Water and electricity consumption management architectures using IoT and AI: A review study

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Abstract. This in-depth article delves into the implemented architectures aimed at optimizing water and electricity consumption through the integration of the Internet of Things (IoT) and artificial intelligence (AI). It provides a detailed analysis of various developments, trends, and key technologies shaping this rapidly evolving field. The article meticulously examines background research and scrutinizes the architecture, thus offering profound insights into the technical challenges, potential benefits, and implementation obstacles of leveraging IoT and AI in resource management. By exploring these architectures, the article highlights significant advancements in terms of efficiency, resource utilization, and predictive capabilities within integrated systems. Convincing results demonstrate the positive impact of this technological convergence on environmental sustainability, waste reduction, and resource optimization, thus offering a promising vision for the future of resource management. Furthermore, an extensive discussion section critically evaluates the discussed approaches, pinpointing the strengths and weaknesses of each method and proposing avenues for improvement and development. This nuanced analysis provides a solid foundation for future research and continuous innovation in the field of resource management. This article serves as an essential resource for professionals and researchers working in the fields of water, energy, and IoT/AI. It offers an in-depth understanding of the challenges and opportunities associated with integrating these technologies and provides strategic guidance for effective and sustainable resource management in the digital age.

Introduction

In a context where the challenges of managing resources such as water and electricity are becoming increasingly pressing, advancements in the fields of the Internet of Things (IoT) and artificial intelligence (AI) offer intriguing prospects for addressing these challenges in innovative and efficient ways. This article delves deep into this technological convergence, exploring various strategies and architectures implemented to optimize water and electricity consumption. The meticulous examination of existing methodologies reveals a wealth of possibilities and complexities. Approaches such as smart telemetry, interconnected sensor networks, and AI-based predictive systems hold considerable promise for real-time monitoring, precise control, and proactive prediction of consumption patterns. These technological advancements pave the way for more efficient and sustainable resource management, with potentially revolutionary implications for industries, municipalities, and households. However, this landscape of innovation is not without its challenges. Data privacy and cybersecurity issues emerge as systems become more interconnected and data volumes increase. Moreover, the need to ensure equitable access to these technologies raises concerns about digital divides and social exclusion. Beyond technological considerations, it is crucial to examine the socio-economic and environmental implications of these advancements. How do these technologies affect the livelihoods of populations, local economies, and the health of our planet as a whole? How can we ensure that the benefits of these innovations accrue to all, without compromising fundamental rights and long-term sustainability? In this quest to address these challenges, a collaborative and interdisciplinary approach is indispensable. Policymakers, scientists, engineers, sociologists, and environmental advocates must come together to design integrated and equitable solutions. It is imperative to adopt a long-term perspective, balancing current needs with the ability of future generations to meet their own.

Literature Review

Fuentes, H[1], proposes an innovative IoT framework for water consumption management. It emphasizes secure data capture through encryption, local preprocessing of consumption data, physical security of devices, Recording and displaying water usage patterns, along with identifying leaks through the implementation of the Water Leak Algorithm. This system involves five primary elements for the collection, retention, examination, and representation of water consumption data. In the "House Data Collection" module, a smart meter captures water usage data at each T1 moment, transmitted to the "Edge Gateway" for archival, with a security feature to detect unauthorized manipulations. Cumulative consumption is sent to the Cloud at broader intervals (T2), stored with user location data obtained from their phone's GPS. The data undergoes analysis for leak detection at the Cloud, and users can visualize real-time water consumption through a web portal. This framework provides a comprehensive solution for gathering, safeguarding, storing, analyzing, and presenting water consumption data, integrating security measures for data integrity and proactive leak detection. The study offers a detailed technological overview, emphasizing the five essential elements, specifying software, programming languages, databases, and operating systems associated with each component.

