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Experimental Evaluation of Pressure Stability under Adaptive Mechanical Control in WASH-Compliant Water Systems

Akshay D Rajput, S Chakradhar Goud, Mayur D Jagtap

Abstract: *One of the determinants of safe continuous and contamination-resistant water delivery is stable hydraulic pressure that ensures delivery systems meet the WASH standard. The change in pressure caused by fluctuation in demand, occasional supply and mechanical interruptions can reduce the reliability of the services, accelerate the degradation of the infrastructure, and increase the probability of the intrusion of contaminants. An adaptive mechanical pressure stabilization and real-time sensing feedback system of variation-based stiffness modulation working on a controlled laboratory testbed is experimentally tested in line with the characteristics of decentralized WASH conditions of operation. The control is increasingly being dominated by the hydro-mechanical dynamics, adaptive control formulation, and performance measures; pressure variance, settling time, and percentage overshoot. The results of test show approximately 45-60 percent reduction of the variation in pressure, 40-50 percent improvement of the settling time and nearly fifty percent reduction of the dynamic overshoot, compared with control procedure of constant stiffness. These quantitative advantages demonstrate an increase in disturbance rejection, enhancement of hydraulic stability and compliance with WASH service pressure constraints. Low power and lightweight sensing combined with supervisory control increases mechanical flexibility allowing it to be operated scalable when operating in a low resource environment. Adaptive mechanical regulation is considered by the results as a valid path to resilient, contamination-resistant and publicly-trustworthy water distribution systems, and the future projections have been made as a field scale validation, hybrid predictive control and network level coordination of distributed stabilization units.*

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1. Introduction

Availability of safe and sufficient water has been a major pillar in guaranteeing the advancement of the health of a people, environmental staying, as well as socio-economic growth in Water, Sanitation, and Hygiene (WASH) constructs [1]. Hydraulic pressure that remains constant in distribution pipelines is one of the top determinants in the delivery of just distribution of water, contamination ingression reduction, and minimal leakage and extended life of a infrastructure. Variation in pressures in traditional water supply systems is often high particularly in the scenario of an intermittently run or decentralized water supply systems or in systems operated by switching between pumps because of the varying demand patterns, height variance and manual operation of valves, not to mention the level of height variation [2]. This instability can compromise the compliance of WASH because it enables backflow contamination, unbalanced service coverage, and mechanical wear; hence, this has an adverse impact on the system resilience in the long term. The recent progress in the sphere of sensing technologies, mechanical actuation, and adaptive control theory has led to the development of new opportunities of stabilizing the pressure conditions with the assistance of the responsive regulation mechanisms that are directly built into the field of distribution infrastructure [3]. The other and viable alternative to the electronic and energy-consuming regulation methods is referred to as adaptive mechanical control, which consists of manipulation of valves or actuators due to changes in real-time pressure as a result of feedback [4].

