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SMART MONITORING OF IRRIGATION CANALS USING IOT SENSORS AND ARTIFICIAL INTELLIGENCE

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Abstract. Water scarcity and inefficient distribution are critical problems in canal irrigation systems. This study presents a conceptual IoT–AI framework for the real-time monitoring and management of open irrigation canals, using the Parkent Canal as a theoretical case study. The proposed architecture outlines the deployment of networked sensors (water-level, flow, gate position, weather) linked via LPWAN (e.g., LoRaWAN) to a cloud platform. Under this framework, data would be processed using AI algorithms: machine learning to forecast future demand and anomaly detection to flag leaks or sensor faults. The paper describes how this system can theoretically enable automated gate control and timely alerts. Based on field implementations of similar IoT canal systems in literature (e.g., ultrasonic sensors + ESP32 microcontrollers with cloud visualization [1]), our conceptual analysis indicates that the proposed approach has the potential to significantly reduce water losses by better matching supply to demand. The main contribution of this work is a comprehensive, theoretical IoT+AI architecture tailored to Parkent Canal's operational needs, integrating predictive analytics with real-time monitoring concepts to improve future irrigation efficiency.

Keywords: IoT sensor network; canal monitoring; water distribution; smart irrigation; machine learning; anomaly detection; LoRaWAN [1, 2]

Аннотация. Актуальность работы обусловлена необходимостью повышения эффективности распределения воды в оросительных каналах. В статье представлена концептуальная модель системы интеллектуального мониторинга оросительных каналов на основе IoT-сенсоров и ИИ (на примере Паркентского канала). Рассматривается теоретическая архитектура сети, включающая датчики уровня и расхода воды, положения створок шлюзов и метеорологические датчики. Предлагается схема передачи данных через LoRaWAN на облачную платформу для последующего анализа. В рамках разработанной концепции алгоритмы ИИ предназначены для прогнозирования потребности в воде и выявления аномалий (утечки,

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отказ датчиков). Описанная теоретическая система призвана обеспечить автоматическое управление шлюзами и раннее предупреждение об отклонениях. Анализ аналогичных систем, описанных в литературе (например, Das et al., 2025, где использовались IoT-модули ESP32 и ультразвуковые датчики [1]), подтверждает техническую исполнимость и потенциал предлагаемого подхода для снижения потерь воды. Научная новизна работы заключается в разработке комплексной теоретической архитектуры IoT+AI для Паркентского канала, закладывающей основу для будущих интеллектуальных систем управления водными ресурсами.

Ключевые слова: IoT-сеть; мониторинг каналов; водораспределение; умное орошение; машинное обучение; обнаружение аномалий; LoRaWAN [1, 2]

Annotatsiya. Kanallar orqali sug‘orishda suvni tejash va taqsimlash samaradorligini oshirish muhim masaladir. Ushbu maqolada IoT-sensorlari va sun’iy intellekt yordamida kanal monitoringi tizimining konseptual loyihasi taklif etiladi (Parkent kanali misolida). Nazariy jihatdan taklif qilingan tizimda suv sathi va oqim tezligini o‘lchovchi datchiklar, shuningdek, darvoza holatini nazorat qiluvchi qurilmalar ma’lumotlarni LoRaWAN orqali bulut platformasiga yuborishi ko‘zda tutilgan. Kelajakda tizimga integratsiya qilinadigan sun’iy intellekt modellari yordamida suv talabini bashorat qilish va anomal holatlarni (oqishlar yoki datchik nosozliklari) aniqlash imkoniyatlari tahlil qimen. Mavjud adabiyotlardagi o‘xshash IoT tizimlari tajribasi (masalan, Das va boshq. (2025) tomonidan ESP32 va ultratovushli datchiklar qo‘llanilishi [1]) ushbu yondashuvning texnik jihatdan samarali ekanligini ko‘rsatadi. Nazariy tahlillar shuni ko‘rsatadiki, taklif etilayotgan model suv yo‘qotilishini kamaytirish va taqsimot aniqligini oshirish imkoniyatiga ega. Ishning ilmiy yangiligi – Parkent kanalining ekspluatatsiya ehtiyojlariga moslashtirilgan, real vaqtda monitoring va bashoratli tahlilni birlashtiruvchi to‘liq konseptual IoT+AI arxitekturasining ishlab chiqilishidir.

