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IoT Based System for Sewage Overflow Prevention using Heterogeneous Communication Networks

Kanchana Rajaram*, Mirnalinee, T.T. and Felix Enigo V.S.
Department of CSE, Sri Sivasubramaniya Nadar College of Engineering, Chennai, Tamil Nadu, India
✉ rkanch@ssn.edu.in

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Abstract: The increasing population along with water scarcity give rise to water management practices. Water scarcity can be eradicated by wastewater treatment that would in turn prevent contamination of water bodies. One of the challenges in wastewater treatment is to efficiently transport and treat the sewage in a Sewage Treatment Plant (STP). Most of the existing STPs in closed campuses of Indian scenarios such as academic institutions, industries, and residential apartments employ several pumping stations in a campus and pump motors in each station that pump sewage to STP for treatment. Manual operation of such motors would lead to sump overflows that negatively impact public health and sanitation. Therefore, an IoT-based system for monitoring and controlling sewage flow is proposed in this paper that uses water level sensors and prevents sewage overflows in pumping station sumps, resulting in the utilisation of all the collected sewage for treatment. Since each campus might have different communication networks such as GPRS, WiFi, RF, or Ethernet, the proposed system is designed to work with any network. The proposed system was tested in the college campus with three pumping stations. Moreover, a test bed was simulated and tested with 100 pumping stations. It is observed that the proposed approach prevents sewage overflows in various scenarios with different constraints.

Key words: IoT, sewage treatment plant, sewage overflows, communication networks, cloud storage, gateway.

Introduction

Prevailing water scarcity due to increased population can be addressed by managing and treating wastewater. Wastewater treatment also prevents contamination of water bodies. An analysis of the CMWSSB helpline reported by Christian (2013) shows that more than 82% of the 78,027 people who called the utility to register complaints in 2012-2013, reported sewage problems. Since sewage overflows negatively impact public health and sanitation, automated control systems must be in place, to prevent sewage overflows in pumping station sumps and reduce manpower.

In producing more volume of treated water, the pumping stations in the sewerage system play a key role. Currently, in Indian cities, the pumps are operated without any global consideration of the capacity of the treatment plant. This causes inefficient utilisation of the infrastructure. Inefficient operation of the pumping stations reduces the efficiency of the STPs due to the non-optimum supply of sewage water. Hence, efficient control of sewage flow from pumping stations is critical to producing more volume of treated water and thus reducing water scarcity.

Automating and controlling the operations of pump motors in the existing STPs of Indian scenarios such as academic institutions, industries, and residential apartments require considering more constraints due to the lack of infrastructure and quality. Hence, the automated solutions for controlling sewage flow in

*Corresponding Author

abroad scenarios cannot be adapted to automating the existing sewerage systems in the above Indian scenarios. The Internet of Things (IoT) is an emerging technology that plays a major role in establishing a smart city wherein sensors communicate with each other via the internet and automatically control their functioning. Though a few automated STPs exist in foreign countries (Denis and Igor, 2013; Rishabh, 2013), none of the Indian cities adapt IoT technology for automating STP operations.

The motivations behind this research work are:

- To reduce the possibility of human errors affecting the operation of the sewage system.
- To prevent sump overflows in the context of health hazards and water scarcity.
- None of the existing systems has been implemented to suit Indian scenarios.

Therefore, an **I**oT-based **S**ystem for **S**ewage Overflow **P**revention (**IS2P**) is proposed that automates the pumping of sewage from the pumping stations to the sewage treatment plants based on various constraints including sump water level. Since each campus might have different communication networks, the proposed IS2P approach supports communication across different networks such as GPRS, WiFi, RF, or Ethernet.