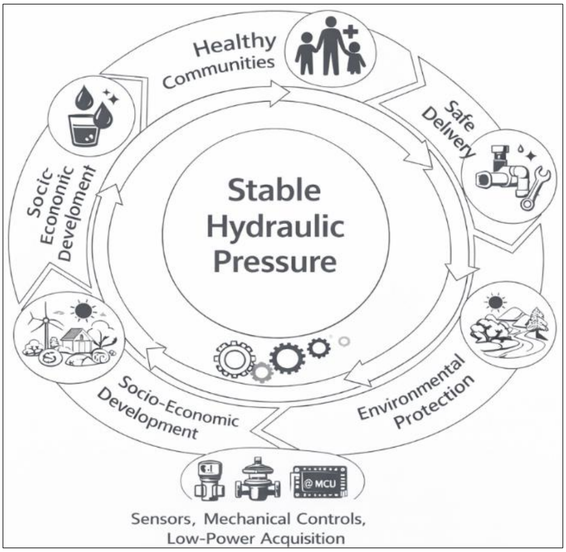

Figure 1. Stable Hydraulic Pressure in Healthy Ecosystem

The approach can be used to localize stabilization by using pressure sensors to gather low-power data and dynamically adjust mechanical response which consequently reduces the substantial computational burden, and this holds particular to WASH-as-constrained settings as those in figure 1 when deployed in resource-constrained settings. There is scanty experimentally supported proof of the efficiency of adaptive mechanical pressure regulation in real situations of operating WASH [5]. In order to turn the theory into practice in relation to the implementation of the infrastructure solutions that assure the consistency, stability, response dynamics, and compliance maintenance need a quantitative measure of the result of the process. The present research meets this need by experimentally testing stability of pressure found in adaptive mechanical control in a under-controlled water distribution test system in respect to operational demands of WASH systems [6] with highlights on quantifiable performance improvement and operational robustness and implications to under-controlled water supply systems that operate effectively at a community scale.

2. Background

Hydraulic pressure control in water supply systems has been conventionally grounded in passive or semi-active mechanical systems such as pressure-reducing valves (PRVs), variable-speed pumping, throttling devices and influenced to maintain the hydraulic pressure downstream of an operationally safe operating range. The first study indicated that a major reduction in the frequency and the likelihood of the leaks and bursting of the pipes can be achieved with a perfect PRV location and the best pump timing [7], [8]. Nevertheless, the slow change of demand, intermittency of supply operation, intermittency of demand, and increase in hydraulic gradient that characterize decentralized and rural WSH initiatives cannot be controlled by either the static or manually controlled regulation plans. It is through these weaknesses that adaptive control systems have been created which can ensure a constant pressure to the dynamically changing operating conditions. The procedures of adaptive control have therefore been of interest both in fluid transport and industrial process. Feedback-based controllers that have been shown to reduce the impact of disturbances oscillatory behaviour and also enhance the hydraulic efficiency of smart distribution networks include Proportional Integral Derivative (PID) regulation, model predictive control (MPC) and sensor-assisted valve modulation [9][10]. The more recent works were concentrated on low-power embedded sensing with derivations to adaptive valve actuation to manage settling time and maintaining pressure within the suggested safety margins [11]. Mechanical feedback configurations, where the actuator of a diaphragm diaphragm-based diaphragm force sensor is directly responsive to the measurement of the discrepancy between the control target diaphragm force, are of interest to resource-constrained WASH systems, and have a lower computational and lower power cost. The examination of the mechanically adaptive pressure stabilization type, and not always electronic or algorithmic control, is not so common in scientific investigation as an experimental fact.

Table 1: Comparison of Pressure Regulation, Adaptive Control, and WASH Monitoring Approaches

Approach Category	Core Technique	Key Advantages	Major Limitations	Relevance to Present Study
Conventional Pressure Regulation [8]	PRVs, throttling valves, pump scheduling	Simple, low cost, proven leakage reduction	Weak response to dynamic demand and pressure transients	Establishes baseline stability performance
Electronic/Algorithmic Adaptive Control [9]	PID, MPC, sensor-driven valve control	Real-time disturbance compensation, improved efficiency	Higher energy demand, computational complexity, maintenance burden	Demonstrates need for lightweight adaptive solutions
Mechanical Adaptive Control [10]	Diaphragm/spring feedback, self-regulating actuators	Low power consumption, rapid local response, suitability for rural systems	Limited WASH-focused experimental validation	Core mechanism evaluated experimentally
WASH Monitoring Systems [11]	IoT pressure/flow sensing, telemetry supervision	Continuous visibility, leakage and contamination detection	Monitoring-centric; lacks stabilization capability	Motivates integration of control with compliance assurance

Similar developments in WASH systems monitoring have added IoT-enabled sensing platforms that can monitor the continuity of pressure, flow, and service reliability in the distributed infrastructure continuously [12], 138]. These surveillance systems facilitate early-stage leakage, contamination threat, and infrastructure deterioration, hence, enhancing the transparency of operations and the protection of health to the population. Ensuring stable hydraulic pressure is generally known as a pre-condition of eliminating contaminant intrusion and delivering services fairly within community water systems [14]. Nevertheless, the current literature has focused much on monitoring and data analytics without a significant mechanical stabilization of the closed-loop that has been proven in controlled experiments. Table 1 summarizes the main categories of technologies, strengths, and weaknesses of the technology that are reported in the conventional regulation, electronic adaptive control, mechanical adaptive mechanisms, and WASH monitoring frameworks to put these research directions into context [15]. The comparison shows the scarcity of experimental data available in the context of mechanically adaptive stabilization structured directly in accordance with WASH compliance, which justifies the need to conduct systematic empirical studies.

