

# A Survey of Smart Diapers with Hydration and Health Monitoring

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**Abstract**— *The IoT-based Smart Diaper with Hydration and Health Monitoring represents a revolutionary strategy for personal health care that transcends conventional moisture- monitoring systems. Equipped with real-time biosensing technology, the intelligent diaper reads urine chemistry to track hydration levels and identify urinary tract infections (UTIs) and electrolyte imbalances. With low-power sensors and a microcontroller, the system sends data through Bluetooth or Wi-Fi to a mobile app, allowing caregivers and healthcare professionals to receive instant alerts. For infant, elderly, and clinical applications, the device allows early diagnosis and tailored care. The project focuses on real-world applications such as patent application, research in academia, and commercial product development.*

## I. INTRODUCTION

The growing need for convenient, real-time health monitoring systems has fueled the development of smart wearable technology, particularly for personal hygiene and patient care. Traditional diapers may be effective at safely absorbing waste, yet they do not provide any feedback or insights into the user's health, thus introducing avoidable risks of prolonged wetness, dehydration, urinary tract infections (UTIs), and imbalances of electrolytes for many users like infants, elderly people, and bedridden patients. IoT-based smart diapers represent a major technological development that would advance preventive healthcare and assistive technologies.

The proposed IoT-enabled smart diaper is a disruptive innovation as it will harness the power of bio-sensing to perform continuous urine monitoring. It would not just be able to detect moisture, but it would provide real-time urine analysis in regard to hydration, electrolytes, and early indicators of UTIs. The proposed implementation would involve incorporating low-powered biosensor and microcontroller components that would truly give the product the ability to minimize energy usage and maximize continuous operation. The lower-powered biosensor component would collect, and the microcontroller

would process data. Once the microcontroller acquired the data, it would wirelessly send it out via either Bluetooth or Wi-Fi to the mobile application. The survey results would generate alerts, which can enable caregivers and health care providers to make timely and informed decisions.

This innovation has the potential to improve health care services across a variety of locations, including not limited to, private homes, eldercare settings, hospitals, and post-op recovery services. The ultimate goal of the smart diaper is accessibility, affordability, and comfort while providing optimal support for timely diagnosis, lessening barriers for caregivers, and leading to improved health outcomes for at-risk populations.

## II. LITERATURE SURVEY

Several research efforts have explored the development of smart diaper systems. Below are some notable contributions: Kyungho Jang et al. [1] created a novel smart diaper system for real-time bedside urine analysis using a colorimetric paper-based sensor. The smart diaper had a chemical sensor layer coupled with a urine-absorbing layer, enabling non-invasive monitoring of multiple urinary biomarkers such as pH, glucose, protein, and leukocytes. A smartphone-based image capture system detected colorimetric changes, which were then analyzed using image processing and machine learning to enhance precision. The system allowed early detection of health conditions like diabetes and infections, offering convenience for the elderly, infants, and bedridden patients. The research demonstrated feasibility for affordable, large-scale diagnostics through smartphone integration with high precision, comparable detection times to clinical standards, and minimal interference.

Vine et al. [2] developed and validated a sodium polyacrylate-based diaper method for collecting urine for qPCR detection of uropathogens and

antimicrobial resistance (AMR) markers. With 17 participants, urine was chemically eluted and tested for 22 bacterial species, 6 fungi, and 18 AMR genes. The diaper-derived samples were compared with clean-catch samples for detection sensitivity and matrix effects. Results showed low interference ( $\Delta Ct = -1.65$ ), supporting this method for populations unable to provide standard samples, like infants and the elderly.

Sung et al. [3] devised a POCT smart diaper that integrates test strips for detecting pH, leukocytes, and nitrite, enabling real-time observation by caregivers. Laboratory testing on 49 samples and clinical validation on 7 patients showed promising results: pH detection sensitivity = 66.67%, specificity = 100%, overall agreement = 97.83%; leukocyte sensitivity = 62.5%. The system emphasized ease of use, safety, and decentralized diagnostics.

