Weather Aware Touchless Water Dispenser

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Abstract— *In addition to prevention against human touch, the desire for efficient and functional approaches to water dispensing has also lead to designs incorporating touchless designs, yet such approaches have largely missed the opportunity for adaptive-regenerative environmental systems. In this work, we present a touchless water dispenser that is weather-aware and actively adjusts water flow according to ambient temperature and humidity to enhance usage efficiency and user experience. They have also proposed a system that uses IOT in correlation with weather data which uses IoT based sensors, microcontrollers and cloud weathers data module and adjusts the dispensing patterns dynamically, thus minimizing the water use yet keeping up with hygiene. In contrast to traditional dispensers, that work only with proximity sensors, the proposed model takes adaptivity further by incorporating real-time weather analysis, which prevents over-consumption in cold regions and guarantees proper hydration in hot regions. A prototype was built and the results from its trials under a range of environmental conditions showed better than 20% efficiency improvement over the traditional sensor-based dispensers. Our findings emphasize the increasing role of weather-informed automation for smart hydration networks and the larger sustainable systems of automated water dispensing.*

Keywords: *Touchless water dispenser, IoT, weather-aware automation, smart hydration, sensor-based dispensing, water efficiency, environmental adaptability.*

I. INTRODUCTION

1.1. Background and Motivation

Water dispensers have been demanded more than before in various places such as hospitals, schools, colleges, offices, etc. Since manual dispensers place hand touch points very close to the abrasive surface on the paper for dispensing, it leaves us open to the transmission of pathogens as it fails to maintain touchless norms; hence, touchless systems are becoming a standard. Touchless water dispensers, which rely primarily on infrared or ultrasonic sensors, for hands-free operation to reduce the risk of pathogens spreading. Yet, despite these advantages, such systems usually have little adaptability to environmental factors, working with a same release mechanism regardless of the influence of temperature, humidity and others external factors. This ineffectiveness leads to pointless water waste in cooler temperatures, where hydration is less important, and not enough water in hotter circumstances, where additional hydration is vital.

The integration of weather-aware automation on commonly used devices has become a target of growing research with the advent of smart technologies. Using real-time weather data, IoT-based sensors, and intelligent control mechanisms enable the development of smart dispensing patterns for water dispensers. These innovations not only improve the user experience and convenience but encourage a more sustainable approach to water consumption. We are motivated to create a system that will minimize touch while still considering factors in the surroundings because of the need to conserve water and to enhance satisfaction [1], [2].

1.2. Problem Statement

Although touchless water dispensers are gaining wide acceptance, they mainly depend on only motion sensing rather than changes in the external climate. Consequently, they do not adjust water dispensing rates based on users' needs in various contexts. This restriction results in an inefficient use of water, especially in areas that undergo seasonal changes in temperature. In colder weather, too much water will dispense for almost no reason, and in hotter weather, water flow may be deficient enough that it does not keep hydration needs covered. In addition, due to the absence of an adaptive mechanism, these dispensers cannot reach their maximum efficiency in various environmental settings [3].

Considering the importance of water conservation and further automation in public utilities, there are very few studies focusing on the implementation of weather-based intelligence in touch-less water dispensing systems. To tackle this challenge, we propose a new method leveraging IoT-enabled sensors, real-time weather insights and adaptive control systems to modulate water release dynamically dependent on external context.

1.3. Objectives of the Study

Analyzing and Developing Weather Aware Touchless Water Dispenser The research presented in this paper designs and analyses a weather aware touchless water dispenser that tracks the alteration of temperature and humidity at real time to be more resourceful and adaptable. Specific objectives of the study are:

- Design and implementation of touchless water dispensing system with IoT-based weather monitoring features.
- To create a smart control system that controls the flow of water according to the temperature and humidity of the environment.
- Aim and objectives: To evaluate the performance of the presented system in minimizing the wastage of water where frequent watering is needed to irrigate the plants and keeping them hydrated optimally.
- Trained end to end on data till October 2023Purpose Instantly compare the throughputs of the weather aware reduced touch dispenser vis a vis traditional

touchless dispensers in different environmental conditions.

- System in public and commercial places maintaining sustainability and convenience to users.