3. System Architecture and Adaptive Mechanical Control Modelling

To enhance the stable hydraulic regulation in the WASH-compliant distribution setting, coordinated interaction of sensing, mechanical actuation and feedback-based modulating logic in the physical water conveyance pathway is required. The proposed design is informed by a cyber-physical architecture of pressure stabilization with three tightly coupled layers which include: (i) hydraulic transmission and disturbance domain, (ii) sensing and feedback acquisition layer and (iii) adaptive mechanical regulation layer. Water flowing in a controlled pumping source propagates to a test pipeline and during the propagation, the fluctuation in demand, valve perturbation as well as elevation gradient lead to pressure perturbations. The signal feedback required to move adaptive mechanical compensation is real time measurements of the pressure which are measured using calibrated transducers.

Hydraulic Pressure Dynamics

Simplified response Pressure evolution in a rigid water pipeline of diameter (D) and length (L) can be modelled by a one-dimensional simplified momentum continuity model. Without regard to compressibility and small losses to treat tractable experimental modelling, the temporarily varying behaviour of the pressure at position (x) and time (t) is treated by approximation.

$$\partial t\partial P(x,t)+\rho a2\partial x\partial Q(x,t)=-RQ(x,t),$$

where (P) denotes pressure, (Q) volumetric flow rate, (∂) water density, (a) wave propagation velocity, and (R) equivalent hydraulic resistance capturing frictional losses.

$$dtdP(t)=CK\big(Qin(t)-Qout(t)\big)-\tau 1P(t),]$$

Pressure stabilization therefore depends on dynamically modulating the controllable flow component.

Mechanical Actuation and Adaptive Regulation

Mechanical stabilization is achieved through a spring–diaphragm valve assembly whose opening area (Av(t)) varies in response to sensed downstream pressure. The actuator displacement (y(t)) follows second-order mechanics

$$\ddot{m}\{y\}(t) + \dot{c}\{y\}(t) + ky(t) = F_{p(t)},$$

where (m), (c), and (k) denote equivalent mass, damping, and stiffness, while $\left(F_{p(t)} = \left(P_{\{ref\}} - P(t)\right)\right)$ is the pressure-dependent restoring force scaled by diaphragm sensitivity. Valve flow obeys the orifice relation

$$Q_{\{out\}(t)} = C_d A_{v(t)\sqrt{\{\backslash frac\{2P(t)\}\{\rho\}\}}},$$

linking mechanical displacement to hydraulic discharge. Coupling these relations yields a closed hydro-mechanical feedback loop capable of attenuating pressure oscillations without high computational demand.

4. Architectural Implications for WASH Deployment

Installation of adaptive mechanical pressure stabilization in water distribution systems meeting WASH criteria brings a serious architectural change of moving to the absolutely passive hydraulic control to an embedded, response-sensitive hydro-mechanical intelligence that can work within resource-limited conditions. The traditional WASH facilities, especially rural and peri-urban facilities are often marked by intermittent supply, fewer electrical reliability, less digital monitoring, and reliance on manually operated pressure-reducing devices. In this case, instabilities of pressure frequently propagate the invasion of contaminants via leakages, unequal allocation among service outlets, and unreasonable mechanical corrosion of pipelines and fittings. Local stabilization is achieved by integrating adaptive mechanical control at key hydraulic nodes including the pump outlets, storage tank discharge lines, and community standpipe branches, which do not require sustained computational control or high-energy electronic actuation. The advantage of this property of architecture is that pressure resilience is not implemented only on the supervisory monitoring or centralized automation, but the physical infrastructure is made to provide such resilience. The hydro-mechanical feedback mechanism based on variance-based stiffness modulation also happens to be compatible with the realities of the operation of the decentralized WASH systems. Since regulation is realized by mechanical self-regulation guided by low-power sensing, the architecture does not need to be rendered non-functional in intermittent outages of electricity or communication. This resilience is especially essential in areas where grid reliability is intermittent or the resources needed to maintain the grid are minimal. Simultaneously, optional connection to lightweight edge data acquisition and supervisory telemetry presents a hybrid architecture that merges mechanical autonomy and digital observability to meet compliance and detect faults and performance audit without requiring continuous cloud reliance. This autonomy and observability balance is a viable way of realizing scalable smart-WASH infrastructure.

