Application of IoT-Driven Water Level Monitoring Systems in Flood Prevention and Disaster Mitigation

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Abstract: Against the backdrop of global climate change, extreme precipitation events are occurring with increasing frequency, elevating the risks of river floods and urban waterlogging. Traditional water level monitoring methods, which often rely on manual processes and are characterized by significant time lags, are struggling to meet the stringent requirements for timeliness and accuracy in modern flood prevention and disaster reduction efforts. Internet of Things (IoT) technology, as a major breakthrough in information technology, provides the core support for building intelligent, networked, and high-precision modern water level monitoring systems through the integration of sensor technology, wireless communication, and cloud computing. This paper aims to explore the deep application models and significant potential of IoT-driven water level monitoring systems in the field of flood control and disaster reduction. The article first analyzes the principles, advantages, and disadvantages of current mainstream contact and non-contact water level monitoring technologies, such as pressure, ultrasonic, and radar sensors, providing a basis for technical selection in system construction. Furthermore, it systematically elaborates on the layered architecture of an IoT system— "Perception-Network-Platform-Application"—and how it enables closed-loop management of the entire process, including real-time data collection, intelligent warning triggering, flood model coupling, and emergency decision support. Research indicates that this application model can significantly enhance the foresight and scientific basis of flood forecasting and warning, provide critical data support for disaster response decision-making, and win valuable time for public evacuation, ultimately effectively mitigating the loss of life and property caused by flood disasters. It holds substantial practical significance for promoting the construction of "Smart Water Resources" and enhancing public safety governance capabilities.

Keywords: Internet of Things (IoT); Water Level Monitoring; Flood Prevention and Disaster Reduction; Sensor Technology; Early Warning System; Smart Water Resources

1. Introduction

In recent years, influenced by the dual pressures of global climate change and accelerated urbanization, extreme weather and climate events have shown a trend of increasing frequency and intensity. The resulting major basin-wide floods and extreme urban waterlogging events have caused enormous socio-economic losses and casualties worldwide, posing unprecedented challenges to traditional flood control and disaster reduction systems. In this context, overcoming the technical limitations of traditional manual inspection methods—such as intermittent data acquisition, low efficiency, high risk, and delayed response—to achieve real-time, accurate, and comprehensive perception of the entire hydrological situation and enable intelligent early warning has become a core problem urgently needing solutions in the field of hydrological monitoring and disaster prevention[1]. The rapid development and widespread application of Internet of Things (IoT) technology, which deeply integrates various intelligent sensors, wireless communication networks, cloud computing, and artificial intelligence, provides a new technological path and solution for building a new generation of intelligent water level monitoring systems. It makes possible the construction of an integrated and automated platform for flood prevention and disaster reduction encompassing automatic data collection, remote transmission, intelligent analysis, and information dissemination. It is against this background that this paper aims to systematically discuss the technical architecture of IoT water level monitoring systems, compare mainstream monitoring technologies, and explore their innovative application models and value in flood control and disaster reduction.

2. Overall Architecture of the IoT Water Level Monitoring System

The overall architecture of an IoT-driven water level monitoring system represents a sophisticated system engineering project that integrates sensing, transmission, processing, and application. Its core objective is to achieve real-time, accurate, and reliable acquisition of hydrological information while enabling intelligent decision-making. The system adopts a hierarchical design and is structured from bottom to top into four layers: the perception layer, the network layer, the platform layer, and the application layer. These layers work in close coordination to form a fully integrated smart monitoring closed loop.

At the foundation lies the perception layer, which serves as the sensory nerve endings of the entire system. It is responsible for the direct acquisition of water level data through various types of sensors deployed at critical locations such as rivers, lakes, reservoirs, and underground drainage networks[2]. These sensors—including pressure-based, ultrasonic, and radar types—continuously measure water level variations, converting physical signals into electrical or digital signals. The design of this layer emphasizes appropriate sensor selection, optimal deployment strategies, and reliable power supply solutions (e.g., solar power) to ensure accuracy, stability, and durability under diverse environmental conditions.

The network layer acts as the neural pathway of the system, transmitting the collected data efficiently and reliably. It utilizes a range of wireless communication technologies such as long-range, low-power LoRa and NB-IoT, as well as high-bandwidth 4G/5G mobile networks, to send data from the perception layer to cloud-based data processing centers. This layer addresses the challenge of the “last mile” in data transmission from distributed monitoring points to a centralized management system. Key design considerations include selecting cost-effective and efficient networking solutions based on geographic distribution, data volume, and real-time requirements, all while ensuring uninterrupted and stable data transmission.