TABLE I  
 SUMMARY OF SELECTED LITERATURE ON SMART DIAPER TECHNOLOGIES

No.	Author(s)	Objective	Methodology	Results	Future Scope
1	Mohammad Salah Uddin et al. (2021)	Real-time diaper wetness detection	Resistance sensor + NodeMCU + cloud + mobile app	Reliable alerts; tested on 112 infants	Wider use in care centers, mobility-impaired
2	Joryan Sennesael et al. (2025)	Sustainable smart diaper via printed sensors	Carbon-printed capacitive sensor + reusable module	Alarm at 169 mL; 50% absorbent reduction	Scale manufacturing, long-term trials
3	Bixun Chen et al. (2022)	Track urine volume and change time wirelessly	Flexible electrodes power wireless transmitter	Alerts > 600mL or 4 hours; 90mr	Hospital scale-up and app optimization
4	Tareq Khan (2022)	Detect urination via temperature rise	BLE wearable sensor + smartphone app	Multi-episode tracking; health monitoring	Integrate dehydration diagnostics
5	Manroop Singh Turna & Youngwook Kim (2022)	Diaper condition via antenna impedance	Microstrip antenna sensing moisture/feces	Clear impedance changes detected	Add wireless transmission, smart integration
6	Chaohao Chen et al.	UTI biomarker detection in diapers	Jet-printed dipstick + app image analysis	Detected nitrites, teins, pro-leukocytes	Expand to women and pet care diagnostics
7	K. Naveen Kumar & Jalakam Sridevi (2021)	IoT wetness alert with temp and humidity	DHT11 sensor + ESP8266 + Blynk app	Consistent alerts; low-cost (350)	Dedicated app and PCB miniaturization
8	Mahdiyeh Ghadiri et al.	Optimize diaper change timing	Polypropylene strip sensor + LEDs	Wetness timing curve created	Add data logging and mobile alerts
9	B. Kaushalya et al.	Conductive thread moisture sensor + IoT	Moisture sensor + Arduino + Wi-Fi + Blynk	Alerts via LED, buzzer, app	Improve portability and data storage
10	Ramesh M et al.	Wireless diaper wetness alert system	Moisture sensor + RF module + buzzer/LED	Wireless alerts; low cost	Integrate smartphone notifications

Jae Heon Kim et al. [4] introduced a Smart Diaper System (SDS) for automatic voided volume detection using changes in electrical resistance. Deployed over 12 months with 97 elderly residents, the SDS transmitted data via Bluetooth every 15 seconds and used AI to forecast urination behavior. High accuracy (Pearson  $r = 0.971$ , ICC = 0.985) and

reproducibility were achieved, demonstrating the system's applicability in continuous health monitoring in elderly care.

Jae Ho Cho et al. [5] piloted a Bluetooth-based smart diaper system in a tertiary hospital with 35 patients

aged 50+. It used wetness sensors and a smartphone app to estimate urine volume in real time. Compared with manual Frequency Volume Charts, the detection rate was 32.8% with high correlation ( $R^2 = 0.88$ ) and acceptable bias (mean difference = -4.2 mL). While performance needs improvement, the system reduced caregiver burden and had no dermatological issues.

Katherine De Lange et al. [6] conducted a survey of sensor technologies in diapers for hygiene and health monitoring. Nursing home observations highlighted issues like delayed waste detection and skin problems. The study explored sensor technologies for wetness and biomarker detection, recommending development of low-cost, wireless, disposable sensors. Challenges included durability, cost, and sustainability, for which biodegradable materials and sensor optimization were proposed.

Xiangling Li et al. [7] developed a CNT-coated electrode array smart diaper for real-time monitoring of sodium and potassium. Using flexible PCBs and ion-selective membranes, the system sent data to smartphones via Bluetooth. Despite effectiveness under mechanical stress, challenges like urine matrix interference and long-term sensor stability remain.

Johan Sidén et al. [8] proposed a low-cost RFID-based diaper with a galvanic moisture-sensing tag. Using printed electronics and NaCl doping, the system activated a 13.56 MHz RFID oscillator upon wetting. Costing under \$0.10 per diaper, it demonstrated feasibility for disposable, scalable diaper monitoring, with potential for future biochemical integration.

Antonio Lazaro, Marti Boada, Ramon Villarino, and David Girbau [9] designed a battery-free intelligent diaper system that incorporates NFC technology to sense moisture in real-time. The system includes a capacitive sensor made of two electrodes, which sense changes in capacitance as urine is absorbed, creating a capacitance-based quantitative measurement of the voided volume. The NFC tag is wirelessly powered by the magnetic field of a smartphone, making the device battery-free. A low-power microcontroller (ATTiny85) captures and stores data readable by any NFC device. The device is externally mountable and does not require modification of commercial diapers. The research

validated that capacitance is directly related to the urine volume. The sensor is reusable, inexpensive ( $\leq \$1.50$ ), and safe for geriatric and pediatric care, offering a sustainable and privacy-respecting option for broader IoT-based healthcare.