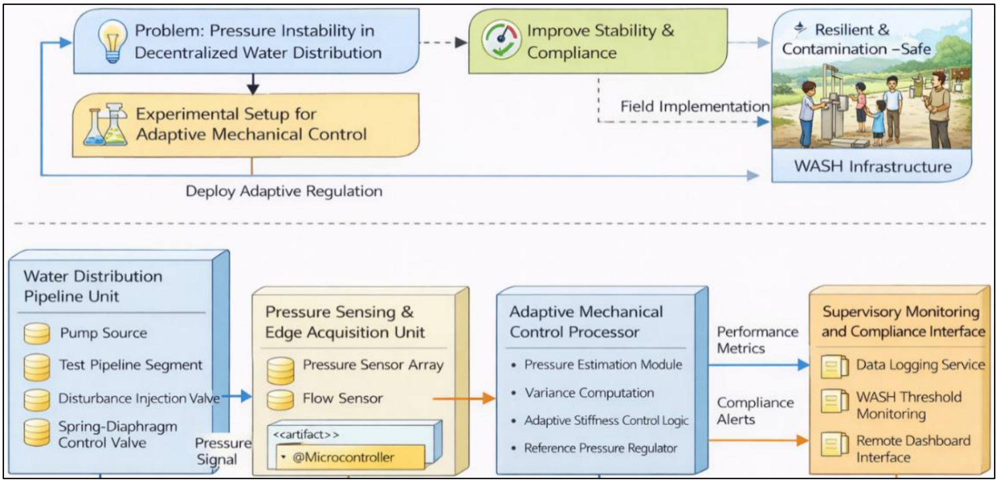

Figure 2. Deployment architecture for adaptive mechanical pressure stabilization in a WASH-compliant water distribution system**.**

Viewed through the prism of public-health system, steady pressure in the specified WASH limits directly minimizes the likelihood of ingress of pathogens through deteriorating negative pressure events or back-siphonage, contributing to microbiological safety of distributed drinking water. Deferred transient stress of the pipeline and joints also minimizes the formation of leaks and infrastructure fatigue, which leads to longer service life and lower lifecycle cost which is also a critical determinant of sustainability in community operated water schemes as depicted in figure 2. When installed in a network of nodes, adaptive mechanical regulators may operate together to promote network-wide hydraulic resilience, even the spatial irregularities of pressure and the equity of water access. The other architectural benefits are scalability and modularity. The adaptive regulation unit can be produced in a mechanical unit with sensing, which is self-contained, which means that retrofitting with an adaptive regulation unit can be made in small steps and to other installed WASH networks, instead of completely replacing the infrastructure. This modular deployment facilitates a stepwise implementation and cost management and location-based adaptation based on settlement size, elevation profile and variability of demand.

