Integrated Platform for Smart Operational Monitoring and Efficient Energy Management of Water Supply Networks

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Abstract

Research project "PerManeNt" (www.permanent-project.gr) aims at developing an integrated platform for operational monitoring, smart control, and sustainable energy management of the external aqueduct system of the city of Patras in western Greece, which consists of more than 60 km of pressurized pipeline, 44 pumping wells, 3 springs, 22 regulating tanks, and 14 pumping stations. Given the significance of the existing infrastructure, 5 main pipelines, 7 pumping wells, 9 reservoirs, and 5 pumping stations were selected to be monitored in the context of: a) real-time data collection, processing and visualization, b) near real-time detection of system malfunctioning and automatic alarm generation, and c) generation of short and longer term forecasts for the water demand and corresponding energy consumption rates, based on hydrometeorological data and environmental indices

The development of the integrated platform is expected to have significant scientific, financial, societal and environmental impacts including: i) efficient water resources management and environmental protection, ii) reduction of the operational costs and regulator expenses for system maintenance and management, iii) promotion of citizens' awareness regarding environmental issues, and iv) significant improvement of the quality of services offered, including pricing and emergency planning.

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1. Pumping wells

Image 1. Pumping wells Eglykada 1 (left) and Eglykada 2 (right)

To detect system malfunctioning, we use the efficiency coefficient (η), which includes all operating parameters (flow, outlet pressure, water level in the pumping well, consumed power etc.) and can accurately represent the real-time operational status of the corresponding infrastructure.

$$\eta(t) = \frac{\rho \times g \times Q(t) \times H_{man}(t)}{P(t)} \qquad (1)$$

- ρ: water density (1000 kg/m^3)
- g: acceleration of gravity 9.81 (m/s^2)
- $Q(t)$: flow at time t (m^3/s)
- $P(t)$: consumed power at time t (KW)
- H_{man}: manometric head (m)

Continuous monitoring of the performance efficiency of pumping wells allows for:

- ✓ Near real-time detection of mechanical failures
- ✓ Reduction of maintenance costs
- ✓ Improvement of the operational level of the infrastructure.

2. Pumping stations

Image 2. Pumping station Tarampoura

Taraboura is the largest pumping station in the external aqueduct of the city of Patras and a vital component for the uninterrupted water supply of the citizens.

To detect system malfunctioning, we use the efficiency coefficient in equation (1), which includes all operating parameters (i.e., flow, inlet pressure, outlet pressure, consumed power) and can accurately represent the current operational status of the corresponding infrastructure.

Similar to pumping wells, continuous monitoring of the performance efficiency of pumping stations allows for:

- ✓ Near real-time detection of mechanical failures
- ✓ Reduction of maintenance costs
- ✓ Improvement of the operational level of the infrastructure.

➡ For both pumping wells and pumping stations, emissions of carbon dioxide per month will be monitored, to calculate environmental and energy related indicators.

3. Regulating tanks and reservoirs

Image 3. Reservoir Anthoupolis (left) and Regulating tank Alsyllio (right)

For regulating tanks and reservoirs, it is critical to estimate and monitor the water losses due to leakage and overtopping:

$$Q_{loss}(t) = Q_{in}(t) - Q_{out}(t) - \frac{V(z_{t+\Delta t}) - V(z_t)}{\Delta t} \qquad (2)$$

- $Q_{loss}(t)$: water losses dur to leakage and overtopping at time t (m^3/s)
- $Q_{in}(t)$: inlet flow at time t (m^3/s)
- $Q_{out}(t)$: outlet flow at time t (m^3/s)
- $V(z)$: total volume of stored water in the tank or reservoir (m^3)
- z_t: water level in the tank or reservoir at time t (m)

Benefits:

- ✓ Continuous monitoring of water leakages and overflows
- ✓ Reliable scheduling of maintenance and repair tasks
- ✓ Significant reduction of water losses

4. Pipelines

- ❑ Continuous and accurate monitoring of water losses based on mass balance equations
- ❑ Robust quantification of performance efficiency based on pressure gradients.

- ✓ Near real-time detection of pipeline failures.
- ✓ Reliable scheduling of maintenance and repair tasks

5. Probabilistic one-day ahead urban water demand forecasting for the city of Patras

To support the need for probabilistic one-day ahead urban water demand forecasts for the city of Patras, we have designed, automated and extensively tested a new practical forecasting system (Papacharalampous & Langousis, 2021) to be integrated into the platform.

This practical system is primarily based on a statistical linear boosting algorithm (Bühlmann & Hothorn, 2007) and specifically facilitates the prediction of the average urban water flow at day t using the following predictors:

- Average urban water flow at days $\{t-k, k = 1, \ldots, 7\}$
- High temperature at days $\{t-k, k = 1, \ldots, 3\}$
- Average temperature at days $\{t-k, k = 1, \ldots, 3\}$
- Low temperature at days $\{t-k, k = 1, \ldots, 3\}$
- High due point at days $\{t-k, k = 1, \ldots, 3\}$
- Average due point at days $\{t-k, k = 1, \ldots, 3\}$
- Low due point at days $\{t-k, k = 1, \ldots, 3\}$
- High humidity at days $\{t-k, k = 1, \ldots, 3\}$
- Average humidity at days $\{t-k, k = 1, \ldots, 3\}$
- Low humidity at days $\{t-k, k = 1, \ldots, 3\}$
- High wind speed at days $\{t-k, k = 1, \ldots, 3\}$
- Average wind speed at days $\{t-k, k = 1, \ldots, 3\}$
- Low wind speed at days $\{t-k, k = 1, \ldots, 3\}$
- High pressure at days $\{t-k, k = 1, \ldots, 3\}$
- Low pressure at days $\{t-k, k = 1, \ldots, 3\}$
- Total precipitation at days $\{t-k, k = 1, \ldots, 3\}$

Its efficiency has been empirically demonstrated through its large-scale comparison with practical systems using other machine or statistical learning algorithms. For this large-scale comparison, daily data from 54 urban water flow stations of the city of Patras has been used.

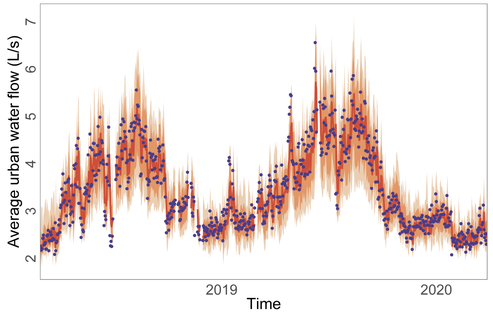

Image 4. Probabilistic one-day ahead urban water demand forecasts (depicted using red nuances) for an arbitrary urban water flow time series (depicted as purple points)

6. Conclusions

The development of the integrated platform through Project '**PerManeNt**' will have significant scientific, financial, societal and environmental impacts:

- ❑ Environmental protection
- ❑ Efficient water resources management
- ❑ Reduction of operational cost
- ❑ Promotion of citizen's awareness
- ❑ Improvement of the quality of services offered

References

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