Mohammad Salah Uddin, Shathi Islam, and Nishat Vasker [10] introduced an IoT smart diaper sensor system for real-time wetness detection. The system uses a custom wetness sensor and temperature sensor interfaced to a NodeMCU microcontroller, which sends data to an IoT cloud platform. A mobile app receives the data and pushes alerts when the wetness threshold is exceeded. The wet sensor works by detecting resistance changes across aluminum strips. Tests with 112 infant urine samples (3 months–2 years) helped establish an optimal wetness threshold. Daycare trials confirmed reliable notifications. The total cost is about \$7.25, and it includes a child-resistant enclosure and low-voltage power, making it ideal for caregiving centers.

Joryan Sennesael, Arno Moerman, Frederick Bossuyt, and co-workers [11] developed a sustainable smart diaper with carbon-printed wetness sensors and a rechargeable, contactless electronic module. Using capacitive coupling for non-contact sensing, the carbon ink sensors are printed on the diaper backsheet for low-cost mass production. A reusable sensor strip transmits data and measures saturation. Field trials in elderly care homes showed reliable alerts at around 169 ml of urine, reducing unnecessary changes, improving comfort, and reducing material use by 50%.

Bixun Chen, Muhammad Zulfiqar Ali, Muhammad Usman, and others (2022) [12] designed a smart diaper system to track urine volume and diaper change time in real-time to improve the management of incontinent patients. The system utilizes flexible electrodes integrated into the diaper to extract power from urine, which is used to power a 433 MHz wireless transmitter. The signal is received by a transfer station that processes the information and sends notifications through Bluetooth to caregivers' mobile phones.

The mobile application displays diaper status and notifies caregivers in case of urine volume greater than 600 mL or four hours since the previous diaper change. Artificial urine tests confirmed a high

correlation between urine volume and signal frequency, and signal alerts at up to 90 meters distance were dependable. Multiple patients can be monitored by the system at once, reducing the workload of caregivers, and reusable parts to prevent electronic waste. Its lightweight and non-invasive nature enables it to be deployed in nursing homes and long-term care centers.

Tareq Khan (2022) proposed a smart wearable system for noninvasive urination detection and notification of diaper wetness. [13]The system is based on the detection of temperature rise on the outer surface of the diaper caused by urination and alerts a caregiver's smartphone using Bluetooth Low Energy (BLE) technology. The system is small, reusable, battery-powered, and mounted externally using hook-and-loop fasteners, without modifying the diaper structure or cost.

The system identifies repeated episodes of urination in a single diaper and records them in a mobile health monitoring application. It is especially handy in daycares, hospitals, and nursing homes, preventing diaper rash and infection through timely reminders of changes. The smartphone application also keeps urination histories, which can be utilized in diagnosing dehydration conditions. The low-cost, easy-to-operate system improves hygiene management and caregiver efficiency.

Manroop Singh Turna and Youngwook Kim [14] (2022) developed a new method for observing diaper conditions based on the input impedance variation of a microstrip dipole antenna. The antenna, mounted on the bottom of the diaper, measures the surrounding electromagnetic environment, which then indicates the presence of either urine or feces by changes in its impedance.

The antenna was designed to resonate at 5.7 GHz and was analyzed in four conditions: free space, a dry diaper, a diaper with urine, and a diaper with feces. The simulations indicated clear impedance changes for each condition, showing the ability to use the antenna as a sensor for moisture levels. The added benefit of this approach is eliminating the other moisture sensors and simplifying the integration of the sensing with the antenna for possible data transmissions. Finally, this study can be the basis for future monitoring of smart diaper systems using antenna impedance measurements.

Chaohao Chen, Yang Wu, and Tao Dong [15] developed a new smart diaper technique for the detection of urinary tract infections (UTIs) in the diaper rather than collecting the urine. They demonstrated a hybrid approach that utilized commercial dipstick chemistry, which was jet-printed into a used diaper to observe the real-time detection of three UTI biomarkers: nitrites, proteins, and leukocytes. The created method employed a handheld printer to deposit chemical indicators directly onto the specific area of the diaper that had been soiled, and these indicators change color in the presence of UTI markers, after which a smartphone camera connected to an image processing application detected and analyzed the colorimetric reactions and provided results faster than conventional means. The experimental results indicated the smart diaper performed with detection consistency for *E. coli* concentrations at a low  $10^5$  CFU/ml CFU/ml, and RGB color values obtained from dipstick sensors in the diaper were not significantly different than those from urine beakers. This innovative, low-cost, and non-invasive technique is a foundation for thinkable, rapid diagnostics for elderly patients, women, and pets and employs the potentials of smart hygiene wearables inside and outside of clinical practice.

K. Naveen Kumar and Jalakam Sridevi [16] (2021) designed an Internet of Things (IoT)-based diaper wetness detection system using a DHT11 sensor to identify temperature and humidity changes on the diaper surface. Once the system detects urine by a change in moisture and heat, the system sends an alert to a parent's mobile using the ESP8266 Wi-Fi module, which is coupled with the Blynk application.