5. Experimental Setup

Adaptive mechanical pressure stabilization should be experimentally verified by means of a controlled hydraulic system that can produce disturbance conditions that are reflective of

WASH compliant water distribution systems. The evaluation platform will thus be an operationalized closed-loop laboratory testbed consistent with the deployment architecture above that includes physical pipeline infrastructure, sensing instrumentation, embedded adaptive control, and supervisory monitoring. The aim of the arrangement is to measure the increase or decrease in pressure stability, transient response behaviour and simultaneous maintenance of compliance during repeatable hydraulic disturbances. Hydraulic subsystem comprises of a storage reservoir attached to a centrifugal pump that provides the water by a rigid test pipeline with a specific length and diameter. Created in downstream of the pump, a disturbance injection valve injects desired variability in demand, step changes in flow and partial closure conditions simulating intermittent consumption behaviour in rural and peri-urban WASH networks.

Table 2. Key Experimental Parameters for Adaptive Pressure Stabilization

Category	**Parameter**	**Typical Specification**	**Experimental Role**
Pipeline	Length LLL, Diameter DDD, Mid-node regulation	8–12 m, 20–32 mm	Generates observable pressure transients
Hydraulic Source	Centrifugal pump, Service pressure	Variable flow, 1.5–3.0 bar	Provides controllable WASH operating conditions
Sensing	Pressure accuracy, Flow range, Sampling	±0.25% FS, 0–30 L/min, 100–250 ms	Captures transient hydraulic behavior
Edge Acquisition	MCU clock, ADC resolution	48–120 MHz, 12–16 bit	Enables real-time variance estimation
Adaptive Control	Pref $P_{\{ref\}}$ Pref, k_0 , γ, Trial duration	≈2.0 bar, tuned, 0.1–0.5, 5–10 min	Governs stabilization and statistical evaluation

Specifically, an adaptive spring-diaphragm control valve will be attached to the location of regulation and the pressure stabilization will be recorded. Tapping points of pressure are provided upstream and downstream of the control valve in order to make space assessment of attenuation of pressure and disturbance propagation. The real-time measurement is obtained with the help of a microcontroller-based edge acquisition unit interfering with calibrated piezoresistive pressure sensors and an inline flow sensor. The sensing subdivision will have a fixed sampling rate that is sufficient to prevent the dynamics of hydraulic variations and low power consumption to Favor the decentralized deployment criteria. Signal conditioning and the conversion of analog to digital is performed by the acquisition circuitry and synchronized timestamping offers a temporal relationship of the pressure and flow data streams and data streams of control responses. Section III is transferred to the adaptive mechanical controller processor by implementing the strain-based plan of stiffness modulation. Adjusting the reference pressure can give an indication of the levels of WASH services and one can use bounded disturbance cases in a systematic way to quantify convergences, overshooting and settling behaviour. The data on the performance is manifested in the experimental data that is logged by a monitoring supervisory software, compliance warnings are provided when the pressure falls outside of permitted limits and offline statistical analysis is supported. This experiment is conducted under a number of operating conditions, which include constant demand, rapid valve perturbation and random change of the flow. This is repeated many times to achieve the statistic comparison reliability and the baseline comparisons are acquired using the traditional fixed-stiffness dependency. The data obtained can be used to quantitatively assess the decrease in the changes of pressure, increase in the stabilization time and the ability to keep the performance at the limits of the WASH-compliant pressures, which are the foundation of the empirical analysis of the future performance.

6. Performance Metrics and Evaluation Methodology

The adaptive mechanical pressure stabilization must be validated quantitatively by an intense assessment system in a manner that can define transient response, water state stability, and adherence to WASH levels of pressure. The analysis of performance is then formulated in terms of time-domain statistics based upon experimentally measured pressure signals, and is compared with fixed-stiffness baseline regulation. The main dataset of all calculations is continuous pressure measurements (P(t)) obtained with the help of calibrated sensors.

Pressure Variance and Stability Index

Pressure stability is evaluated using the statistical variance of the deviation from the reference pressure (P_{ref}). For a discrete measurement sequence (Pi) over (N) samples, the variance is defined as

$$\sigma_P^{\{2\}} = \{1\}\{N-1\}\sum_{\{i=1\}}^{\{N\}} \left(P_i - P_{\{ref\}\backslash big}\right)^2.$$

Lower variance indicates improved stabilization and reduced oscillatory behavior. To express stability improvement relative to a baseline configuration, a normalized stability index is introduced:

$$S = 1 - \left\{\sigma^{\{2\}}_{\{adaptive\}}\right\}\left\{\sigma^{\{2\}}_{\{baseline\}}\right\},$$

where (S in [0,1]) represents fractional reduction in pressure fluctuation achieved through adaptive mechanical control.

