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Research Article

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Redefining Outdoor IoT and Business Model: Creating a Unified, AI Ecosystem for Pools and Backyards Systems

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Abstract: The Internet of Things (IoT) has revolutionized home automation, but its application in pools and backyards remains fragmented and limited. This paper proposes a unified, AI-driven IoT ecosystem for pools and backyards to enhance user experience, optimize energy efficiency, and drive industry growth. The current challenges, such as standalone devices, connectivity issues, and harsh outdoor conditions, are addressed through emerging technologies like edge computing, LoRaWAN, and data analytics. The proposed conceptual framework comprises a centralized communication hub, IoT sensors, individual systems, and user interfaces. Integrating AI and machine learning enables sophisticated automation, predictive maintenance, and personalized user experiences. The technical architecture emphasizes sensor network design, cloud integration, data processing, and hardware durability. A case study on smart pool and light management systems demonstrates the potential benefits of the proposed ecosystem. The economic and environmental impact analysis highlights cost savings, increased market size, and improved sustainability. The paper concludes by emphasizing the importance of adopting open platforms and standards for cross-device communication, innovation, and industry growth. Companies that embrace this unified IoT framework early will be well-positioned to lead the market and create new revenue models while contributing to a more sustainable outdoor environment.

Keywords: Internet of Things (IoT), Outdoor IoT, Smart pools, Smart backyards, AI ecosystem, Edge computing, LoRaWAN, Data Analytics, Predictive maintenance, Energy efficiency, Sustainable environment, Open platforms, Industry growth, Cloud integration, Sensor networks

1. Introduction

A. Background on IoT in Outdoor Spaces

The outdoor equipment industry is expected to be $18 billion and expected to reach $35 billion by 2030. The Internet of Things (IoT) has changed the way we live by connecting every device around us to interact with each other and exchange information and data, enabling them to be smarter as a system or ecosystem than individual selves [1]. Home automation is taking a boom and converting every appliance and device, such as lighting systems, thermostats, and security systems, to smarter systems that are accessible from any part of the world through the Internet [2]. While home automation is evolving and increasing the connectivity of systems, it primarily focuses on indoor smart devices. Products such as smart irrigation systems, automated pool equipment such as underwater lighting systems, backyard fires, water decorative systems, and even water sanitation systems have started to be enabled with IoT technologies but are often operated in isolation without integration into the indoor IoT ecosystem.

Home outdoors, particularly pools and backyards, have a unique challenge for IoT connectivity because of their distance from the source of connectivity. Additionally, these spaces are exposed to harsh conditions, from heat to rain, which require durable hardware designs. Considering these challenges as opportunities, outdoor IoT has a high potential to enhance user experience, save energy, and help manage the overall outdoor environment as a unified system [3]. Companies that realize this could help build efficient ecosystems and establish a monopoly

not only for indoor smart systems but also for outdoor ecosystems. Companies such as Lutron, Leviton, and Copper Lights focus on building their ecosystems within the space of dimmers, led drivers, and smart switches, whereas other companies such as Fluidra, Hayward, and other pool companies concentrate on building ecosystems for managing pumps, pool lights, and even waterfalls to some extent. As most companies in the pool and backyard industries are portfolio companies consisting of multiple sub-companies, often called brand companies, they try to utilize their technology and operate independently. They often do not realize that a unified intelligent ecosystem integrates all outdoor devices and enhances their efficiency and ease of use.

The unified IoT ecosystem for pool and backyard industries addresses the limited growth of the outdoor industry [4]. This paper proposes an approach to unify all pool and backyard equipment under an intelligent IoT ecosystem and ways to leverage advanced technology to enhance user experience and increase profitability by designing products based on collected data. Companies can create ecosystems by setting aligned standards and transforming outdoor spaces into integrated, energy-efficient, and intelligent environments. Additionally, it proposes a conceptual framework, technical architecture, and implementation challenges associated with the backyard and pool industry.

2. Literature Review

A. Existing IoT solutions for pools and backyards

The adoption of IoT in outdoor spaces, especially in the pool and backyard industries, has started recently. This slow adoption has forced the application of IoT knowledge specific to individual functionality and equipment rather than holistic solutions. The current application of IoT is specific to devices designed to automate tasks such as cleaning pools, outdoor lighting, and running station systems; however, these systems are not equipped to collect or analyze data to improve performance or diagnostics for the system [5]. These systems lack the applications of sensors, data analytics, and remote controllability.