Related Work

A semi-automated STP involves automated sewage treatment and manual control of the equipment. Automated water treatment solutions are based on expert systems and wireless technologies (Bouza-Fernandez, 2010a; Denis and Igor, 2013; Rishabh, 2013). An automated STP based on Supervisory Control and Data Acquisition System (SCADA) automates the control process by supervising water levels in multiple pumping station sumps and switching off the pumps when the water level reaches the maximum (Rishabh et al., 2013). However, this system does not consider the water level at the STP tank. Another work based on an expert system with SCADA (Bouza-Fernandez, 2010a) considers sewage from the wood industry for control and supervision of the actuators. Remote monitoring of urban sewage treatment (Zhen and Jiacun, 2008) is realised using Controller Area Network (CAN) field bus with internet technologies. However, these two works did not control or maximize the sewage flow.

A survey has been conducted (Prasad, 2016) to identify the need for wireless monitoring using Wireless Sensor Networks (WSN) for the water monitoring system. WSN and GSM-based technologies (Balaji and Ganesan, 2012) are employed for measuring quality parameters like turbidity and generating alarms whenever the value of parameters crossed the threshold. GPRS-based Zigbee sensor node is employed in each residential area so that the blockage and leakage in the sewer infrastructure can be monitored in a proactive way (Chan et al., 2012). Efficient monitoring of chemical parameter quantities in industrial sewerage was implemented with the aid of long-distance communication and dynamic routing (Xianhui, 2012). A Zigbee-based WSN involves acquiring data from the sensor node and transmitting it to the FPGA-based monitoring centre for analysis (Liting, 2009). However, all these systems do not address monitoring and controlling sewage flow.

Department of environmental protection, New York evolved a system (NYC, 2016) that combines sewer data with a geographic distribution of sewer backups and installed monitoring devices in strategic locations. However, the system does not address optimal operations of the sewerage system. An attempt to apply knowledge-based systems (Bouza-Fernandez, 2010b) does not continuously monitor the plant, with data gathered through online sensors. IoT and graph theory-based smart sewerage management systems (Saba et al., 2017) and a few third-party solutions were used for monitoring sewer levels in STP for the sewage treatment process (WIKA, 2019; Sensphone, 2019).

A real time sewage monitoring in urban regions was performed by combining IoT, embedded technology with WSN (Zhenhao, 2018). Deep Belief Networks (Harrou, 2018) were used to detect the faults in wastewater treatment plants, by extracting the features and classifying them using a support vector machine. Multi-scale optimised exponentially weighted moving average (MS-EWMA) (Imen et al., 2013) approach detected faults in the wastewater treatment plant. All these systems and techniques are not capable of controlling the sewage levels and preventing overflows. Hence in this study, we provide a solution for effective monitoring of sewage water level at STP sumps to enable generating treated water sufficiently for re-use.

Proposed System and Methodology

The automated sewage flow monitoring and controlling system IS2P consists of three components as shown in Figure 1, namely, sensor nodes, a cloud server, and an emulated IoT gateway. Each sensor node involves an array of four float sensors, a microcontroller for data acquisition, and a communication modem. The sensor

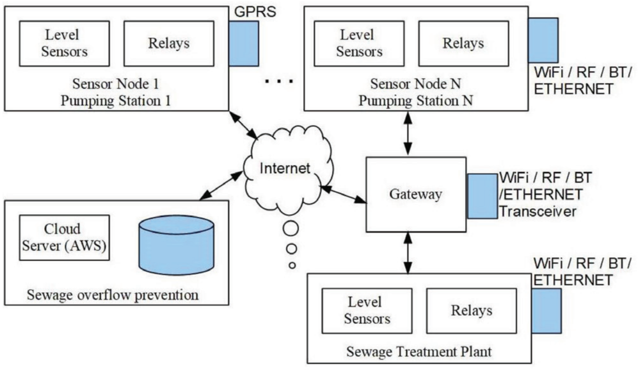

Figure 1: IoT based sewage flow monitoring and controlling system.

node has a PImv 3.0 motherboard, RS232 and USB communication ports, and a 0.8 inch LED display as shown in Figure 2. The microcontroller in the sensor node receives sensor data and sends it through a communication network to a gateway, receiving commands to operate a RELAY switch through a communication transceiver. Four float sensors are installed in four levels of the sump to determine the sewage level. These sensors are physically connected to a sensor node. The transmitted data consists of the sensor node identifier followed by level sensor inputs. The format of the data frame transmitted is shown in Table 1a. The sensor nodes are configured with a sampling interval to sense the sewage level data periodically. Depending on the sewage level data received, the controlling logic in the cloud server sends ON or OFF commands to the RELAYs in the sensor node. The format of the received data frame is shown in Table 1b.