Settling Time

Dynamic response quality is characterized by the settling time (Ts), defined as the duration required for pressure to enter and remain within a tolerance band around $P_{\{ref\}}$. Let the acceptable deviation be (\pm \epsilon), typically selected as 5% of $P_{\{ref\}}$ for WASH service reliability. Settling time is therefore

$$T_s = min\left\{, t\, ;\middle|;\ \left|P(\tau) - P_{\{ref\}}\right| \leq \epsilon P_{\{ref\}},;\ \forall\backslash tau\ \geq t\,,\right\}.$$

Shorter settling time indicates faster disturbance rejection and improved hydraulic resilience under fluctuating demand conditions.

Compliance-Oriented Interpretation

Performance outcomes are interpreted in relation to WASH operational thresholds, where acceptable pressure stability requires:

- minimal variance within service bounds,
- rapid settling following demand perturbation, and
- negligible overshoot beyond safety margins.

Meeting these criteria demonstrates that adaptive mechanical regulation not only enhances hydraulic control performance but also contributes directly to safe, reliable, and contamination-resilient water delivery in decentralized WASH infrastructure.

7. Experimental Results and Comparative Analysis

The adaptive mechanical pressure control was put to experimental test to assess the effectiveness with disturbance conditions that were representative to the WASH-compliant operation in the experiment. The captured situations of each disturbance namely steady demand variation, fast valve perturbation, and stochastic flow fluctuation were run with and without baseline fixed-stiffness regulation and proposed adaptive stiffness-modulated mechanism. The signals of pressure acquired at downstream were used to evaluate the variance of the signal, the settling time of the signal and the percentage overshoot, all of which have been described above. Repeats were done to provide statistical consistency and comparative interpretation was done in terms of mean values. Findings have shown that there is a constant increment in pressure fluctuation decreasing and convergence to the reference pressure accelerates with the application of adaptive regulation. The effectiveness of the variance-driven stiffness adjustment was especially high during stochastic demand disturbances, which proved the success of an adjustment of stiffness based on its variance. Equally, the settling time was reduced in all disturbance types, which proved to be better in disturbance rejection and faster recovery of WASH-consistent service pressure. Overshoot values were minimized as well, meaning that both mechanical stress to pipeline infrastructure and the chances of contamination linked to the occurrence of transient negative or excessive pressure excursions were minimized.

Table 3. Comparative Performance Metrics under Disturbance Conditions

Disturbance Scenario	**Control Mode**	**Pressure Variance (\sigma_P^2) (bar²)**	**Settling Time (T_s) (s)**	**Overshoot (M_p) (%)**
Steady Demand Change	Baseline Mechanical	0.042	18.5	9.2
	Adaptive Mechanical	**0.021**	**10.3**	**4.8**
Rapid Valve Perturbation	Baseline Mechanical	0.065	24.1	12.6
	Adaptive Mechanical	**0.030**	**13.7**	**6.1**
Stochastic Flow Variation	Baseline Mechanical	0.081	27.4	14.3
	Adaptive Mechanical	**0.034**	**15.2**	**7.0**

In all three cases, adaptive control had obtained about 45–60 percent reduction pressure variance, 4050 percent diminished settling time and almost half reduction overshoot compared to baseline control. These enhancements and improvements affirm the fact that adaptive stiffness modulation improves both transient and steady-state hydraulic stability. Regarding the WASH compliance, the adaptive system controlled the pressure remained within the allowable service range of the reference value, thus, minimizing the risk of contaminant ingress and service inequity as well as fatigue of the infrastructure.