Data converges at the platform layer, which functions as the central brain of the system. Typically built on cloud computing or IoT platforms, this layer is responsible for receiving, cleansing, storing, and managing large-scale heterogeneous real-time water level data. More importantly, it employs big data analytics, artificial intelligence algorithms, and hydrological models to perform advanced processing and analysis—such as predicting trends, detecting anomalies, and simulating flood scenarios by integrating multi-source data like rainfall measurements. When data exceed predefined thresholds, the platform automatically triggers a multi-level early warning mechanism and supplies standardized data interfaces and decision-support evidence for upper-layer applications.

Ultimately, the value of the entire system is realized at the application layer, which delivers actionable insights to end-users. Through web portals, mobile applications, and large-screen command systems, it provides intuitive visualization of hydrological information, disseminates early warnings, supports flood simulation, facilitates dispatch decision-making, and enhances emergency response capabilities for water authorities, disaster management agencies, and the public. By transforming raw data into actionable intelligence, the application layer closes the loop from sensing to decision-making and operational response, thereby fulfilling the core mission of reducing flood risks and mitigating disaster impacts.

3. Analysis of Mainstream Water Level Monitoring Technologies

The current technological foundation of IoT-based water level monitoring systems lies in diversified sensor technologies, which can be broadly categorized into contact and non-contact types based on their measurement principles. Among contact-based monitoring technologies, the float-type water level gauge is one of the most historically applied methods. Its working principle involves a float that moves with changing water levels, driving an internal mechanical structure or encoder to accurately measure variations. This technology offers high maturity and stable, reliable measurements. However, its drawbacks include the need for a dedicated stilling well, higher construction costs, and susceptibility to clogging and interference in waters with high sediment content or floating debris, which can compromise data accuracy. Another common contact-based technology is the pressure sensor water level gauge, which calculates water level height by measuring hydrostatic pressure and applying hydrostatic principles. Its greatest advantage lies in its simple installation, elimination of the need for a stilling well, and relatively high cost-effectiveness[3]. That said, its measurement accuracy can be affected by changes in water temperature and density, requiring periodic on-site calibration to maintain data reliability. Additionally, there is a contact-based ultrasonic water level sensor installed at the bottom of the water body. It emits ultrasonic waves upward and measures the distance to the water surface by receiving echoes. This method benefits from having no moving mechanical parts and being less prone to clogging, but it comes at a relatively higher cost, and measurements can be easily affected by bubbles and suspended matter in the water.

With technological advancements, non-contact monitoring technologies are increasingly becoming a hotspot in IoT systems due to their advantages in ease of installation and maintenance, as well as their resilience to the physical properties of water bodies. A typical example is the radar water level gauge, which emits microwave pulses toward the water surface and calculates distance by measuring the time difference of the reflected echoes. It offers extremely high measurement accuracy and is largely unaffected by environmental factors such as temperature, humidity, vapor, or dust. Its flexible installation options are an advantage, but it is the most expensive among non-contact technologies, and measurement stability may be challenged under conditions of calm water (specular reflection) or highly turbulent surfaces. The non-contact ultrasonic water level gauge, installed above the water surface, measures distance by emitting ultrasonic waves downward. It is more cost-effective than radar gauges, easier to install, and suffers no mechanical wear. However, its accuracy is susceptible to interference from environmental temperature gradients and wind, often necessitating temperature sensors for compensation and calibration. Laser water level sensors also belong to the category of high-precision non-contact technologies. They use focused laser beams to measure the distance to the water surface, making them particularly suitable for confined spaces or long-distance measurements. Nevertheless, their performance significantly declines under adverse weather conditions such as rain, snow, fog, or smoke, limiting their application scenarios, and they come with high costs.

In addition to traditional sensor technologies, video-based water level recognition, as an emerging supplementary method, is demonstrating unique application value. This technology uses cameras deployed at monitoring sites and employs computer vision and artificial intelligence algorithms to automatically identify gauge scales, water level edges, or other reference objects in images to calculate water height. Its greatest advantage is the ability to provide intuitive live video footage, not only capturing water level data but also simultaneously monitoring surrounding environmental conditions, such as the accumulation of floating debris or unauthorized entry into hazardous areas, thereby enabling multi-purpose use. However, the effectiveness of this technology highly depends on image quality. In low-visibility conditions such as nighttime, fog, heavy rain, or lens contamination, its recognition rate and accuracy decrease significantly. Moreover, the complex algorithms require substantial computational resources.