The system is notable for its portability, reusability, and external mounting without altering the diaper's design. It stores urination records in the cloud for future use and maintains hygiene by avoiding direct urine contact. In testing with customized thresholds, the configuration showed stable alerting behavior. The low-cost design, around Rs. 350, offers a working and inexpensive solution for monitoring infant hygiene. Future work is focused on the creation of a dedicated app and a miniaturized printed circuit board for improved usability.

Zirui Ning, Zhihe Long, Guangyou Yang, Lili Xing, and Xinyu Xue et al.[17] (2022) constructed a self-powered wearable biosensor on baby diapers for non-

invasive, real-time neonatal jaundice monitoring using urine-based bilirubin detection. The sensor involves ZnO nanowires that are functionalized with bilirubin oxidase (BOx) to allow for a hydrovoltaic-biosensing mechanism where urine flow causes voltage generation by contact electrification and enzymatic reactions control the output.

The miniaturized, batteryless sensor sent alarms through LED indicators or wireless modules. It responded linearly to bilirubin concentrations of 12.5–50.0 mg/L, had a detection limit of 8.0 mg/L, and showed minimal interference from common urine constituents. Enzymatic activity validation ensured that voltage changes were caused by enzymatic activity, not redox reactions. Field testing showed that the embedded sensor accurately reported bilirubin concentrations through voltage modulation, offering a safe, cost-effective, and scalable solution for continuous neonatal jaundice screening.

Seo et al. [18] present a new diaper-embedded system for autonomous urinary tract infection (UTI) detection based on a urine-activated self-powered sensor module. The system includes a paper-based colorimetric nitrite sensor, a boost dc–dc converter, and a low-power PWM-based sensor interface to enable efficient operation. Most importantly, urine-activated Zn–Cu battery use offers activation only when urine is present, reducing power requirements and preventing incorrect readings due to reagent fading. Wireless result transfer to a caregiver device is supported by the BLE module. The system exhibits good sensitivity ( $1.35 \text{ ms/mg}\cdot\text{L}^{-1}$ ) and a detection limit of 4 mg/L for nitrite, better than the conventional dipstick method in terms of accuracy and convenience. The authors also leverage calibration and differential reading methods to prevent process variations, successfully reducing measurement errors from 33% to 3.5%. Shown with stringent experimental setups, this research illustrates the feasibility and reliability of an autonomous, wearable diagnostic system, with its integration potential into healthcare monitoring of infants and elderly patients.

Baek et al. [19] present a state-of-the-art predictive analytics care model that leverages a multi-sensor IoT system to track diaper usage and body posture among bedridden elderly patients. The system employs several sensors, such as temperature, humidity, VOC gas, multi-capacitance, and

acceleration sensors, to detect episodes of urination, defecation, and body posture. Based on a machine learning-based neural network, the model effectively classifies sensor data patterns as individual events (e.g., urine, feces, or flatulence detection, and lying posture). Monitoring and caregiver alerting are facilitated by the Smart Care App and web interface, with the possibility to prevent pressure ulcers and hygiene-related complications in elderly care. The system was extensively tested with simulated artificial data and proved to have an outstanding 100% accuracy in detecting diaper usage and patient posture fluctuations. The study addresses serious challenges in elderly care, such as pressure ulcer and hygiene-related complications prevention, and suggests a scalable, non-invasive, clinically validated solution for continuous remote monitoring.

Tekcin et al. [20] have fabricated a wearable humidity sensor embedded in disposable diapers for urinary incontinence and wetness detection. The sensor was fabricated using the inkjet printing of PEDOT:PSS-based conductive polymer on the polyamide-based taffeta substrate. Feature extraction was carried out by the observation of sensor resistance response with respect to different humidity levels; with relative humidity ranging from 35% to 100%, the resistance varied from  $17.05 \text{ M}\Omega$  to  $2.09 \text{ M}\Omega$ . Along with this, the sensor indicated response and recovery times of 42 seconds and 82 seconds, respectively. Flexibility, repeatability, and mechanical stability of the sensor were demonstrated through bending and cyclic tests, thus proving the sensor's applicability in wearable devices.

To mimic urinary incontinence, saline water between 0.1 mL and 100 mL was dropped onto the sensor-integrated diaper. The resistance change showed a good correlation with the volume of the fluid, thus confirming the sensor to identify small as well as large wetness events. Compared with current systems that employed external and rigid devices, the current work presents a cheap, soft, and disposable method that promotes not only the comfort of the user but also real-time wetness monitoring. Thus, the sensor appears to be a promising solution for bedridden and elderly patients' healthcare monitoring.