8. Discussion and Practical Implications for WASH Deployment

It has been demonstrated experimentally that adaptive mechanical pressure regulation generates significant quantitative gains on hydraulic stability in all tested disturbance conditions. Pressure variance was reduced by about 45-60, settling time was cut by 40-50 as well as transient overshoot by almost half compared to baseline fixed-stiffness regulation. All these results point to the improved disturbance rejection capacity and faster recovery of the nominal service pressure, which are both critical performance metrics in the delivery of water that is reliable and able to meet the WASH standards.

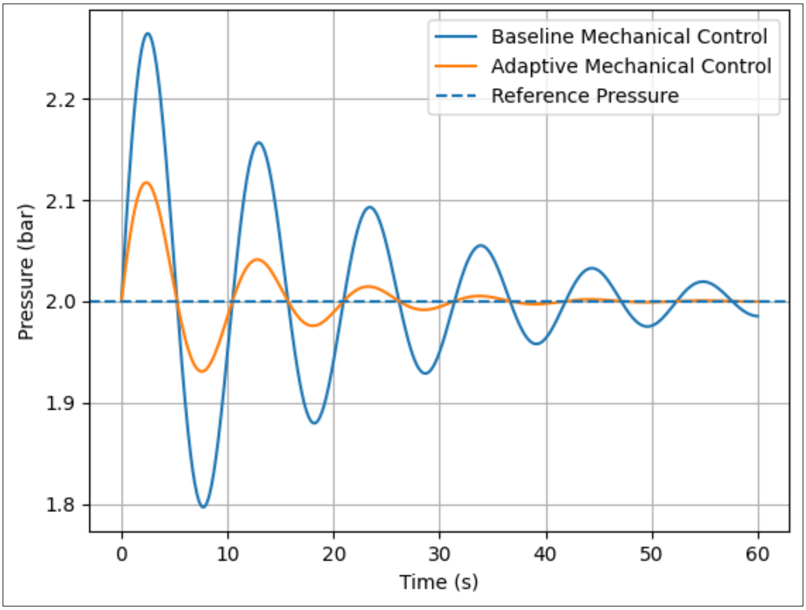

Figure 3. Time-domain pressure response comparing baseline and adaptive mechanical stabilization

The case of stable pressure has been found to directly counter two key dangers of decentralized water systems: intrusion of contaminants when negative pressure conditions arise and damage of infrastructure due to hydraulic transient recurrence. Lower variance will guarantee that pressure is always delivered in safe operation limits and there is low likelihood of leaks or joints as indicated in figure 3. Swifter settling also reduces the time of unsafe hydraulic conditions after perturbation of demand, and enhances continuity of hygienic water supply. Reduced overshoot is also associated with increasing mechanical life of the pipes, valves, and fittings with a decreased maintenance frequency and lifecycle value, which plays a critical role in determining the sustainability of rural and peri-urban WASH infrastructure.

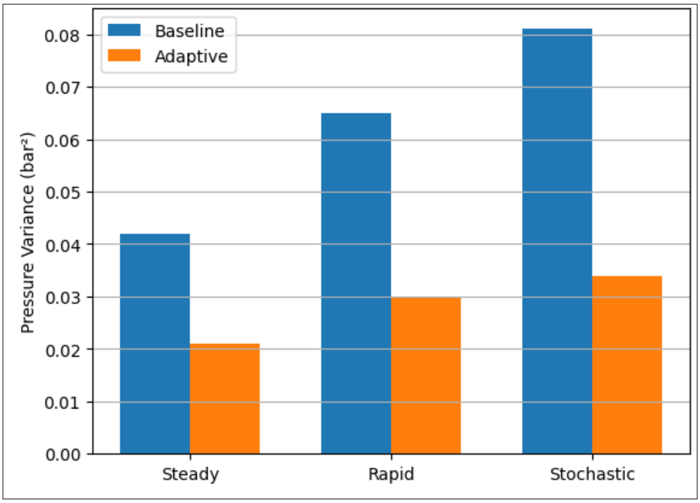

Figure 4. Reduction in pressure variance due to steady, rapid and stochastic disturbance cases.