B. Limitations of current systems

IoT-enabled pool systems, such as Pentair IntelliConnect [6], Hayward Omnilogic [7], and Custom Molded Products [8] Brilliant Wonder Controller, automate pool cleaning, pool light control, and turn-on sanitation systems or pumps. However, they cannot sense the need to clean or diagnose the functionality or even recommend maintenance to the user, limiting their potential to be part of a larger ecosystem. Currently, they can only turn the systems on and off, and they are limited by their ability to operate interdependently and lack interoperability [9]. For example, one must worry about turning the pumps ON while running the sanitation system. Often, these two pieces of equipment are manufactured by different companies and, hence, have different applications to control them. While the irrigation system could sense that it rained, it may not be able to inform the pool system to adjust water or to vary sanitation levels. Although the controllers are equipped to control lights based on time, they may not be able to control them based on ambient light. Additionally, power management remains a key challenge, as outdoor IoT devices require frequency battery replacements, as they are often placed away from power sources, limiting the application of this knowledge. Security concerns pose a special threat, as outdoors are often unguarded, and the potential for hacking on breaches is high [10]. This equipment provides multiple wireless networks, which in turn provide multiple entry points for cyberattacks threatening homeowner networks.

C. Current Challenges in Outdoor IoT

Integration Most outdoor products are designed as standalone systems, each requiring its application, connection protocols, and hardware setup. Event pool constructors, contractors, and distributors must be aware and understand how to operate and set up multiple devices, often creating inefficiency and duplication of effort. For instance, a typical outdoor pool system consists of sanitation systems, pool lights, backyard lighting, landscape lighting, irrigation systems, pool cleaning robots, and pool pumps. Therefore, a typical homeowner with this equipment setup needs to use multiple apps to control each of the above-mentioned equipment, creating inconsistencies and disrupting user experience. Additionally, these systems often create technical challenges, such as cross-device communications, creating the need for a higher bandwidth, and even using different technologies. This often leads to inconsistencies and inefficiencies.

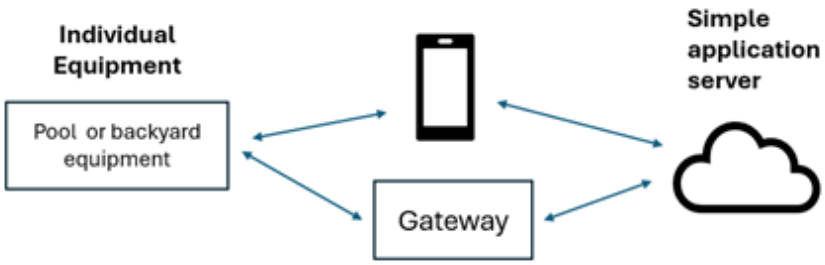

Figure 1: Existing systems

Another critical challenge is the reliability and durability of IoT devices in outdoor weather conditions, such as rain, temperature, and humidity. Many product designs are considered to operate globally, pushing them to operate under various electrical conditions. This is true in the case of indoor systems; however, in outdoor systems, safety and reliability overcome electrical and functional requirements. This change in design prioritization can lead to performance and durability issues. Connectivity can also be challenging in outdoor spaces, as the Wi-Fi source typically sits at the center of the house, and the signal dampens over the distance and interference of other systems and infrastructure.

When one can appreciate the utilization of hardware technological skills in outdoor IoT systems, the applications of new technologies such as data analytics, AI, and even new user-friendly development remain underdeveloped. IoT systems have a great capability of understanding user behavior and collecting data to improve both the user experience and products, but the industry is slower to adopt technology-driven functionalities.

D. Emerging technologies in outdoor IoT

Many emerging technologies can overcome these limitations and accelerate the creation of a more unified ecosystem.

Edge Computing: Edge computing reduces latency and bandwidth issues by locally processing data at the source point. This helps devices such as pool lights operate more autonomously while still communicating with the central cloud system [11].

LoRaWAN connectivity: Low-power wide-area networks are known for improving reliability and range of connectivity. Hence, LoRaWAN can offer a low-power communication protocol that is suitable for outdoor sensors [12].

Data analytics: Data analysis and machine learning are becoming essential in smart systems, particularly for optimizing the user experience and diagonalizing possible system failures.

Open Platforms and Standards: New platforms are emerging that allow interoperability between IoT devices. For example, the Dali protocol [13] developed for lighting systems and I2C for automotive systems aimed to establish a unified connectivity standard to enable different manufacturers to work together. The utilization of such platforms and standards could help to unify outdoor ecosystems.