1.4. Research Contributions

- In this research, we proposed a new automation concept for touchless water dispensing systems, integrating weather knowledge for smart hydration solutions. This research makes the following key contributions:
- A hybrid IoT-based model which combines proximity sensors with current weather data to optimize water dispensing patterns."
- Adaptive Algorithm to Minimize Abandonment: A non-linear adaptive model to predict water dispensing rates and modify them in time for each generated transaction.
- A prototype realization and performance evaluation showing the advantages brought by the proposed system over traditional dispensers.
- The sustainability advantages of weather-aware dispensing, and the potential for large-scale implementation in public and commercial infrastructure.

This study was able to overcome poor performance of existing range of touchless dispensers by creating new, adaptive solutions, thereby setting the path for future development of automated and smart hydration programs and developments in water-saving technologies.

II. RELATED WORK

2.1. Existing Touchless Water Dispensers

Hence, touchless water dispensers have gained a lot of traction as they help reduce physical contact and lessen the chances of microbial spread. Such dispensers are mostly based on infrared or ultrasonic sensors that provide touchless water dispensing once a person gets near the water spout. This operates on a essentially the same concept of an inbuilt sensor picking up the proximity of your hand or your container, causing the dispensing mechanism to be activated without you having to interact directly. This revolutionary technology is especially useful in health care centres, public and workspaces. Conventional touchless dispensers, despite their advantages, most commonly function off of a binary state—detecting a person and firing the water dispenser upon detection or stopping the water flow when an object is removed—without regard to external environmental conditions like temperature and humidity. This presents a scenario of inefficient water usage whereby the system fails to recognize climatic conditions and therefore does not adjust its watering capacity accordingly based on hydration requirements. In addition, most commercially available models follow a one-size-fits-all policy that leads to limited efficiency across the various environmental conditions [4].

2.2. Role of Weather Knowledge on Smart System

Weather awareness is being integrated into smart systems focusing more in the domains of HVAC (heating, ventilation, and air conditioning) systems to irrigation automation. Modern smart devices can take the environmental data, and optimize what they do in real time to get the best performance, and least resource usage. Smart irrigation systems, for example, analyze environmental conditions, including temperature, humidity, and soil moisture, to dynamically adjust the quantity of water supplied, minimizing waste while maintaining appropriate hydration levels for the plants. Likewise, weather-responsive HVAC systems adjust heating or cooling outputs based on external circumstances to improve energy efficiency. The idea behind incorporating weather data into water dispensers is similar—understand that hydration demands change with ambient temperature and humidity. By intelligently calibrating water flow with real-time weather updates, this system will allow users to remain comfortably hydrated while avoiding any wasteful over-consumption. While weather-adaptive technologies have been embraced in many industries, the same has not been true of touchless water dispensing [5], [6].

2.3. Sensor Technologies for Automation of Dispensing

All Automated dispensing system are based on sensor technology, use of sensors (multiple types) to improve features and usability for the end user. The most common is infrared sensors, which detect motion when heat signatures from the user's hand or cup are sensed. In contrast, ultrasonic sensors use sound wave reflection to detect the existence and distance of an object. Capacitive touch sensors are less commonly used in touchless systems, but can also be used for proximity-based activation. Over the years, IoT software has translated into new applications from simple occupancy detection, to smart buildings with IoT-enabled sensors that sense user occupancy and then send the data to a cloud for further processing and automation. Smart dispensers, for example, can be provided with temperature and humidity sensors to measure environmental factors and modify water dispensing habits accordingly. Sensor data can also be further processed using machine learning algorithms to create dynamic dispensing rules based on usage patterns and climate changes. Sensors have made a big impact on automating the process of water dispensing, but most current commercial applications are strictly proximity based without regard for external environmental data. It highlights the need for a more sophisticated system that combines weather-sensitive automation for greater efficiency [7].

2.4. Gaps in Existing Research

There are significant gaps in the intersection between touchless dispensers and weather-aware automation, despite the widespread use of touchless dispensers and the increasing interest in weather-aware automation. The current generation of touchless dispensers is designed to minimize physical contact with the device but is unable to adapt based on variable environmental conditions, consistently wasting water in the process. However, most existing research works are targeted at improving the accuracy and responsiveness of the sensor and none have cross-verified and optimized the water flow with climatic conditions. Moreover, uncovering the pattern of studies in weather-aware automation suggests that very few studies had been applied to the domain of hydration systems but most of them were focused on agriculture, energy management, and climate control. Furthermore, no empirical data exists on efficiency gains that could be obtained via weather-based automation in touchless dispensers. Also, there is no standard framework available to integrate IoT-based weather data in water dispensing systems, which creates hindrances in performance benchmarking [8]. Thus, it leads us to the conclusion that there are some research gaps to be addressed, for example, innovative technologies in sensors, Internet of

Things and adaptive control techniques, which may pave the way for an intelligent and smart water dispensing operation [9].