Lin et al. [21] describe a smart diaper system based on a uni-electrode self-capacitance sensor to detect wetness by detecting changes in capacitance due to moisture. In contrast to resistive or RFID-based

systems, the sensor is externally mounted on the diaper, hence not in direct contact with the skin and enhancing its reusability. Quantification of moisture detection is achieved through a urine moisture indicator (UMI) derived from voltage changes in a capacitive voltage divider circuit. The system had high sensitivity, with measurable changes occurring even with as little as 1 mL of urine. Both static and dynamic testing supported stable performance, as indicated by a low coefficient of variation (0.059%), thereby establishing the reproducibility

and accuracy of the sensor. The system also exhibits a quick response to wetness changes and has clear thresholds to alert caregivers.

The sensor is interfaced with an Internet of Things (IoT)-based system with ESP8266/Wi-Fi technology for real-time data transmission. The alerts are forwarded to a web-based dashboard showing the moisture content and battery conditions. This type of design significantly enhances remote monitoring ability, which is particularly beneficial in neonatal and geriatric care settings. Besides, the externally mounted reusable sensor effectively addresses environmental issues of disposable sensor systems. The solution overall is an ideal combination of high sensitivity, sustainability, and user-friendliness, and hence a viable solution in healthcare technologies for incontinence and infant hygiene care.

Shiu et al. [22] suggest a reusable smart diaper design that incorporates antibacterial yarns and metallic wires into woven cloth, thus meeting environmental needs as well as healthcare improvements. The outer layers of the smart diaper consist of melt-blown polypropylene (PP) nonwoven fabric, which is not only hydrophobic but also environmentally friendly, and the interlayer is woven cotton yarns impregnated with silver or zinc ions to provide antibacterial effects. Two parallel metallic wires of silver-plated copper, copper, or stainless steel are embedded 6 cm apart within the interlayer. The wires act as moisture sensors by detecting changes in electrical resistance upon exposure to moisture through a short-circuit principle. This design provides fast and accurate wetness detection while being comfortable and sanitary.

The device combines a micro-sized moisture sensor and Bluetooth chip to send real-time information to smartphones or caregiver stations. The results

indicate silver-based yarns possess stronger antibacterial effects than zinc-based ones, lowering bacterial populations such as *Staphylococcus aureus* and *E. coli* up to 95%. Electric resistance varies linearly with moisture, and the type of wire produces different levels of sensitivity. No coatings or special treatments of conventional circuits are included, facilitating easier mass production. Not only does the green concept contribute to sustainability with reusability and degradable materials, but it also provides infants, elderly people, and people with disabilities a hygienic, intelligent baby diaper solution.

Coyle et al. [23] introduces a fabric-based microfluidic device incorporating a novel lateral valve for controlled liquid handling. The system is constructed from a moisture-wicking fabric layer for sample collection and a superabsorbent non-woven (SAB) material situated at the channel terminus to facilitate fluid wicking and storage. A polypyrrole (PPy) lateral flow valve is integrated within the fluidic channel to enable precise control over the movement of liquid samples and reagents.

The described fluidic architecture is designed to support various analytical functionalities, including the potential for sample separation, reagent introduction, in-channel mixing, and subsequent analyte detection. The authors emphasize the inherent advantages of a fabric-based approach, such as ease of fabrication, potential for integration into wearable technologies, and the capacity for zero-power fluid transport. The paper posits that this technology holds promise for a diverse range of applications, encompassing environmental monitoring, personalized health management, drug delivery systems, and point-of-care diagnostic assays for both clinical and home use.

Wen et al. [24] introduce the "Goo9" system utilizes a combination of sensor technology and IoT to provide active reminders for diaper changes, addressing the limitations of passive wetness indicators found in some commercial diapers. The system comprises a detection sensor module (including humidity and temperature sensors), a data processing module, a cloud-based database, and a baby profile module. The humidity and temperature sensors monitor diaper conditions, and this data is analyzed by the data processing module to determine wetness levels. These levels are then represented by emoticons (happy, mild,

uncomfortable, and crying) and sent to the caretaker's mobile phone via an Android or iOS application.

A key feature of the Goo9 system is its ability to learn and provide more precise and customized reminders based on feedback from the caretaker. The system uses Bluetooth 4.0 for low-power wireless communication and the SHT21 sensor for accurate temperature and humidity readings. Data is collected and stored in a cloud-based database for tracking urination patterns and improving the system's accuracy. A usability evaluation with 17 baby caretakers demonstrated positive results regarding the system's overall interactions, hardware design, and application interface.