Paramasivan's [2] proposed system introduces an inventive resolution for implementing prepaid energy supply while consolidating the oversight of all energy meters. The primary aim is to thwart unauthorized tampering with electricity at consumer premises while concurrently curbing labor expenses associated with billing. The GSM unit establishes a connection with the intelligent meter installed in individual residences, with each meter being allocated a unique quantity by electricity suppliers. The intelligent meter consistently records electricity usage and displays the consumed units on an LCD screen linked to the meter. The microcontroller diminishes the unit quantity in response to consumption. Upon a request from the electricity provider's server, the GSM modem is prompted to instruct the microcontroller to take necessary actions. The MAX232 module facilitates communication between the microcontroller and the GSM modem. The GSM plays a vital role in furnishing information about electricity consumption to both the electricity provider and the consumer, in real-time or as required. The GSM assumes a pivotal role in disseminating information about energy consumption to the application management and the consumer, as needed. The aerial container, affixed on or near the meter, heightens GSM communication for effective energy monitoring.

The advanced system, introduced by Ramadhan and Ali [3], offers a sophisticated solution for the cost-effective surveillance of water quality in a minimum of five water treatment stations. Its design ensures prolonged and uninterrupted operation through low energy consumption, facilitated by solar panels. Precise monitoring of water quality parameters is achieved through the utilization of ten specific sensors within the system. These parameter values are promptly displayed in real-time on a dedicated web page, providing immediate insights into the water quality across the monitored areas. The system possesses the capability to issue real-time alerts to relevant personnel via SMS and emails when abnormal or problematic values are detected. The recorded data is also archived for subsequent statistical analysis. The sensors employed in this system have undergone rigorous laboratory testing, demonstrating exceptional performance in terms of accuracy and reliability. The monitoring system is composed of three primary components: the detection node (SN), the data router (DR), and the website (WS), seamlessly integrated. Each water station is represented by a detection node (SN), and each node comprises four fundamental elements: the control unit, sensors, transceiver, and power unit. The control unit is facilitated by a programmable logic controller (PLC) of the CONTROLLINO MEGA type.

Segun O. Olatinwo [4] introduces a pioneering system architecture that integrates a Wireless Sensor Network (WSN) with multiple sensors categorized into two groups: Group 1 and Group 2. The classification is based on their prioritized schedule for information transmission, determined by a sequential data transmission method. Group 1, consisting of sensors i, becomes active during the initial cycle of the Up-Link (UL) transmission phase, while Group 2, comprising sensors q, is designated for transmitting data regarding the quality of water. in the subsequent cycle of the UL phase. Consequently, sensors from both Group 1 and Group 2 engage in data communication. To efficiently oversee the concurrent transfer of water quality data from every sensor group to a designated receiving node., a Successive Interference Cancellation (SIC) mechanism is implemented at the receiver. This mechanism acts as a congestion control measure, facilitating the separation of data emitted simultaneously by the sensors. The sensor nodes utilized in this system are Water Quality Sensors (WQS) designed to measure essential microbiological and chemical properties of water at treatment stations. These nodes are powered by Distributed Power Sources (DPS) equipped with omnidirectional antennas. The system controller possesses extensive knowledge of network resources, sensors in Groups 1 and 2, and a scheduler for activating Group 1 or Group 2 based on a predefined priority.

The architecture of the IoT application has been organized to facilitate sequential sharing of functions among all components, as suggested by Khan, M.A [5], starting from current IoT devices to the Managed-Cloud, in which data undergoes processing for making insightful decisions. The smart circuit is designed to enable the sequential measurement of current and voltage for three household appliances, utilizing ACS712 current sensors and ZMPT101B voltage sensors. Once the measured data is acquired, it is transmitted towards inputs of a Wi-Fi access controller, such as an ESP8266 module. This module, known for its online monitoring and control capabilities, is chosen for its power efficiency and affordability. Following data processing, it is forwarded to an MQTT server in the cloud, serving as a intermediary between the user and the loads. This cloud server facilitates multiple clients/users to connect and access the data. Users can oversee and control the data through a HumanMachine-Interface using either a personal computer and/or a mobile app. Furthermore, there are two additional loads included to indicate power and detect overloads. Initially linked to the power using a 4- channel relay, these loads can function in two modes: "normally open (NO)" and "normally closed (NC)." To prioritize safety, the initial configuration is set to "NO," and the voltages are consistently maintained at 220 V.