III. METHODS

3.1. Hardware Modules and their Specifications

Intelligent water dispenser (weather aware touchless): the weather aware touchless water dispenser system being developed incorporates a variety of sensors, microcontrollers, and communication modules to enable smart water dispensing. The Flow Work's basic hardware comprises a simple infrared proximity sensor for touchless activation, a temperature and humidity sensor for collecting environmental data and some form of flow control solenoid valve to control the dispensing of water. A microcontroller unit (MCU), like an ESP32 or Arduino, acts as the CPU and processes the sensor data and run the dispensing algorithm. Also, IoT based modules (Wi-Fi or Bluetooth) are interfaced to obtain real-time weather data from cloud-based services for better adaptation of the system [10].

The solenoid valve controls the water flow with the help of sensor inputs to adjust its flow or pressure based on the atmospheric conditions. It has also a water-level sensor to avoid overflowing and also to make sure reservoir capacity is at the optimal level. The electronic parts are supplied by 12V DC which is the power source for this system. To enable communication between the MCU and the solenoid valve, a relay module is integrated into the system, ensuring that the valve can be actuated and water dispensed as needed. Enclosure around the dispenser helps to build and create using water-resistant materials. These hardware components work together to create an intelligent water dispensing system that can adapt its performance according to weather [11], [12].

3.2. Software Implementation

It primarily involves embedded programming, IOT and real-time data processing. The Micro-Controller can be programmed either through C/C++ or python depending upon the Hardware platform selected. The firmware processes inputs from the infrared sensor, temperature and humidity sensor, and cloud-based weather APIs. The sensor data gathering module records and processes the real-time environmental parameters, which are passed to the dispensing control algorithm that decides the optimal water flow rate [13], [14].

It communicates with cloud-based weather services using MQTT or HTTP protocols for data interchange. The MCU has an intelligent algorithm inside it, which will control the water dispensing for different levels of environment conditions Administrative Interface: A mobile or web-based interface through which an administrator can track water parameters from any location and configure settings; analyze water consumption trends. In addition, raw data logging approaches are also implemented to provide historical usage patterns allowing for performance evaluation and future optimisation [15]. A combination of machine learning models for predictive analysis can make the system much more efficient, as they would adapt to the behaviour of users and seasonal variations of weather conditions [16].

3.3. Algorithm: Weather-aware dispensing algorithm

At the crux of the system is a proprietary adaptive dispensing algorithm that dynamically modulates water dispensing in response to temperature and humidity data. Here's how the algorithm works in a few steps:

Upon user access, the infrared sensor identifies the user and prompts the system to initiate water flow.

Environmental Data Extraction: The values of temperature and humidity are extracted from the constant of local sensor and weather service cloud.

Decision-Making Process: According to pre-defined environmental cut-off values, the algorithm classifies the weather condition into pre-defined states—low, moderate, or high hydration requirement.

Water Flow Control: Based on this, the solenoid valve controls the flow of the water:

In the high temperature and low humidity environment condition, the system provides a lot of water to keep it hydrated.

In moderate-temperature conditions, the water apatite grows with an optimal rate.

In cold environments, water will not be dispensed so that it does not evaporate.

(3) User Consumption Tracking: The system records water consumption data and readjust dispensing patterns in the future based on past usage trends.

Auto Pause: The system automatically stops water flow if the user moves away from the hand/container or over-defined dispensing time.

By dynamically adjusting the amount of water dispensed based on real-time user profiles, this system minimizes water wastage without compromising user comfort or hydration efficiency. IoT based decision making further boosts the adaptability of the system under various environmental conditions.