3. Conceptual Framework

A. Vision for a unified outdoor IoT ecosystem

The vision for a unified outdoor IoT ecosystem is to eliminate the fragmented operations of outdoor systems and to enable the user to utilize the full potential of the ecosystem. Based on successful platforms such as Apple's ecosystem, which allows different devices such as mobiles, computers, automation products, and outdoor IoT ecosystems to be built around centralized control hubs. This allows for deeper integration between different equipment. For example, pool lighting systems can be turned ON, allowing the decorative features of water and fire systems to be synchronized. This allows sanitation systems to synchronize their operation with pool cleaning robots, pumps, etc., while being able to measure the UV light lifetime or ozone level in the water.

B. Key components and their interactions

The unified outdoor IoT ecosystem consists of a centralized hub for device communication, IoT sensors, or individual systems and can be integrated with machine learning algorithms and user interfaces for control.

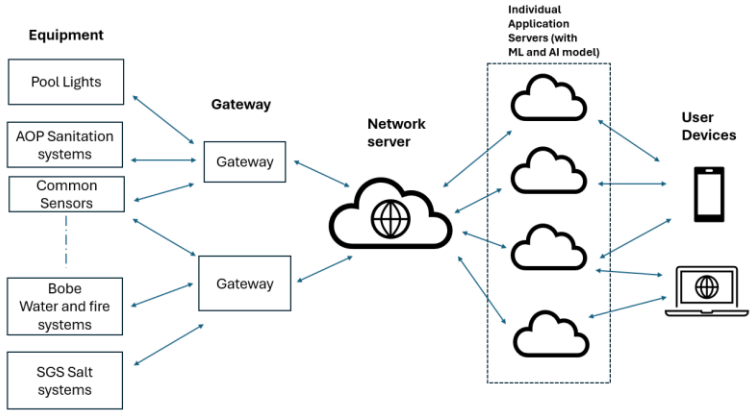

Figure 2: Proposed framework for future system

Centralized Network server for communication: A centralized control hub will help in creating a unified IoT ecosystem, allowing all backyard devices to interact and access each other's information.

IoT sensors: Sensors play a vital role in making any system intelligent and allowing it to understand the environment, including temperature, humidity, and ambient light [14]. These sensors collect and input data into the central hub to make data-driven intelligent decisions. The addition of common sensors eliminates the requirement for the same sensors in different systems. For example, the water temperature measured by the sensor in the pool drain helps eliminate the need for sensors in sanitation systems and pumps.

Individual systems: The ecosystem consists of current individual systems that perform the functions they are designed to perform. However, unlike existing systems, they are less bulky, eliminate the need for common sensors, and are more efficient and effective in performing their functions because of their interconnectivity.

Individual application servers: These cloud servers act as specialized functional units maintained by individual companies or manufacturers. These cloud-based analyses allow the ecosystem to move beyond automation. Based on historical data, machine learning models can forecast potential system failures, maintenance, and even future performance improvement parameters.

User Interface and Controls: The new ecosystem helps users access all the information and controls for the pool and backyard equipment using one user interface under one application, which can be accessible from smartphones, tablets, or computers. It also allows for the integration of voice command systems via Alexa, Siri, etc.

C. Potential benefits and applications

The key advantage of a unified outdoor IoT ecosystem is the simplicity of automation and the creation of a unified ecosystem that can sustain and regulate its internal control environment for better performance and user experience.

Enhanced efficiency: The new ecosystem not only eliminates the need for additional network devices and maintenance but also improves the system's holistic performance. This reduces the need for frequent battery changes while adding additional functional features.

Lean system design: The utilization of common sensors eliminates the need for these sensors in individual systems, providing operational efficiency and maintaining cost efficiency for the manufacturers both at production and in the design phase. This decreases the time to market, while historical data could help improve existing systems or even design new systems. The added advantage of using the open standard or open platform is that it provides access to shared knowledge, eliminating the need for resources to maintain internal standards.

Safety and security: Open standards help the industry set a standard that is acceptable to all industry players. Adhering to these standards eliminated crosstalk and other inter-product technical issues. The elimination of multiple routers and gateways for individual equipment eliminates the number of nodes and entry points for potential hacks and threats.

Additional revenue model: The new enhanced feature has the ability to provide users with the experience they may be willing to pay for. Instead of subscribing for the contractors to make routine check-up visits or only

during a failure, homeowners can now use self-diagonalizing tools using the app to obtain real-time data and diagnostic reports to make data-driven decisions.

4. Technical Architecture and Implementation Challenges

A. Technical Architecture and Considerations

Designing a unified outdoor ecosystem for pools and backyards requires high technical considerations in terms of architecture and implementation. The data architecture must be reliable, from sensor networks to data and hardware durability to power management and security.