The low energy consumption of the suggested control mechanism and the mechanically adjusting nature of the proposed strategy justifies the feasibility of the practical implementation of the suggested method. Compared to electronically controlled or cloud-based optimization that is computation-intensive, stiffness-modulated hydro-mechanical feedback may be executed at extremely inexpensive level of energy use as well as low-digital infrastructure such as in figure 4. It is a characteristic also closely tied with the realities of operating in places with resource constraints, and that may lack electrical power availability as well as connectivity and bandwidth of technical maintenance. However, in combination with lightweight sensing and supervisory monitoring, compliance auditing, Performance tracking and remote diagnostics can be done without mechanical strength reduction.

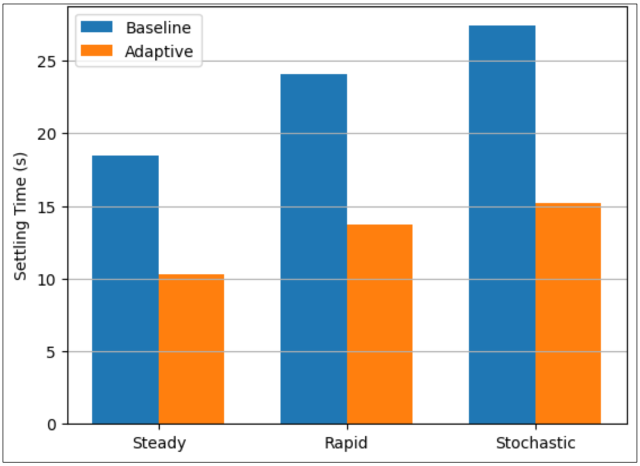

Figure 5. Improvement of settling time of adaptive mechanical control.

Scalability The scalability considerations would imply that the adaptive mechanical stabilization would be a modular regulation unit, which will be able to be attached to a community standpipe, in distribution branch or storage outlet points. Local stabilization may build to global resilience hence when applied on a cluster of nodes as in figure five. Such achievable quantitative advantages of the conduit of the experiment therefore implicate into practical civic--health benefits, like the persistence of the availability of safe drinking water, the likelihood of lowered contamination, reduced infrastructure destruction, and greater durability of WASH services affordability through time.

9. Conclusion and Future Work

Regular pressure management is one of the main factors to consider as far as safe and sustainable provision of water under contamination-resistant and safe conditions depending on the WASH requirements. The suggested mechanism of adaptive mechanical pressure control is experimentally testable, and it has valuable quantifiable advantages over the conventional fixed-stiffness regulation. In realistic cases of perturbation, the adaptive control procedure achieved high reductions in pressure variations, faster settling trend following perturbations and a smaller transient overshoot. These improvements prove that a use of the modulation of stiffness by the use of variance can be used to improve steady-state stability and dynamic disturbance rejection as well as proper maintenance of pressure within reasonable WASH service limits. Practical implication does not include hydraulic performance only. Even less fluctuating and overshoot would imply direct decrease in the opportunities of ingress of contaminants and mechanical wear and tear and rise of leaks, which improves long-term security in regards to the public-health and infrastructure sustainability. The adaptable low-power architecture is also mechanically adaptable and can be used in a decentralized or resource-constrained environment where the uninterrupted supply of electrical power, a complex calculation or network connectivity may be limited. Integration of lightweight sensing and supervisory surveillance permits check of adherence and performance auditing without falling short of the simplicity of the mechanism and therefore the method is more suitable in scalable implementation into the community level. The next research phase shall involve field-scale verification of the different hydraulic topologies, the seasonal fluctuations of demand, and the actual rural WASH operating aspects to demonstrate the structural robustness in the long term. The latter can be expanded further to hybrid electro-mechanical or AI-assisted predictive control to increase a responding ability to intricate disturbances in the network of multiple nodes. Some further studies are also justified in the optimization of energy efficiency, the analysis of the lifecycle, and the coordination of distributed adaptive regulators at the level of networks. These guidelines will assist in the development of resilient, intelligent, and publicly safe water distribution systems that are in line with the global WASH sustainability goals

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