Sharif et al. [25] introduces an innovative method for detecting diaper wetness using an inkjet-printed ultra-high frequency (UHF) radio frequency identification (RFID) sensor. The technology aims to provide timely alerts to caregivers, enhancing care for individuals who rely on diapers, such as infants, the elderly, and those with disabilities. The proposed system seeks to replace traditional, less efficient methods of checking diaper wetness, ultimately promoting better hygiene and reducing the risk of health complications.

The core component of this system is a specialized RFID sensor designed to be printed directly onto the diaper. The sensor features a unique antenna design, incorporating an L-shaped radiator, a T-shaped loop connected to an Impinj R6 RFID chip, and two small stubs. Operating in the UHF band (900-935 MHz), the sensor detects changes in electrical properties caused by moisture, which are then read by an RFID reader. The research details the sensor's design and testing, demonstrating its potential to accurately and cost-effectively determine diaper wetness.

Kurita et al. [26] introduces a novel in-diaper sensor probe that utilizes metamaterials to detect moisture, aiming to improve remote monitoring and reduce the burden on caregivers. The sensor employs split-ring resonators (SRR), which exhibit specific electromagnetic properties, to detect changes in the diaper's dielectric constant as the water-absorbing polymer absorbs urine. This change is measured by observing shifts in the resonance frequency of the metamaterial, allowing for wireless determination of

diaper wetness.

The metamaterial device, designed to operate around 1 GHz, is integrated within the diaper structure. Experiments were conducted to evaluate the device's transmission characteristics and its response to moisture, both alone and when incorporated into a diaper on a human phantom. The results demonstrate the feasibility of using metamaterials for wireless urine detection in diapers, offering a potential advancement in remote monitoring technologies for infant and elderly care.

Beniwal et al. [27] introduces a flexible humidity sensor fabricated using screen-printing techniques on a polyvinyl chloride (PVC) substrate. The sensor utilizes a graphene-carbon electrode, and the research investigates the impact of modifying this electrode with poly(3,4-ethylenedioxythiophene):polystyrene sulfonate (PEDOT:PSS) on the sensor's humidity-sensing capabilities. The study focuses on comparing the performance of the sensor with and without the PEDOT:PSS modification across a humidity range of 25-90% relative humidity (RH).

The results indicate that the sensor modified with PEDOT:PSS exhibits improved humidity sensing performance compared to the unmodified sensor. Specifically, the modified sensor shows a higher sensitivity (1%/RH vs. 0.8%/RH), particularly in the low to moderate humidity range ( $\leq 60\%$  RH). The paper also analyzes the repeatability, response time, and recovery time of both sensor types. Furthermore, the potential application of these flexible humidity sensors is demonstrated in neonatal care by monitoring the humidity levels of wet baby diapers.

Uddin et al. [28] introduces a smart diaper system that uses Internet of Things (IoT) technology to monitor diaper wetness. The system includes a wet sensor placed inside the diaper, a microcontroller to process the sensor data, and a mobile application to notify caregivers. When the sensor detects wetness, the microcontroller sends this information to the cloud, and the mobile app sends a notification to the user's mobile device. This system aims to address the issue of diaper rash, which can develop when diapers remain wet for extended periods.

The system utilizes a wet detector sensor, a temperature sensor, and an ESP8266 microcontroller

(NodeMCU). The microcontroller sends data to the IoT cloud, and a mobile application displays this information and sends notifications. The application's push notifications alert caregivers when the diaper is wet, prompting a diaper change. The authors also conducted tests on the system's performance and compared the wet detector sensor with a DHT22 sensor.

Table 1 summarizes a comparative analysis of selected smart diaper systems discussed in the literature, highlighting the sensing methods, key features, communication mechanisms, and targeted user groups. This tabular representation provides a consolidated view of existing approaches and their technological components, offering a clearer understanding of the research landscape.

### III. PROPOSED MODEL

The proposed LifeSync diaper prototype is designed to provide an intelligent, non-invasive approach for the early detection of Urinary Tract Infections (UTIs). The system integrates colorimetric sensing, embedded computation, and cloud-based analytics into a single workflow.

1. **Hardware Sensing Layer** At the core of the system are three TCS34725 color sensors connected to an ESP32 microcontroller via a PCA multiplexer. Each sensor targets a specific biomarker on urinalysis test strips: pH (for urine acidity/alkalinity), Leukocytes (immune response indicator), and Nitrites (bacterial activity indicator). By sequentially activating each sensor channel, the ESP32 captures reflected light intensities in RGB values, translating the visible color changes on the strip into quantitative data.