The sensor node can communicate the data through various modes of communication such as GPRS, WiFi, Bluetooth, Ethernet, and RF to an IoT gateway. Since the hardware of the IoT gateway is expensive, it is emulated (Kanchana and Susanth, 2017) in the local computer to receive sensor data in one of these communication modes and to send it to a cloud server via the internet using WiFi or GPRS transceiver. If

(a) (b)

Figure 2: Sensor node hardware setup. (a) Front panel and a level sensor (b) Internal view.

Table 1: Format of input and output data frames

(a) Input data frame sent from sensor node to the gateway

Identifier	*Level sensor input (1 byte)*					
Sensor Node ID (SNId)	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6

(b) Output data frame sent from gateway to the sensor node

Start	*Relay Command*		*End*
RELAY	Output1	Output2	T

the sensor node is enabled with GPRS connectivity, it can directly send and receive data to or from the cloud server via the cellular network. However, when the sensor node is enabled with other communication modes, the emulated gateway performs the required protocol conversion.

Since the proposed system, IS2P is intended for sewerage systems installed in closed campuses, the following constraints are identified in terms of maintaining the pump motors and minimizing power consumption.

1. A pump motor must operate for a minimum duration of time before it is OFF to avoid motor damage.
2. Every pump motor has a specific output flow rate and maximum running time.
3. A pump motor should not operate without water in the sump.
4. Every pump motor has a specific resting period between subsequent operations.
5. The number of pump motors that can be ON at a given point in time is limited due to power constraints.

The sewage level in each of the pumping stations and STP are sensed periodically at sampling intervals. The motor controlling algorithm shown below determines which motor should be ON and when, based on the sewage level, the priority of the sump and the above constraints.

Experimental Results and Analysis

It is necessary to prove that our IS2P system prevents sewage overflow and thus wastage of sewage as compared to the manual or traditional systems. A prototype comprising three pumping station sumps and a STP sump was built on the college campus and the overflow of sewage was observed. Four sensor nodes were installed for monitoring the sewage levels in each of the three pumping stations and in the STP.