Kalit so‘zlar: IoT tarmog‘i; kanal monitoringi; suv taqsimoti; aqlli sug‘orish; mashina o‘rganishi; anomal aniqlash; LoRaWAN [1, 2]

INTRODUCTION.

Efficient management of irrigation canals is essential for water-scarce agriculture. Traditional open-channel systems often rely on manual gate operation and fixed schedules, leading to inefficiencies, overflows, or shortages along the canal. As reported by Phan and Vu, manual gate control in paddy-field canals “often results in localized water shortages or excesses” [2]. Conversely, real-time monitoring and control frameworks can greatly improve distribution. For example, Das *et al.* (2025) developed an IoT-based monitoring system using

ultrasonic sensors and an ESP32 microcontroller to measure canal discharge, demonstrating high accuracy in field tests and providing continuous flow data to a cloud app [1]. On a larger scale, China's South-to-North Water Transfer middle canal (1,400 km) employs over 100,000 IoT sensors for flow, quality, and structural monitoring [5].

These examples illustrate that sensor networks can "empower users to make informed decisions" by visualizing water levels and flows in real time [1]. Recent advances in AI further augment these concepts: deep learning models can theoretically predict irrigation demand with low error rates (~2%) [4], and anomaly-detection algorithms (autoencoders, GANs) are capable of flagging abnormal sensor readings or leaks with high accuracy (>90%) [3]. Motivated by these insights, this paper proposes a conceptual smart monitoring system framework for the Parkent Canal in Uzbekistan, theoretically integrating IoT sensors, low-power communication (e.g., LoRaWAN), and AI analytics to optimize water delivery and design early warning mechanisms.

LITERATURE ANALYSIS.

Several studies have applied IoT to irrigation canal monitoring, establishing a baseline for conceptual system design. Das *et al.* tested an ESP32+ultrasonic sensor system on canal sections, transmitting depth measurements to Firebase for a mobile dashboard [1]. They used channel geometry and Manning's equation to convert level to flow, achieving results consistent with official gauge data [1]. Their hardware design emphasized durability and power efficiency, choosing non-contact ultrasonic units (JSN-SR04) that avoid damage from debris [1]. These low-cost components demonstrate that accurate canal monitoring is structurally feasible without expensive instrumentation.

IoT communications vary, but LoRaWAN has proven highly effective for wide-area irrigation. Phan and Vu (2024) deployed a LoRaWAN network to remotely monitor and control canal gates over distances up to 2 km, noting that compared to cellular (4G) setups, LoRa's low power makes it ideal for rural canals [2]. Alternatively, Narrowband IoT (NB-IoT) modules can send periodic sensor data via existing LTE networks, enabling battery-operated ultrasonic level sensors in remote channels [2]. In these frameworks, cloud platforms (AWS, Azure, or open solutions like The Things Network) collect data for visualization; for instance, Das *et al.* pushed data to Firebase for a "Flow Tracker" app [1].

Artificial intelligence models can significantly enhance these monitoring setups when integrated into the backend:

• **Time-series forecasting models (LSTM, Transformer):** These models learn from historical usage, weather, and crop data to predict future water needs. González-Perea *et al.* (2024) reported that a Transformer-based model (with fuzzy

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logic and genetic algorithms) could forecast weekly irrigation demand with an average error of ~2.1% [4]. Accurate forecasts help irrigation managers schedule canal releases and pumping in advance, reducing uncertainty [4].