2. **Data Processing & Classification** The acquired RGB values are compared against a calibration dataset of reference test outcomes. A Euclidean distance-based matching algorithm determines the closest reference point, thereby classifying the test result with reliability. This ensures that subtle color variations are consistently and objectively interpreted, minimizing human error associated with manual observation.

3. **Cloud Intelligence Layer** Once processed locally, the test outcomes are transmitted to a cloud-hosted UTI analyzer. This module applies predefined diagnostic rules and manages real-time alerts. If early signs of infection are detected, instant notifications (via mobile push, SMS, or email) are sent to

caregivers.

4. **User Interface & Data Management** A companion mobile/web application provides: A live dashboard with current readings, historical trend tracking for long-term monitoring, and customizable alert preferences for caregivers and clinicians. All results are securely stored in a scalable cloud database, enabling longitudinal analysis and supporting integration with healthcare systems.

5. **System Characteristics** The LifeSync diaper is designed to be:

Modular – adaptable for additional biomarkers or use cases  
Secure – ensuring privacy and compliance with healthcare data standards

Scalable – suitable for home use, nursing facilities, or hospitals.

### IV. CONCLUSION

In this paper, we present the design and implementation of an IoT-enabled smart diaper system that allows real-time analysis of urine for monitoring of hydration level as

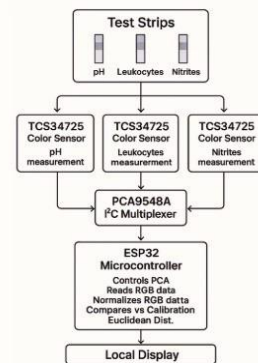


Fig. 1. System architecture of the proposed model.

well as detection of urinary tract infection and electrolyte imbalance. The implementation of low-power biosensors, microcontrollers, and wireless communication modules in the solution proposed is superior to the conventional moisture-detection system.

The system allows health data to be sent via mobile application thereby alerting caregivers and medical officials on time for early detection and personalized care. This technology can be used for various applications in pediatric and geriatric care, as well as in a clinical setting as monitoring can be done for long hours. This long-term monitoring can positively influence health outcomes.

Future efforts will concentrate on validating it clinically, enhancing sensor accuracy, and improving scalability for mass production. The proposed smart diaper system suggests a promising approach in advancing remote health monitoring and enabling data driven health care delivery with more development efforts.

#### REFERENCES

- [1] Jang, Kyungho, et al. "Smart diaper for bedside urine testing." 2022.
- [2] Vine, Tyler, Rob E. Carpenter, and Debbie Bridges. "Dataset for a validated method of non-invasive urine collection using sodium polyacrylate-based diapers for PCR detection of uropathogens." 2024.
- [3] Sung, Wei-Hsuan, et al. "Urinalysis Using a Diaper-Based Testing Device." 2020.
- [4] Kim, Jae Heon, et al. "Accuracy of a Smart Diaper System for Nursing Home Residents for Automatically Detecting Voided Volume: Instrument Validation Study." *JMIR Formative Research*, 2024.
- [5] Cho, Jae Ho, et al. "A Smart Diaper System Using Bluetooth and Smartphones to Automatically Detect Urination and Volume of Voiding: Prospective Observational Pilot Study in an Acute Care Hospital." *Journal of Medical Internet Research*, 2021. <https://doi.org/10.2196/29979>
- [6] De Lange, Katherine. "Equipping diapers with sensor technologies." *Scilight*, 2025. <https://doi.org/10.1063/10.0035922>
- [7] Li, Xiangling, et al. "A Smart Diaper Based on Integrated Multiplex Carbon Nanotube Coated Electrode Array Sensors for In Situ Urine Monitoring." 2024. <https://doi.org/10.1063/10.00359221>
- [8] Side'n, Johan, Andrei Koptioug, and Mikael Gulliksson. "The Smart Diaper Moisture Detection System." 2004. <https://doi.org/10.1109/MWSYM.2004.13360732>
- [9] Lazaro, Antonio, et al. "Battery-Less Smart Diaper Based on NFC Technology." *IEEE Sensors Journal*, vol. 19, no. 22, 2019, pp. 10848–10856. <https://doi.org/10.1109/JSEN.2019.2938236>
- [10] Uddin, Mohammad Salah, Shathi Islam, and Nishat Vasker. "Smart Diaper: Non-stop Diaper Monitoring System." *RAAICON*, 2021.
- [11] Sennesael, Joryan, et al. "An Environmentally Friendly Carbon-Printed Contactless Smart Diaper." *IEEE Sensors Journal*, vol. 25, no. 2, 2025, pp. 3309–3316. <https://doi.org/10.1109/JSEN.2024.3344073>
- [12] Chen, Bixun, et al. "A Wearable and Smart System for Diaper Change Identification." *ICECS*, 2022. <https://doi.org/10.1109/ICECS202256217.2022.9971004>
- [13] Khan, Tareq. "A Smart Wearable Gadget for Noninvasive Detection and Notification of Diaper Moisture." *IEEE Xplore*, 2022.
- [14] Turna, Manroop Singh, and Youngwook Kim. "Monitoring Diaper Condition Using the Impedance Variation of a Dipole Antenna." *IEEE Xplore*, 2022. <https://doi.org/10.1109/MWSYM.2004.13360732>
- [15] Chen, Chaohao, et al. "Dipsticks Integrated on Smart Diapers for Colorimetric Analysis of Urinary Tract Infections in the Field." *IEEE Sensors Journal*, vol. 22, no. 23, 2022, pp. 22912–22921. <https://doi.org/10.1109/JSEN.2022.3215741>
- [16] Kumar, K. Naveen, and Jalakam Sridevi. "Diaper Wetness Detection Based on Sensor and Using IoT." *ICECA*, 2021, pp. 527–531. <https://doi.org/10.1109/ICECA52323.2021.9675889>
- [17] Turna, Manroop Singh, et al. "Estimation of Diaper Condition Based on Antenna Impedance Variation Through Rational Function Approximation." *IEEE Access*, vol. 8, 2020, pp. 2441–2446. <https://doi.org/10.1109/ACCESS.2019.2962186>