Liu, Yi [6] introduces a system proposing A framework for energy management built upon the Internet of Things (IoT), integrating advanced computing technologies and a Deep Reinforcement Learning (DRL) network. The structure is composed of three primary elements: energy devices, energy edge servers, and energy cloud servers. In this design, data is processed locally by energy edge servers and then sent via the central network to the cloud server. Agents for Deep Reinforcement Learning (DRL) are installed on edge and cloud servers. When a computing task is needed, an energy device sends it to the closest edge server, where the edge DRL agent does the task computation. Deep neural network (DNN) weight pre-training can be done in the energy cloud server to improve energy consumption in the edge server. After training, the DNN advances to the boundary, where Deep Q-Learning assumes control. Edge servers collect data from devices and transmit it to the cloud for effective processing, hence reducing energy consumption.

Background study

1. Data Sources for Adaptive Water-Electricity Management

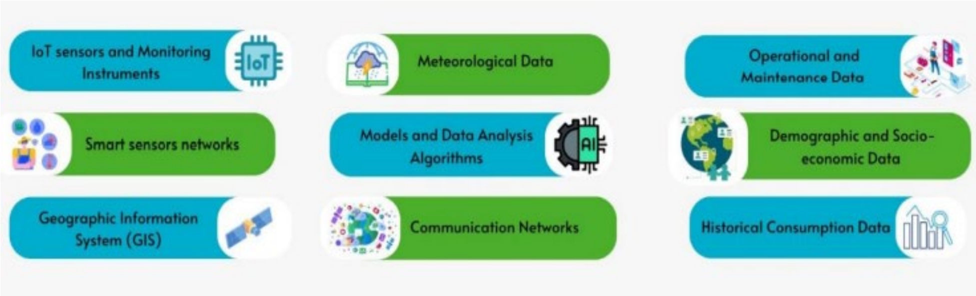

Figure 1: Data Sources for Adaptive Water-Electricity Management

Leveraging diverse data sources is vital for adaptive water and electricity system management to optimize processes, enhance efficiency, and enable informed decision-making. Common data sources for adaptive approaches in water and electricity management include:

- **IoT Sensors and Monitoring Instruments**: Real-time data on consumption, quality, temperature, water levels, and pressure [7, 8] can be obtained using sensors deployed in distribution infrastructures. Smart Sensor Networks creating distributed monitoring systems with interconnected smart sensor networks allows for extensive data collection from multiple points [9].
- **Geographic Information Systems (GIS):** GIS provides spatial information to analyze geographical distribution, plan maintenance routes, and optimize resource management [10].
- **Meteorological Data:** Crucial for anticipating electricity demand, especially for renewables [11], and predicting weather conditions impacting water resources.
- **Historical Consumption Data:** Analyzing past consumption patterns is vital for forecasting future demand and planning capacity [12].
- **Communication Networks:** Wired and wireless networks facilitate reliable data transmission between system components [13].
- **Operational and Maintenance Data:** Information on infrastructure operations, maintenance reports, downtime, and equipment performance is crucial for optimizing processes [14].
- **Demographic and Socio-economic Data:** Understanding population factors helps tailor management strategies to changing water and electricity demand [15].

2. Data transmission protocols

The data pathway in adaptive management of water and electricity systems can traverse various channels, with certain methods evolving in prominence [16]. Contemporary implementations predominantly leverage Bluetooth and Wi-Fi transmissions. Some systems embrace standard wireless technologies like ZigBee, XBee, and ZWave. While GSM has historically offered stability in mobile communication, it has witnessed a decline in use, being superseded by advanced cellular standards such as 3G, 4G, and 5G, offering enhanced data transfer speeds. It's noteworthy that Table 1 illustrates a comparison between some protocols [17], highlighting their distinct characteristics and functionalities.