Sensor network design: The sensor networks act as input devices that collect various information about the operational environment, such as water temperature, ambient light, surface temperature, humidity, pH level, etc. The placement of these network components becomes critical, as they need to cover large and open areas while maintaining connectivity. Based on experience and research, it is recommended to use sensors that support low-power network protocols, such as LoRa and Zigbees [15]. These sensors are often connected to gateways to log the data. These sensors have no computing power or functional action output.

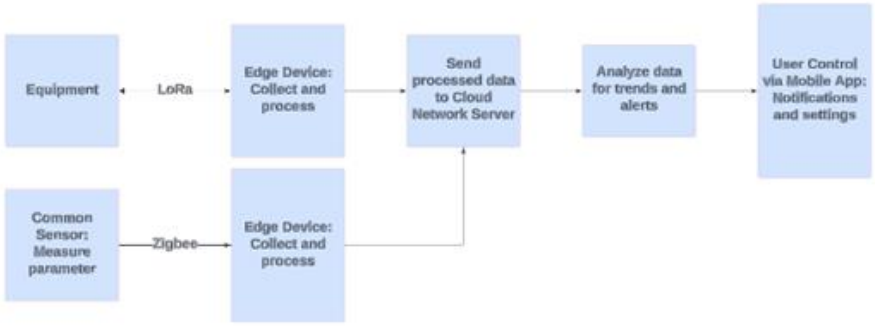

Figure 3: Example of data and information flow chart

Individual equipment: The equipment designed will be less complex because of the elimination of the sensors but will be equipped with intelligence to act based on the data received from common sensors.

AI Integration and Data Processing: The data collected from the sensor network must be transmitted, stored, and processed for reliable notification and action. While the network cloud server helps compute and handle large amounts of data, edge computing is recommended to process data locally and initiate actions without constantly requesting cloud communication. Cloud computing can aid in deep analysis and identify patterns that help optimize performance and energy consumption. Individual cloud servers with machine learning and AI models can help organizations understand user-level customization and focus on providing personalized services while detecting anomalies in individual equipment performance [16].

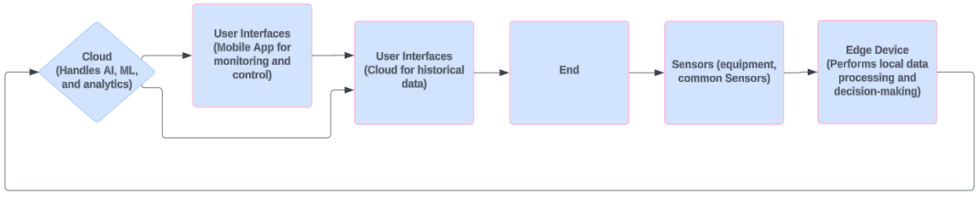

Figure 4: Simple AI/ML input flow chart

With the application of artificial intelligence and machine learning, the system can sense and understand the number of adults and children in the pool or backyard, learn from the data across the connected pools in the industry, predict the probability of accidents, and prevent accidents. The utilization of AI, Data, and machine learning not only improves the customer experience in managing the equipment but also ensures the safety of using unsupervised pools in homes and communities.

User interface and control systems: The user interface and user experience should be designed for a robust mobile application, allowing users to understand notifications outside the language barrier. The open platform must determine and enforce common symbols to indicate water quality, safety, and even preventive notifications to help homeowners and pool managers gain a common understanding. Voice-controlled systems, such as Google Assistant and Alexa, can also be integrated, enabling hands-free control while using the pool.

Hardware durability: IoT devices and sensors used in outdoor applications must be at least IP67 [17] and NEMA 4X/6P certified, providing them with the required sealing from water while ensuring dust and UV protection. The tolerance of the sensor's design should be set based on the variation in sensor operation due to temperature and pressure variations. These advanced systems can also incorporate predictive maintenance algorithms, alerting users to potential issues before they become critical and require expensive repairs. The integration of sensors and a data analysis module can enhance the detection of unusual patterns. Additionally, the implementation of AI-driven energy management systems can optimize pool heating and filtration schedules, resulting in significant cost savings and reduced environmental impacts for pool owners.