- **Anomaly detection models (Autoencoders, GANs):** Deep learning architectures can identify sensor faults or abnormal water use. Benameur *et al.* (2024) developed a fog-IoT system for farmers, using autoencoders to detect anomalies in soil moisture and weather data with ~90–97% accuracy [3]. Their approach replaced detected outliers with reconstructed values to ensure data quality.

While focused on field sensors in literature, this principle applies theoretically to canals: for example, a sudden drop in measured water level could trigger an alert for a possible leak or unauthorized draw-off. By integrating these AI methods, smart irrigation frameworks can enhance decision support (predictive demand, fault alerts) beyond traditional rule-based controls. Literature thus confirms that IoT provides the data structure and AI provides the intelligence needed for optimal canal management design.

PROPOSED RESEARCH METHODOLOGY.

This study outlines a conceptual full-stack design framework for Parkent Canal monitoring. The **study area** (Parkent Canal) is an open earthen canal in Tashkent Province that distributes mountain-water to downstream farms. The proposed methodology outlines how a monitoring framework could be structured, assuming multiple theoretical measurement points along its length: upstream inlet, mid-sections, and tail-outlets feeding branches.

Proposed Architecture Components

[Sensor Nodes: ESP32 + Ultrasonic] ---> (LoRaWAN Gateway) ---> [Cloud Platform: AWS/Firebase] ---> [AI Backend: LSTM & Autoencoder] ---> [User Dashboard / Gate Alerts]

- **Sensor Network Design:** Each target site is proposed to be equipped with: (1) a non-contact water-level sensor (e.g., ultrasonic JSN-SR04 or radar) mounted above the canal; (2) a flow estimation model (utilizing calculation via Manning‘s formula using measured depth and channel geometry); (3) a gate-position encoder if an automated gate or valve is present; (4) a solar-powered weather station (rain gauge, temperature, humidity). The ultrasonic sensor is selected for its precision (±3–5 mm) and outdoor durability based on literature benchmarks [1]. Sensor nodes are designed around low-power microcontrollers (e.g., ESP32) featuring deep-sleep modes [1].
- **Communication Infrastructure:** Nodes are designed to communicate via a LoRaWAN network. LoRa’s kilometer-scale range is ideal for rural canals [2]. Gateways placed at elevated points would relay data to the internet (using 4G

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backhaul or fiber). In areas without LoRa coverage, NB-IoT/GPRS modems serve as alternate links (e.g., an NB-IoT ultrasonic sensor sending hourly updates as a backup [2]). The network configuration aims to ensure frequent (e.g., 15-minute) updates of water level and gate status.

- **Data Platform:** All sensor streams are designed to ingest into a cloud database (e.g., AWS IoT, GCP, or Firebase). A web dashboard or mobile app interface is conceptualized to visualize real-time levels, flows, and alerts, emulating established systems like Flow Tracker [1].
- **AI Analytics Architecture:** Two theoretical AI modules are structured for backend execution:

1. *Water Demand Forecasting:* A time-series model (e.g., LSTM or Transformer) intended to be trained on past flow records, weather, and irrigation schedules to predict canal inflow/outflow requirements for the next 1–7 days. González-Perea *et al.* achieved ~99.9% scenario coverage using a transformer-based forecast [4], suggesting high potential accuracy if implemented.

2. *Anomaly Detection:* An unsupervised model (autoencoder or isolation forest) designed to learn normal patterns of level/flow readings. Deviations beyond calculated thresholds would trigger alerts. For instance, Benameur *et al.* used an autoencoder-GAN hybrid to detect anomalies in soil moisture and humidity data with >90% accuracy [3]. Similarly, the canal system would flag sharp drops in level (possible leak) or unlikely oscillations in sensor signals.

- **Decision Control Concept:** Forecast outputs are designed to inform a rule-based or RL-based gate control policy. If upstream demand surges, the system pre-opens gates; if excess flow is forecast, it throttles gates to minimize spill. The system is fundamentally structured to provide decision support: it sends alerts (SMS/email) if observed flow differs significantly from forecast or if anomalies are detected, enabling human operators to intervene quickly.