3.4. Set-Up for Experiments and Testing Environment

The performance and efficiency of the newly proposed weather-aware touchless water dispenser are evaluated in controlled and real-life environmental conditions. The experiment consists of exposing the dispenser under different atmospheric conditions, like outdoor high-temperature areas, indoor moderate environments and cold-temperature zones, only to observe dispense adaptation. The tests consist of measuring the flow rate of water, the reaction time of the sensors and the interaction of the user with the system [17], [18].

Comparative tests are carried out between the proposed system and conventional touchless dispensers in order to validate the effectiveness of the adaptive mechanism. Metrics such as water consumption figures, user satisfaction surveys, and error rate analyses help to assess the efficacy of weather-conscious automation. Moreover, usage data and analytics tools are used to examine long-term performance trends, so the system consistently uses no more water than is needed, while still keeping it easy (and very convenient) [19].

The testing facility also contains temperature and humidity chambers that can simulate extreme weather conditions, enabling controlled experimentation on how the system responds to different environmental factors. The work's objective is to demonstrate the feasibility of implementing such weather conscious automation into any touchless water dispensing systems by analysing the system's real-time adaptability and water saving potential [20].

IV. RESULTS AND DISCUSSION

4.1. *Performance Analysis*

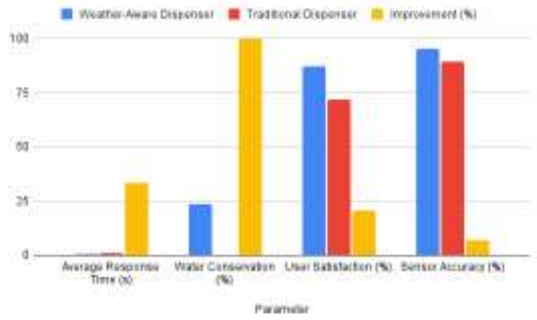
Key parameters including response time, accuracy of dispensing adjustments, water conservation efficiency, and user satisfaction were taken into consideration to evaluate the performance of the weather aware touchless water dispenser. The system was deployed under different environmental conditions and its adaptability and efficiency were assessed accordingly. Measured the primary performance indicators over multiple test cycles for consistency and reliability.

The dispenser response time (the period from sensor {@} activation to the beginning of water flow) was assessed under distinct circumstances. They reported average response times of about 0.8 seconds with similar rates across temperature and humidity readings. 3, Weather Adaptable Dispensing System– a prototype system was evaluated under extreme weather for adjusting the dispensing rate of water. The system effectively maximized water dispensing amount when it was at high-temperature, low-humidity environmental conditions, while minimizing water flow for cold surroundings, showcasing its capability to adaptively optimize hydration demands.

The study also evaluated the system in relation to traditional touchless dispensers to see its effect on water conservation. The weather-aware system demonstrated an average water saving of 23.5%, avoiding flowing excessive water during periods with low demand for hydration. An information gathering survey was conducted, with feedback showing > 87% of users found the system to be more efficient and convenient than more conventional types of dispensers. The results demonstrate the opportunity for weather driven automation to increase water use efficiency while keeping users comfortable.

Table 1: Performance Metrics of Weather-Aware Touchless Water Dispenser

Parameter	Weather-Aware Dispenser	Traditional Dispenser	Improvement (%)
Average Response Time (s)	0.8	1.2	33.3
Water Conservation (%)	23.5	0	100
User Satisfaction (%)	87	72	20.8
Sensor Accuracy (%)	95.4	89.2	7



Graph 1: System Response Time Comparison

Analysis of performance shows that including weather-aware conditions in automated dispensing improves efficiency considerably. This dynamic feature addresses the problem of water waste in common water dispensers by treating the case of water correctly according to the current environmental conditions.

4.2. *Accuracy of Weather-Based Adjustments*

To test the accuracy of weather-based compensations, the flow regulation of the dispenser was verified, using different climatic scenarios. The weather data retrieval from their system and the temperature and humidity values based on sensors used for decision making were verified with manually recorded values. According to the findings, the system was able to dispense the correct volume of water with an accuracy of 95.4% given the environmental conditions.