- [18] Ning, Zirui, et al. "Self-Powered Wearable Biosensor in a Baby Diaper for Monitoring Neonatal Jaundice through a Hydro Voltaic-Biosensing Coupling Effect of ZnO Nanoarray." *Biosensors*, vol. 12, no. 3, 2022, article 164. <https://doi.org/10.3390/bios12030164>
- [19] Seo, Weeseong, et al. "Diaper-Embedded Urinary Tract Infection Monitoring Sensor Module Powered by Urine-Activated Batteries." *IEEE Trans. on Biomedical Circuits and Systems*, 2017. <https://doi.org/10.1109/TBCAS.2017.2654421>
- [20] Baek, Jaeho. "Smart Predictive Analytics Care Monitoring Model Based on Multi-Sensor IoT System." *Sensors International*, vol. 4, 2023, p. 100213. <https://doi.org/10.1016/j.sintl.2022.100213>
- [21] Tekcin, Meltem, et al. "Wearable and Flexible Humidity Sensor Integrated to Disposable Diapers." *Electronics*, vol. 11, no. 7, 2022, p. 1025. <https://doi.org/10.3390/electronics11071025>
- [22] Lin, Jiun-Hung, et al. "Self-Capacitance Sensor for Smart Diaper." *IEEE Access*, vol. 13, 2025, pp. 22989–22997. <https://doi.org/10.1109/ACCESS.2025.3535144>
- [23] Shiu, Bing-Chiuan, et al. "Using Antibacterial Fibers and Metallic Wires to Make Woven Fabrics Used as Smart Diapers." *Journal of Industrial Textiles*, vol. 51, no. 5S, 2022, pp. 9017S–9030S. <https://doi.org/10.1177/1528083720930378>
- [24] Coyle, S., et al. "Fabric-based fluid handling platform with integrated analytical capability." *EMBS*, 2007, pp. 6450–6450. <https://doi.org/10.1109/IEMBS.2007.4353835>
- [25] Wen, M.-H. "Goo9: A wireless sensor network system for wet diaper detection." *ICASI*, 2017, pp.893–895. <https://doi.org/10.1109/ICASI.2017.7988580>
- [26] Sharif, A., et al. "Inkjet Printed Passive RFID Sensor for Wetness Detection of Diapers." *IMAS*, 2023, pp. 172–175. <https://doi.org/10.1109/IMAS55807.2023.10066932>
- [27] Kurita, A., et al. "Wireless Urine Monitoring for Diapers With Passive Antenna Using Split Ring Metamaterial." *Transducers*, 2023, pp. 1915–1918.
- [28] Beniwal, A., et al. "PEDOT:PSS Modified Screen Printed Graphene- Carbon Ink Based Flexible Humidity Sensor." *FLEPS*, 2022, pp. 1–4. <https://doi.org/10.1109/FLEPS53764.2022.9781534>
- [29] Uddin, M. S., Islam, S., and Vasker, N. "Smart Diaper: Non-stop Diaper Monitoring System." *RAAICON*, 2021, pp. 18–21. <https://doi.org/10.1109/RAAICON54709.2021.9929957>