3. Data Storage

In IoT systems dedicated to monitoring water and electricity consumption in Morocco, the data aggregation phase assumes a pivotal role. This stage involves consolidating information from multiple sensors through intelligent IoT gateways, creating a unified representation for simplified processing and analysis [18]. Utilizing buffers or local databases ensures data availability during temporary network disruptions. This approach optimizes data transmission to the central platform, maintaining efficient information flow despite potential connectivity fluctuations. Upstream of in-depth analysis, data preprocessing becomes instrumental. This stage involves processes like noise filtering, normalization of measurement units, and error correction, refining raw data quality for consistency and readiness in advanced analyses [19]. Some systems employ local storage at the sensor or gateway level, ensuring immediate data availability even without connectivity. Simultaneously, a cloud-first architecture allows direct transmission of other data to the cloud [20]. This hybrid strategy accommodates the specific constraints of each system, facilitating effective information management aligned with infrastructure needs and capabilities [21].

Table 1: Comparison between data transmission protocols

Specifications	Wi-Fi	Bluetooth	GSM	Zigbee
Network type	Point-to-point, WLAN, WAN, Mesh, Point-to- multipoint	PAN	Cellular network	Mesh network
Communication	Radio Frequency, Protocols (IEEE 802.11, 802.11b, 802.11g…)	Wireless	Wireless	Wireless
Security	Protocol (WEP, WPA, and WPA2/WPA3),	Encryption methods	Encryption methods	Encryption methods
Range	Up to 100 meters	Up to 10 meters	Several kilometers	from 10 to 100 meters
Frequency	2.4 GHz and 5 GHz	2.4 GHz	900 MHz and 1800 MHz	2.4 GHz
Bit rate	From 11Mpbs to up than 9,6 Gbps depending on the Wi-Fi standard being used	Depends on the Bluetooth version, ranging from 1 Mbps to 3 Mbps.	Up to 9.6 kbps	Between 20 and 250 kbps
Continuous sampling	Yes	Yes	NO	Yes
Interoperability	Different and same devices	Compatible devices	GSM compatible devices	Same devices

4. **AI Processing**:

Table 2: The processing AI steps

Phase	Description
Retrieval and Preparation	Following the storage of data, the AI-driven processing phase commences with the retrieval of stored information. The data is subsequently prepared for analysis, encompassing tasks such as formatting, structuring, and ensuring compatibility with AI algorithms [22].
Preprocessing with AI	AI is utilized for intricate preprocessing tasks, where machine learning models can autonomously identify patterns, outliers, and anomalies within the stored data. This step guarantees that the data is refined and well-prepared for more sophisticated analyses [23].
Predictive Analytics	AI algorithms, encompassing machine learning and predictive modeling [24], come into play for forecasting future trends based on historical data [25] [26] . This facilitates proactive decision-making and resource planning in response to anticipated consumption patterns.
Real-time Insights	AI transcends traditional batch processing limitations, enabling real-time analytics [27]. Continuously analyzing incoming data, AI algorithms furnish immediate insights into consumption patterns, potential inefficiencies, or abnormalities.

Continuous Improvement	In the realm of data processing, AI systems are engineered for continuous improvement [28]. Employing feedback loops and continuous learning mechanisms, these models evolve over time, progressively enhancing their accuracy and efficacy in dealing with a myriad of data scenarios.

Conclusion

In conclusion, this comprehensive study delved into water and electricity management architectures integrating AI and IoT, providing insights into current trends and key technologies. The background research highlighted the diverse data sources used in these architectures, emphasizing IoT sensors, communication networks, and other advanced technologies. Transmission protocols were scrutinized, comparing multiple options to inform implementation choices. It is crucial to acknowledge that this study presents findings based on the examination of six specific architectures and the comparison of four transmission protocols. The conclusions indicate significant advancements in terms of efficiency, resource utilization, and predictive capabilities in these integrated systems. However, certain limitations need to be emphasized. The restriction to six architectures and four protocols may not cover all possible variants. For a more comprehensive and nuanced understanding, future research could explore a broader range of architectures and protocols. As for future perspectives, an in-depth bibliometric study on water and electricity consumption topics, integrating AI and IoT, could provide a more holistic view of the field. This would help identify emerging trends, gaps in current research, and guide future work towards areas of innovation and particular importance.

References

[1] Fuentes, H., & Mauricio, D. (2020). Smart water consumption measurement system for houses using IoT and cloud computing. Environmental Monitoring and Assessment, 192, 1-16. https://doi.org/10.1007/s10661-020-08535-4

[2] Rajesh, M. (2021). GSM Based Smart Energy Meter System.