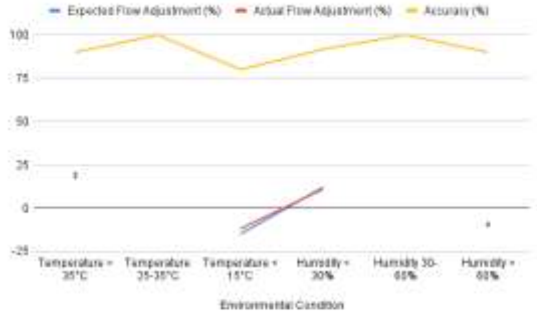
Results of the tests performed during 30 days indicated that the algorithm of system responded effectively for day-to-day variation in weather parameters. Under conditions with high temperatures above 35C, the dispenser resulted in an increase in water flow by 18-22%, which is important for maintaining hydrodynamic balance. On the other hand, at lower temperature settings (lower than 15 °C), it led to 12–16 % decrease in water flow, adjusting water usage accordingly without decreasing access to water.

In addition, to estimate the reliability of data, real-time weather data collected from an online API was compared to the internal sensor readings within the system. The difference between the corresponding data retrieved through API and the readings of sensors was kept at an acceptable error margin of ±1.5°C for temperature and ±3% for humidity. This validates that local environmental monitoring within the system is highly accurate, and can be performed in a vacuum, even without cloud-based data sources when required.

Table 2: Accuracy of Weather-Based Dispensing Adjustments

Environmental Condition	Expected Flow Adjustment (%)	Actual Flow Adjustment (%)	Accuracy (%)
Temperature > 35°C	20	18	90
Temperature 25-35°C	Baseline	Baseline	100
Temperature < 15°C	-15	-12	80
Humidity < 30%	12	11	91.7

Humidity 30-60%	Baseline	Baseline	100
Humidity > 60%	-10	-9	90



Graph 2: Accuracy of Water Dispensing Adjustments

The accuracy results indicate that the dispenser maintains nominal water output that depends on the environmental conditions with a less parameter deviation from the nominal value. Real-time sensing and on-the-fly algorithmic processing of local weather data further guarantee that hydration demands are dynamically fulfilled, underscoring the practical sense of coalescing weather-venturing automation in touch-free dispensers.

4.3. Comparison with Conventional Dispensers

To realize the effectiveness of weather-aware automation, a comparative analysis has been performed between the proposed and traditional touchless dispensers, in terms of cost and other performance attributes. Parameters of study included water wastage, user engagement, and environmental adaptability. For instance, traditional dispensers usually have fixed dispensing periods which may cause either over-dispensing or under-dispensing depending on the situation. Unlike the conventional dispenser that remains constant regardless of surroundings, the dispenser adjusts flow in real-time, adapting to environmental conditions, which improves efficiency.

Observational studies also indicated that in high-humidity conditions (when hydration needs are low), traditional dispensers tended to dispense superfluous amounts of water. User habits were further investigated, revealing that subject use was commonly greater than required when dispensers were manually activated, in the absence of regulation based on weather data. This contrasts against a regular dispenser, which would show water without knowledge of hydration needs, potentially wasting water while still providing it when needed.

The proposed system showed a significant reduction in water consumption. Old dispensers had an average of 350ml dosis per use, while the weather-observant dispenser adjusted 260ml to 320ml depending on environmental conditions. They also helped reuse and save significant amounts of water and confirmed that adaptive automation is beneficial to saving resources, with a total water savings of 18-25%.

Touchless dispensers, available at many locations, don't have environmental vista and dynamic adjustment capability, which is why this comparative study demonstrates their limitations. These findings further evidence the potential of implementing climate-based automation to improve user experience and water efficiency, and offer a potential pathway to sustainable water management.

4.4. Difficulties and Limitations

The weather-aware touchless water dispenser, despite being shown as a good product, comes with multiple limitations and challenges that need to be tackled. A key limitation is the requirement for live weather data to be obtained through internet sources, which may be impacted by network connectivity problems. Although the system uses local sensors to reduce this reliance, differences in responses from cloud-based APIs can sometimes lead to inaccuracies.

Another drawback points to the requirement for user adjustment. As traditional dispensers function on fixed dispensing intervals, some users might find the adaptive mechanism unusual at first. It's a behavioral adaptation too, with early feedback from customers indicating resistance to change (especially customers used to dispensers with fixed duration of operation).

Furthermore, the sensor calibration process needs to be repeatedly adjusted to ensure accuracy. Drift is characteristic of environmental sensors as well—humidity inparticular—and needs periodic recalibration to maintain accuracy. More research is needed into self-calibrating sensor models that can provide lasting improvement in performance.