THEORETICAL DISCUSSION AND ANTICIPATED RESULTS.

The proposed IoT-AI architecture is conceptualized to enable **continuous monitoring** and proactive management. While a physical deployment has not yet been executed, established performance metrics from literature allow us to project the potential efficacy of this framework when applied to the historical constraints of the Parkent Canal.

Based on performance benchmarks of similar deep learning architectures, an AI demand-forecasting model applied to historical canal data could theoretically reduce forecast uncertainty by up to 60% compared to traditional manual estimation baselines, allowing tighter control of gate openings. Anomaly detection models like autoencoders are capable of flagging synthetic leak scenarios (sudden persistent drops) within one hour of inception, whereas manual

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checks along the canal path often take several hours or days to detect physical issues.

Table 1

Presents the targeted improvements that a full implementation of the proposed IoT-AI system aims to achieve relative to traditional manual operation:

Metric	Baseline (Manual Operation)	Proposed IoT–AI System (Targeted)	Projected Improvement
Flow measurement error (MAE)	10–15%	3–5%	~70% error reduction
Water delivery accuracy	85% of demand met	95% of demand met	+10% efficiency gain
Water loss (seepage/overtop)	High (unmonitored)	Reduced via early alarms	>15% loss reduction
Gate operation frequency	~5 manual changes/day	2–3 automated adjustments	–40% mechanical wear

Table 1. Anticipated performance improvements of the proposed system based on literature benchmarks. These projected gains align with modern hydrological literature: real-time sensing of discharge and levels has been shown to "enhance distribution efficiency and minimize wastage" [1]. Likewise, Phan & Vu demonstrated that automated LoRa-based gate control can operate reliably over large distances, avoiding local shortages [2]. The theoretical AI enhancements (forecasting, anomaly detection) would minimize human error and adapt dynamically to environmental variability (e.g., changing crop water use).

Implementation Challenges Note: In practical field deployment, the primary challenges will center on ensuring sensor robustness (especially in freezing or high-sediment clogging conditions) and maintaining network connectivity over remote terrain. However, studies like Choe & Lee (2025) emphasize that modern AI-PHM (Prognostics and Health Management) methods can accommodate intermittent data and automatically flag sensor malfunctions [6]. Our design includes hardware safeguards (solar backups, deep-sleep cycles) and software filtering to mitigate noisy data streams. Overall, the proposed architecture is technologically feasible and leverages established IoT standards to modernize open canal management.

CONCLUSION AND SUGGESTIONS.

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This paper presents a comprehensive theoretical framework demonstrating how smart IoT monitoring, coupled with AI analytics, can transform irrigation canal management. By designing a conceptual architecture to equip the Parkent Canal with networked water-level sensors, flow sensors, and automated gates, we demonstrate a path toward **real-time visibility** in canal performance without prohibitive deployment costs.

Theoretically, AI-driven demand forecasts allow operators to plan water releases days ahead, reducing structural waste and ensuring equitable distribution, while unsupervised anomaly detection enables early identification of leaks or sensor malfunctions. Literature indicates that such integrated frameworks drastically improve performance, outperforming traditional physical gauging methods in accuracy and responsiveness [1].

We therefore recommend the following roadmap for future pilot implementation on the Parkent Canal:

- **Phase 1:** Physical installation of ultrasonic level sensors at strategic target sections.
- **Phase 2:** Establishment of a dedicated local LoRaWAN gateway connected to a cloud server instance.
- **Phase 3:** Development and calibration of the proposed LSTM and autoencoder AI modules using collected field data.
- **Phase 4:** Engagement of canal operators to refine gate-control logic based on AI decision-support outputs.

Future work should extend this theoretical framework by integrating reinforcement learning (RL) agents for fully automated gate control and incorporating localized weather radar data for advanced irrigation scheduling. Ultimately, this research provides the architectural blueprint demonstrating that data-driven management of open canals can optimize water conservation and increase crop productivity under the constraints of Uzbek irrigation networks.

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