[3] Ramadhan, A. J., Ali, A. M., & Kareem, H. K. (2020). Smart waterquality monitoring system based on enabled real-time internet of things. J. Eng. Sci. Technol, 15(6), 3514-3527.

[4] Olatinwo, S. O., & Joubert, T. H. (2020). Energy efficiency maximization in a wireless powered IoT sensor network for water quality monitoring. Computer Networks, 176, 107237. https://doi.org/10.1016/j.comnet.2020.107237

[5] Khan, M. A., Sajjad, I. A., Tahir, M., & Haseeb, A. (2022). IoT application for energy management in smart homes. Engineering Proceedings, 20(1), 43. https://doi.org/10.3390/engproc2022020043

[6] Liu, Y., Yang, C., Jiang, L., Xie, S., & Zhang, Y. (2019). Intelligent edge computing for IoT-based energy management in smart cities. IEEE network, 33(2), 111-117. https://doi.org/10.1109/MNET.2019.1800254

[7] Ibrahim, S. N., Asnawi, A. L., Abdul Malik, N., Mohd Azmin, N. F., Jusoh, A. Z., & Mohd Isa, F. N. (2018). Web based Water Turbidity Monitoring and Automated Filtration System: IoT Application in Water Management. International Journal of Electrical & Computer Engineering (2088-8708), 8(4). https://doi.org/10.11591/ijece.v8i4.pp2503-2511

[8] Li, J., Herdem, M. S., Nathwani, J., & Wen, J. Z. (2023). Methods and applications for Artificial Intelligence, Big Data, Internet of Things, and Blockchain in smart energy management. Energy and AI, 11, 100208. https://doi.org/10.1016/j.egyai.2022.100208

[9] Jaradat, M., Jarrah, M., Bousselham, A., Jararweh, Y., & AlAyyoub, M. (2015). The internet of energy: smart sensor networks and big data management for smart grid. Procedia Computer Science, 56, 592-597. https://doi.org/10.1016/j.procs.2015.07.250

[10] Zulkifli, C. Z., Garfan, S., Talal, M., Alamoodi, A. H., Alamleh, A., Ahmaro, I. Y., ... & Chiang, H. H. (2022). IoT-based water monitoring systems: a systematic review. Water, 14(22), 3621. https://doi.org/10.3390/w14223621

[11] Saheb, T., Dehghani, M., & Saheb, T. (2022). Artificial intelligence for sustainable energy: A contextual topic modeling and content analysis. Sustainable Computing: Informatics and Systems, 35, 100699. https://doi.org/10.1016/j.suscom.2022.100699

[12] Rochd, A., Benazzouz, A., Abdelmoula, I. A., Raihani, A., Ghennioui, A., Naimi, Z., & Ikken, B. (2021). Design and implementation of an AI-based & IoT-enabled Home Energy Management System: A case study in Benguerir—Morocco. Energy Reports, 7, 699-719. https://doi.org/10.1016/j.egyr.2021.07.084

[13] Rahmadya, B., Zaini, Z., & Muharam, M. (2020). Iot: A mobile application and multi-hop communication in wireless sensor network for water monitoring. https://doi.org/10.3991/ijim.v14i11.13681

[14] Krishnan, S. R., Nallakaruppan, M. K., Chengoden, R., Koppu, S., Iyapparaja, M., Sadhasivam, J., & Sethuraman, S. (2022). Smart water resource management using Artificial Intelligence—A review. Sustainability, 14(20), 13384. https://doi.org/10.3390/su142013384

[15] Ansari, S., Ayob, A., Lipu, M. S. H., Saad, M. H. M., & Hussain, A. (2021). A review of monitoring technologies for solar PV systems using data processing modules and transmission protocols: Progress, challenges and prospects. Sustainability, 13(15), 8120. https://doi.org/10.3390/su13158120

[16] Kanellopoulos, D., Sharma, V. K., Panagiotakopoulos, T., & Kameas, A. (2023). Networking Architectures and Protocols for IoT Applications in Smart Cities: Recent Developments and Perspectives. Electronics, 12(11), 2490. https://doi.org/10.3390/electronics12112490