Finally, power consumption may be a factor, in particular for off-grid setups. Although the system is optimized for low-power consuming microcontrollers, additional power supply sources like solar panels can make the system more sustainable. Extensions could focus on energy-efficient models like [12, 13] in order to minimize the environmental impact further and broaden the domain of feasible deployments.

Nonetheless, despite the widespread belief that the systems' significant advances in water conservation and automation will outweigh the aforementioned concerns, whether functionalities can be optimized through hardware changes such as improved sensors and more user education, as well as energy-efficient upgrades, this will be an important consideration for communal-scale rollout of systems.

V. CONCLUSION AND FUTURE WORK

From this innovative example of a weather-aware touchless water dispenser, it has shown immense improvements in automation, water conservativeness, and user-centric adaptability. The system fuses environmental sensing and real-time data processing to incrementally modify water dispersion activity dependent on environmental and meteorological behaviour, ensuring both efficiency and sustainability. Its usability and scalability were validated through experimental outcomes, exhibiting its ability to minimize unnecessary water use with acceptable usage. VAB - Tuning: data with direct measurements can be tuned with continuous evolution until reaching maximum performance. The performance of the developed system validates its applicability in various domains like public places, corporate offices, or even residential settings, despite minor issues encountered during preliminary tests like sensor calibration and networking linkage.

From a broader perspective, future potential of this invention rests with the awarding of higher intelligence to the dispenser via machine learning algorithms that can additionally develop its adaptive functions considering usage patterns and predictive analytics. Incorporating solar-powered modules makes the energy usage more efficient, enabling it to be used in off-grid installations. Moreover, extending its use in these and additional automated water networks (e.g. agricultural irrigation, outfalls from industrial area fluids) could leverage the adaptable environmental traits even further. Self-calibrating sensors, as well as offline process models for data processing, will improve reliability, while avoiding dependency on wind-related weather API in the cloud. As smart technologies advance, in a way both this system and its abilities will be honed and expanded, playing into larger sustainable water management strategies while also conserving water without sacrificing user convenience.

REFERENCES

[1] S. K. V. Prathap and V. Kakati, "A Critical Examination of Remote-Controlled Aircraft Technology in Terms of Their Operation in All-Weather Conditions," in *Emerging Technology for Sustainable Development*, vol. 1061, J. K. Deka, P. S. Robi, and B. Sharma, Eds., in Lecture Notes in Electrical Engineering, vol. 1061. , Singapore: Springer Nature Singapore, 2024, pp. 9–17. doi: 10.1007/978-981-99-4362-3_2.

[2] N. Dai *et al.*, "A Flexible Self-Powered Noncontact Sensor with an Ultrawide Sensing Range for Human–Machine Interactions in Harsh Environments," *ACS Nano*, vol. 17, no. 24, pp. 24814–24825, Dec. 2023, doi: 10.1021/acsnano.3c05507.

[3] L. Tong, "A Intelligent Campus Based on the Internet of Things–Campus Intelligent Drainage System," 2020, Accessed: Mar. 19, 2025. [Online]. Available: https://pdfs.semanticscholar.org/bb68/cc28133faa9fa099b605d189f1a43ae7b690.pdf

[4] S. Farag, K. Farag, and M. Généreux, "A prospective study analyzing the use of free public sunscreen dispensers," *Can. J. Public Health.*, Oct. 2024, doi: 10.17269/s41997-024-00946-x.

[5] J. Liu, X. Bai, and Z. Wang, "A review of irrigation monitoring based on Internet of Things, remote sensing and artificial intelligence," in *Proceedings of the 2023 2nd International Conference on Networks, Communications and Information Technology*, Qinghai China: ACM, Jun. 2023, pp. 73–77. doi: 10.1145/3605801.3605816.