B. Case Study and Future Direction

CMP's Brilliant Wonders [8] (BW) Pool controller, 1.5" lights, bubbles, laminar, sanitation system, chlorine salt system, Smart sync waterfall controller, and fire and water features can be connected in a pool setting to understand the connectivity and implementation. Additional common sensors, such as pH, temperature, ambient light, and chlorine detectors, are used to collect the common data. Based on the data sensed by the pH and temperature data, the BW controller determines the duration of the sanitation system, and the AI/ML module in the cloud compares the data with the historical values to understand user comfort and manage the pH and temperature variations. Based ON or OFF ambient light variation, it can also decide whether to turn the pool and backyard lights and other decorative features ON or OFF while controlling intensity. It also provides insights into the operations and self-diagnostics of homeowners' references while suggesting possible maintenance and energy-saving settings.

Figure 5: Concept of User Interface of Unified System

The integration of artificial intelligence (AI) and machine learning (ML) can greatly improve outdoor IoT systems by facilitating sophisticated automation and decision-making processes. These technologies can analyze data from outdoor sensors to optimize various functions, such as pool filtration timing, occupancy-based lighting adjustments, and preemptive equipment failure detection. AI-driven predictive maintenance can notify

users when pool equipment or irrigation systems require servicing, thus avoiding expensive repairs and minimizing downtime.

ML algorithms can be utilized to understand user preferences over time, offering tailored suggestions for backyard activities. These may include optimal lighting configurations, pool temperature recommendations, or irrigation schedules based on past weather trends. As outdoor IoT systems grow in complexity, AI will play a crucial role in simplifying management for users who might otherwise be overwhelmed by the abundance of data.

C. Economic Impact and Business Model

A unified ecosystem, especially powered by AI and IoT in pools and backyards, has a high potential to generate both economic and environmental benefits for society. Automated systems can optimize energy consumption by adjusting pool control parameters and enhancing resource utilization and sustainability.

Cost-benefit analysis: One of the primary advantages of a unified system is the reduction in operational costs. Automated systems optimize energy consumption by adjusting the pool performance parameters based on usage patterns and real-time data. For instance, Pentair's IntelliFlo [6] pumps can reduce energy consumption by 30 % using variable-speed pumps, and dimming ability in LED can improve energy savings by up to 50 %. The use of common sensors results in the simplicity and elimination of duplicated functions in individual systems, saving manufacturing costs while eliminating maintenance and failure costs. Traditional outdoor management systems are often inefficient and rely on fixed schedules or manual intervention. IoT systems, on the other hand, can be dynamically adjusted based on real-time data, thereby significantly reducing waste. Additionally, companies can pass on these savings to customers, making the pool affordable, which may lead to an increase in the market size of the pool and backyard industry while opening new markets.

Sustainability: Utilizing the concept of a unified system empowered by AI and IoT, pool systems could lead to environmental benefits in terms of sustainability while creating an eco-friendly community by reducing the consumption of water and electricity. With the utilization of AI and data analysis, homeowners could gain insights into resource usage patterns that can be used to create awareness in the community. The utilization of the LoRaWAN and common sensors helps eliminate additional battery changes and duplicate parts by eliminating electronic waste. In the long run, AI-enabled IoT systems could help address issues such as energy shortages, grid overload, and carbon emissions in alignment with the United Nations Sustainable Development Goals (SDGs).

5. Conclusion

The Integration of IoT in outdoor pool and backyard systems has a huge potential to enhance customer experience while optimizing energy efficiency. Despite the current limitations of standalone devices, such as connectivity issues, repetitive battery replacement, and inefficient operations, emerging technologies such as LoRaWAN, edge computing, and AI-driven data-based decision-making could change the landscape of how these systems are operated. With the unified IoT framework, companies can not only build an effective ecosystem but also establish a monopoly on customer retention. With the help of real-time diagnostics and predictive models, companies can improve interoperability while reducing operational and manufacturing costs. As the pool and backyard industry evolves, the utilization of an open platform could enable the industry to operate in sync and create greater customer delight, opening up new markets with new business models. The proposed system also helps to conserve energy and has a global environmental impact. Companies that adopt the proposed approach and design considerations earlier will develop market and new revenue models for future growth. Despite the current limitations, such as standalone devices, security challenges, and connectivity issues, emerging technologies such as edge computing, LoRaWAN, and AI-driven analytics are paving the way for the future of the outdoor IoT. By adopting a unified IoT framework, companies can build seamless ecosystems that not only simplify user interactions but also provide real-time diagnostics, predictive maintenance, and improved system interoperability. As the outdoor IoT industry evolves, embracing open platforms and standards will be crucial for enabling cross-device communication, reducing costs, and driving innovation. Companies that adopt these approaches early will be poised to lead the market, creating not only a more sustainable outdoor environment but also new revenue models for future growth.

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