A1 proposes determining urine volume by measuring changes in capacitance between symmetrical electrodes, enhancing the potential for quantitative detection [3][4].

Optical/Color Sensing: This method utilizes the color-changing strips commonly found on traditional diapers. An external RGB color sensor is affixed or clipped to detect these changes automatically, enabling non-invasive monitoring. The main advantage of this approach is that it avoids embedding electronic components inside the diaper. However, it may be affected by ambient lighting conditions or clothing obstruction [5][6].

Pressure/Weight Sensing: To address the difficulty in distinguishing the amount of urine solely based on humidity, some patents propose the use of flexible film pressure sensors. When

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the absorbent core expands after absorbing liquid, it exerts pressure on the sensor, allowing for an estimation of the absorption amount [7][8].

Gas/Odor Sensing: To more accurately differentiate between urine and feces, some cutting-edge solutions incorporate gas sensors. For instance, patent CN119632759A introduces an odor sensor to collect data, which is then analyzed by a deep learning model to distinguish excretion types and determine optimal changing times [9].

(2) Monitoring of Multidimensional Physiological Indicators:

Temperature and Posture Monitoring: In addition to excretion, other physiological states of the user are equally important. By integrating temperature sensors and triaxial accelerometers, it becomes possible to monitor whether the user has a fever, their sleeping posture (e.g., to prevent infant suffocation from prone sleeping), and their activity status [10][11].

From the analysis of these patents, current sensing technology trends exhibit the following three characteristics:

From Single-Point to Multimodal: Development has shifted from simple moisture detection to the integration of multiple sensors—measuring humidity, temperature, gas, and motion—to provide a more comprehensive physiological profile.

From Qualitative to Quantitative: Progress has moved from binary wet/dry judgments to quantitative analysis of urine volume, frequency, and type of excreta.

From Intrusive to Imperceptible: Sensor design is increasingly oriented toward comfort through the use of technologies such as flexible printed electronics and conductive ink, thereby enhancing wearability to the greatest extent possible.

2.3.2 Energy and Structural Design: Focusing on Cost, Comfort, and Sustainability

(1) Reusable and Low-Cost Designs:

Detachable Modular Design: This is currently the most mainstream solution. The smart hardware—containing the processor, battery, and communication module—is designed as a reusable clip-on device, patch, or magnetic unit [12], while the diaper itself serves as a low-cost disposable item embedded with simple sensing circuits. When changing diapers, users only need to detach the smart module and attach it to a new diaper.

Passive NFC Solutions: To further reduce disposable costs, patent CN111508208A proposes a passive solution based on Near Field Communication (NFC). The diaper contains only an NFC chip and an impedance-sensing coil. During detection, an external device (e.g., a smartphone) supplies the radio frequency field and reads data, significantly lowering per-diaper costs and reducing electronic waste [13].

(2) Self-Powered Technologies:

Urine-Activated Battery: This is a revolutionary innovation. Electrodes made of different metals (e.g., copper and zinc) are embedded in the diaper and separated by a dry membrane containing metal salts. When urine (acting as an electrolyte) is present, a micro galvanic cell—also known as a "sensorial battery"—is spontaneously formed, generating enough current to power a low-energy wireless transmitter. Patents such as KR101382138B1 describe this technology in detail [14].

Current developments in energy and structural design show three key characteristics:

Modular and Reusable Designs Have Become Industry Norms: This effectively resolves the conflict between cost control and environmental sustainability.

Battery-Free Self-Powered Technologies Are a Research Hotspot: These innovations offer the potential to completely eliminate the need for charging or replacing batteries.

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Comfort and Integration Are Continuously Improving: Through the use of flexible materials and printed electronics, designers aim to make the electronic components imperceptible to the user.

2.3.3 Intelligent Systems and Health Management: From “Alerts” to “Early Warnings”

(1) Remote and Cloud-Based Monitoring:

Almost all modern patents support Bluetooth, Wi-Fi, or other wireless connectivity to smartphone apps.

More advanced systems upload data to cloud platforms, enabling multiple family members or caregivers to monitor users remotely and manage multiple users simultaneously—especially important in nursing homes, hospitals, and other institutional care settings [15][16].

(2) Data-Driven Health Analysis and Early Warnings:

Excretion Pattern Analysis: By tracking the time and volume of urination/defecation over time, systems can learn and analyze users’ excretion patterns. For instance, the system proposed in WO2022181852A1 uses historical data to predict the timing and amount of the next excretion, allowing users or caregivers to prepare in advance [4]. Similarly, CN110063841A can estimate future excretion events based on current data [17].

Health Status Assessment: Some systems can assess potential health risks such as dehydration, urinary tract infections, or digestive issues by analyzing certain indicators in the urine (as in CN214157699U, which mentions electrochemical sensing) or by detecting abnormal excretion behavior [18].

Current intelligent system development presents the following three characteristics:

Cloud-Based and Platform-Oriented: The transition from standalone applications to SaaS-based cloud platforms allows centralized management for multiple users and scenarios.

Data-Driven Decision-Making: Systems are evolving from simple data display to pattern recognition and trend prediction using historical data.

Expanded Application Scenarios: Beyond basic wetness alerts, smart diapers are now integrated into broader care services such as sleep monitoring, posture alerts, fall prevention, and health risk assessments.

3. CONCLUSION AND RECOMMENDATIONS

With the deepening of global population aging and the widespread adoption of refined parenting concepts, smart diapers are gradually becoming the mainstream direction in the field of disposable excretory care products. Despite notable technological advancements, large-scale adoption still faces several challenges, including cost, user habits, and data privacy concerns. To address these issues, the following recommendations are proposed:

Strengthen Multi-Technology Integration and Fundamental Research: It is essential to advance the study of flexible and biocompatible sensing materials and explore the deeper correlations between multidimensional physiological signals and specific health conditions. Additionally, research on AI algorithms should be intensified to develop more accurate and personalized health prediction models.

Promote Industry Standardization and Ecosystem Development: The industry should work toward establishing unified standards for data interfaces and communication protocols to enable secure data flow across various caregiving platforms and healthcare information systems. This would facilitate the construction of an open and interconnected smart health ecosystem.

Focus on Cost Control and User Experience: Continued optimization of reusable module design is needed, along with the development of disruptive technologies such as battery-free

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self-powering systems, to fundamentally reduce usage costs. Meanwhile, incorporating more skin-friendly, breathable, and even biodegradable materials will enhance product comfort and environmental sustainability, ultimately gaining broader market acceptance.

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