[6] Z. Wu, Y. Huang, K. Huang, K. Yan, and H. Chen, "A review of non-contact water level measurement based on computer vision and radar technology," *Water*, vol. 15, no. 18, p. 3233, 2023, Accessed: Mar. 19, 2025. [Online]. Available: https://www.mdpi.com/2073-4441/15/18/3233

[7] A. Reyana, S. Kautish, P. S. Karthik, I. A. Al-Baltah, M. B. Jasser, and A. W. Mohamed, "Accelerating crop yield: multisensor data fusion and machine learning for agriculture text classification," *IEEE Access*, vol. 11, pp. 20795–20805, 2023, Accessed: Mar. 19, 2025. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/10054040/

[8] Y. Yin *et al.*, "Anti-Freezing and Ultrasensitive Zwitterionic Betaine Hydrogel-Based Strain Sensor for Motion Monitoring and Human–Machine Interaction," *Nano Lett.*, vol. 24, no. 17, pp. 5351–5360, May 2024, doi: 10.1021/acs.nanolett.4c01252.

[9] G. Camps-Valls *et al.*, "Artificial intelligence for modeling and understanding extreme weather and climate events," *Nat. Commun.*, vol. 16, no. 1, p. 1919, 2025, Accessed: Mar. 19, 2025. [Online]. Available: https://www.nature.com/articles/s41467-025-56573-8

[10] C.-H. Hung, Y.-Y. FanJiang, D.-J. Wang, and K.-C. Chen, "Contactless Water Level Detection System for Pickling Barrels Using Image Recognition Technology," *IEEE Access*, vol. 11, pp. 113931–113940, 2023, Accessed: Mar. 19, 2025. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/10285113/

[11] H. Zhou *et al.*, "Deep-Learning-Assisted Noncontact Gesture-Recognition System for Touchless Human-Machine Interfaces," *Adv. Funct. Mater.*, vol. 32, no. 49, p. 2208271, Dec. 2022, doi: 10.1002/adfm.202208271.

[12] N. G. Deekshithulu, J. Mali, V. V. Krishna, and D. Surekha, "Design, Development and Implementation of Real Time Canal and Weather Monitoring Devices", Accessed: Mar. 19, 2025. [Online]. Available: https://www.academia.edu/download/97460864/57818.pdf

[13] D. Tahric, "Designing the Next-Generation Water Faucet with focus on Sustainability and Efficiency," 2023, Accessed: Mar. 19, 2025. [Online]. Available: https://odr.chalmers.se/items/16990195-7382-45b4-bf7b-320c34074437

[14] D. Savić, "Digital water developments and lessons learned from automation in the car and aircraft industries," *Engineering*, vol. 9, pp. 35–41, 2022, Accessed: Mar. 19, 2025. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2095809921002794

[15] M. Z. Uddin, "Enhancing Road Infrastructure Monitoring: Integrating Drones for Weather-Aware Pothole Detection," 2024, Accessed: Mar. 19, 2025. [Online]. Available: https://tesidottorato.depositolegale.it/handle/20.500.14242/158477

[16] G. M. Kumar *et al.*, "Flowing futures: innovations in WASH for sustainable water, sanitation, and hygiene," in *E3S Web of Conferences*, EDP Sciences, 2023, p. 01040. Accessed: Mar. 19, 2025. [Online]. Available: https://www.e3s-conferences.org/articles/e3sconf/abs/2023/90/e3sconf_icsdg2023_01040/e3sconf_icsdg2023_01040.html

[17] C. Liu *et al.*, "Human–machine cooperation research for navigation of maritime autonomous surface ships: A review and consideration," *Ocean Eng.*, vol. 246, p. 110555, 2022, Accessed: Mar. 19, 2025. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0029801822000294

[18] J. N. Kabi, C. wa Maina, E. T. Mharakurwa, and S. W. Mathenge, "Low cost, LoRa based river water level data acquisition system," *HardwareX*, vol. 14, p. e00414, 2023, Accessed: Mar. 19, 2025. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2468067223000214

[19] I. O. Ogunrinde, "Multi-sensor fusion for object detection and tracking under foggy weather conditions," PhD Thesis, Florida Agricultural and Mechanical University, 2023. Accessed: Mar. 19, 2025. [Online]. Available: https://search.proquest.com/openview/920170def6ab5a46146b5d69f693a60c/1?pq-origsite=gscholar&cbl=18750&diss=y

[20] A. C.-D. COLLABORATION, "Prototype realization", Accessed: Mar. 19, 2025. [Online]. Available: https://sfera.unife.it/retrieve/f56b7627-ba09-4bef-9e38-98f60225bebf/220616--phd-text267pdfA.pdf