[17] Dehbi, A., Bakhouyi, A., Dehbi, R., & Talea, M. (2024). Smart Evaluation: A New Approach Improving the Assessment Management Process through Cloud and IoT Technologies. International Journal of Information and Education Technology, 14(1), 107-118. https://doi.org/10.18178/ijiet.2024.14.1.2030

[18] Bedi, P., Goyal, S. B., Rajawat, A. S., Shaw, R. N., & Ghosh, A. (2022). Application of AI/IoT for smart renewable energy management in smart cities. AI and IoT for Smart City Applications, 115-138. https://doi.org/10.1007/978-981-16-7498-3_8

[19] Goudarzi, S., Anisi, M. H., Soleymani, S. A., Ayob, M., & Zeadally, S. (2021). An IoT-based prediction technique for efficient energy consumption in buildings. IEEE Transactions on Green Communications and Networking, 5(4), 2076-2088. https://doi.org/10.1109/TGCN.2021.3091388

[20] Lakshmikantha, V., Hiriyannagowda, A., Manjunath, A., Patted, A., Basavaiah, J., & Anthony, A. A. (2021). IoT based smart water quality monitoring system. Global Transitions Proceedings, 2(2), 181-186. https://doi.org/10.1016/j.gltp.2021.08.062

[21] Praveena, D., Thanga Ramya, S., Gladis Pushparathi, V. P., Bethi, P., & Poopandian, S. (2021). Hybrid Cloud Data Protection Using Machine Learning Approach. In Advanced Soft

Computing Techniques in Data Science, IoT and Cloud Computing (pp. 151- 166). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-75657-4_7

[22] Bourechak, A., Zedadra, O., Kouahla, M. N., Guerrieri, A., Seridi, H., & Fortino, G. (2023). At the Confluence of Artificial Intelligence and Edge Computing in IoT-Based Applications: A Review and New Perspectives. Sensors, 23(3), 1639. https://doi.org/10.3390/s23031639

[23] Himeur, Y., Elnour, M., Fadli, F., Meskin, N., Petri, I., Rezgui, Y., ... & Amira, A. (2023). AI-big data analytics for building automation and management systems: a survey, actual challenges and future perspectives. Artificial Intelligence Review, 56(6), 4929-5021. https://doi.org/10.1007/s10462-022-10286-2

[24] Rajawat, A. S., Mohammed, O., Shaw, R. N., & Ghosh, A. (2022). Renewable energy system for industrial internet of things model using fusion-AI. In Applications of AI and IOT in Renewable Energy (pp. 107-128). Academic Press. https://doi.org/10.1016/B978-0-323-91699-8.00006-1

[25] Jiang, D., Lian, M., Xu, M., Sun, Q., Xu, B. B., Thabet, H. K., ... & Guo, Z. (2023). Advances in triboelectric nanogenerator technology—Applications in self-powered sensors, Internet of things, biomedicine, and blue energy. Advanced Composites and Hybrid Materials, 6(2), 57. https://doi.org/10.1007/s42114-023-00632-5

[26] Olatinwo, S. O., & Joubert, T. H. (2023). Resource Allocation Optimization in IoT-Enabled Water Quality Monitoring Systems. Sensors, 23(21), 8963. https://doi.org/10.3390/s23218963

[27] Nasiri, F., Ooka, R., Haghighat, F., Shirzadi, N., Dotoli, M., Carli, R., ... & Sadrizadeh, S. (2022). Data analytics and information technologies for smart energy storage systems: A state-of-the-art review. Sustainable Cities and Society, 84, 104004. https://doi.org/10.1016/j.scs.2022.104004

[28] Kamyab, H., Khademi, T., Chelliapan, S., SaberiKamarposhti, M., Rezania, S., Yusuf, M., ... & Ahn, Y. (2023). The latest innovative avenues for the utilization of artificial Intelligence and big data analytics in water resource management. Results in Engineering, 101566. https://doi.org/10.1016/j.rineng.2023.101566