In summary, each type of water level monitoring technology has distinct advantages, disadvantages, and specific application scenarios. In the practical construction of IoT systems, technology selection must be comprehensively considered based on specific application requirements, environmental conditions, accuracy needs, and project budgets. For example, in river environments with high sediment content, non-contact radar level gauges may be a superior choice. In hydrological stations where construction conditions permit and long-term stable records are needed, traditional float-type gauges remain reliable. For urban waterlogging points requiring visual monitoring, video-based recognition technology can provide richer on-site information. This strategy of technological integration and demand-oriented selection forms the critical foundation for achieving efficient, precise, and intelligent flood prevention and disaster mitigation.

4. Specific Application Modes of IoT Systems in Flood Prevention and Disaster Reduction

The specific application of IoT water level monitoring systems in flood prevention and disaster reduction represents the concentrated embodiment of the value of the aforementioned sensing technologies and network architecture. This system is far more than a simple data dashboard; it is an intelligent core deeply integrated into the flood control command and decision-making process. Its application model begins with real-time monitoring and automatic alerts: radar, pressure, or ultrasonic sensors deployed at key nodes such as rivers, reservoirs, and underground utility tunnels collect water level data at frequencies of minutes or even seconds, and transmit it in real-time to the cloud platform via NB-IoT or 4G/5G networks. The platform's built-in intelligent threshold management module dynamically compares real-time data with preset multi-level thresholds such as warning water level and guarantee water level. Once an anomaly is triggered, the system can automatically issue tiered warnings (e.g., blue, yellow, orange, red) to responsible departments and the public via SMS, app push notifications, and broadcasts, fundamentally transforming the traditional model that relied on lagging manual reporting.

Its core value is further demonstrated in the deep integration of forecasting and decision support. The system platform integrates real-time water level data with meteorological department radar rainfall forecasts and hydrological models through API interfaces. For example, in the smart flood control system of a city in the middle and lower reaches of the Yangtze River, the platform incorporates quantitative precipitation forecast (QPF) data for the next 72 hours to drive distributed hydrological models for flood peak flow and evolution simulation. The system can predict that the water level at a key section in the city will exceed the warning level 6-12 hours in advance and simulate the surrounding inundation range. Decision-makers are no longer passively responding but can proactively schedule based on prediction results: how to pre-discharge reservoir capacity to reduce the peak, whether to reinforce embankments in advance, or organize the relocation of residents in low-lying areas. This shifts flood control from “post-event response” to “pre-event defense.”

A very specific case is the application of Hangzhou City, Zhejiang Province's “Smart Drainage” system in urban waterlogging prevention. The system deploys a large number of IoT water level monitors (mostly radar-based for strong anti-interference capability) at low-lying waterlogging-prone points, main sewer inlets, and key river sections. During the passage of Typhoon Muifa in the summer of 2022, the system detected that the water level at a point on Wensan Road in Xihu District rose rapidly by 40 cm within one hour, and the rainfall forecast model predicted that heavy rainfall would continue for the next two hours. The platform immediately triggered an orange warning automatically and pushed the warning information along with real-time images to the district flood control command center, urban management bureau, and street officials via DingTalk. Simultaneously, the system's built-in dispatch model, based on real-time pipeline network water level data, automatically generated and recommended the optimal emergency drainage plan: it suggested immediately remotely starting nearby pumping stations for forced drainage and dispatching a mobile pump truck for support. Staff could remotely start and stop the pumping stations with a single click on the command center's large screen. Ultimately, the waterlogging at this point was effectively controlled within 40 minutes, avoiding large-scale traffic disruptions and property losses.

5. Conclusion

In summary, the IoT-driven water level monitoring system, by integrating various advanced sensing technologies, reliable wireless transmission networks, and powerful cloud platform data analysis capabilities, has fundamentally transformed the traditional passive and lagging model of flood prevention and disaster reduction. It establishes an intelligent perception and early warning response system that operates 24/7, offers comprehensive coverage, and manages the entire process. It not only greatly enhances the accuracy of flood forecasting and the timeliness of warning issuance, providing scientific basis for commander decision-making and dispatch, but more importantly, it constructs a robust technological barrier for protecting people's lives and property. Although challenges remain in areas such as sensor reliability, data security, and long-term operational maintenance costs, with the continuous integration and application of technologies like artificial intelligence, 5G and even future 6G communication, and digital twins, future flood control and disaster reduction systems will inevitably evolve towards more intelligent, precise, and integrated “Space-Air-Ground” stereoscopic monitoring. This evolution will ultimately provide indispensable key technological support for building sponge cities and achieving sustainable development.

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