Algorithm 1. *Sewage Overflow Prevention*

```
Input:
SamplingInt,                        // Sampling Interval
PumpingStation{
        SNId,                       // Sensor node ID
        PsPriority,                 // Pumping Station (PS) priority
        PsONStat,                   // PS status when ON (LOCK or UNLOCK)
        PsStat,                     // PS status - ON/OFF/Available
        PumpID,                     //Pump motor ID
        PsWL,                       // PSsewage level
        PsMTTE                      // Minimum time for the sump to become empty
        PsCapacity,                 // sump capacity
        PsOFFat,                    // Time at which Pump motor was switched OFF
        PsONat,                     // Time at which Pump motor was switched ON
        }PS[n],
Motor{
        MotorRating,                // Pump motor's rating
        MinRunTime,                 // Minimum Running Time
        MaxRunTime                  // Maximum Running Time
        }PM[10]                     // 10 motors of different ratings
Treatment Plant{
        TpWL,                       // STP sewage level
        TpStat                      // STP status - ON/OFF
}TP,
NumPSON                             // Number of motors that can be ON at a time

Output: Updated status of TP and PS[ ]   // Pump motors that should be ON
1.  if TP.TpWL== 4 then
        TP.TpStat ← OFF
        Generate alert                      // Critical level
else
        TP.TpStat ← ON
2.  for every pumping station PSi do
        2.1 PSi.PsWL ←PSSensorInput[PSi.SNId]
        2.2 PSi.PsMTTE← ((PSi.PsWL/5) * PSi.PsCapacity) / PM[PSi.PumpID].MotorRating
        2.3 if PSi.PsStat == OFF then       // Cooling Period=Running Duration/5
                            // Resting time = time elapsed after motor is switched OFF
                If (PSi.PsMTTE>PM[PSi.PumpID].MinRunTime) AND
                 (SYSTIME - PSi.PsOFFat>PSi.PsOFFat -PSi.PsONat /5) then
                        PSi.PsStat ← AVAILABLE

// Monitoring sewage levels and operating motors
3.  if TP.TPStat == OFF then                // STP sump is full
        for each PumpingStation, I where PsStat=ON do
                PSi.PsOFFat ← SYSTIME
                PSi.PsStat ← OFF
 elsefor each PumpingStation, I where PsStat=ON do      // STP sump is not full
        // if motor has run for minimum duration, it can be switched off
```

```
        if (SYSTIME - PSi.PsONat) >= PM[I.PumpID].MinRunTime then
                PSi.PsONStat ← UNLOCK
        // Ensure motor does not run beyond max duration or when the sump is empty
        if PSi.PsONStat==UNLOCK then
        if ((SYSTIME - I.PsONat) >PM[PSi.PumpID].MaxRunTimeOR
        PSi.PsMTTE<SamplingInt) then
                        PSi.PsONStat ← LOCK
                        PSi.PsStat ← OFF
                        PSi.PsOFFat ← SYSTIME
// Finding out which motor should be ON
    Queue ← Pumping stations with PsONStat = AVAILABLE, sorted in desc
                order of PsWL, PsPriority, and PsMTTE
    if number of Pumping Stations with (PsONStat= ON)<NumPSONthen // Slot free
        // Switch ON & update parameters
        PSi ← Queue[front]
        PSi.PsONat ← SYSTIME
        PSi.PsStat ← ON
        PSi.PsONStat ← LOCK
    for each Pumping Station PSi where PsStat=ON do
        if PSi.PsONStat == UNLOCK ANDPSi.PsWL<Queue[front].PsWLthen
                // if queued sump has higher water level than I, swap
                PSi.PsStat ← OFF
                PSi.PsOFFat ← SYSTIME
                PSj ← Queue[front]
                PSj.IOnAt ← SYSTIME
                PSj.PsStat ← ON
                PSj.PsONStat ← LOCK
```

Experiment 1: Operating Motors in a Round-Robin Fashion

First, the experiment was performed by manually operating the pump motors in a round-robin fashion periodically every 12 minutes and then every 1.30 hours. It is assumed that only one motor can be ON on the campus, at any time. When the motors were operated every 12 minutes, they were switched ON and OFF several times, irrespective of the incoming sewage flow as seen in Figure 3. Though this method provides the simplest solution, it consumes more power and the motors' lifetime reduces drastically. However, with longer intervals of 1.30 hours, sumps reach overflow states (level 4) quickly resulting in the wastage of sewage as shown in Figure 4.

Experiment 2: Operating Motors Based on Incoming Sewage Flow

Each pumping station is assigned a priority based on its sewage inflow and sump capacity. This experiment aims to operate the sump motors based on their priority. From Figure 5, it is observed that the pumping stations never reached level 4 and there was no sewage overflow.

Experiment 3: IS2P-Based Controlling of Motors

Experiment 3 involves operating the pump motors based on sewage level, priority and constraints identified in Section: Proposed System and Methodology. The sewage levels in the pumping station sumps were monitored for about one day and shown in Figure 6. It is observed that the sewage level did not raise to level 4 and there was no overflow. Therefore, the proposed IS2P approach is verified to prevent sewage overflow.

Scalability Testing

The sewage system is simulated with different scenarios involving constraints discussed in Section: Proposed System and Methodology to ensure the absence of overflows and to enable scalability testing. The parameters such as the number of pumping stations, pump motor rating, the motor's minimum and maximum running time, and sump capacity were suitably initialised. The minimum time to empty a sump is calculated based on the sump capacity and incoming flow. The resting time of any pump motor after it is switched OFF was calculated based on the motor rating. The simulator was run by varying the number

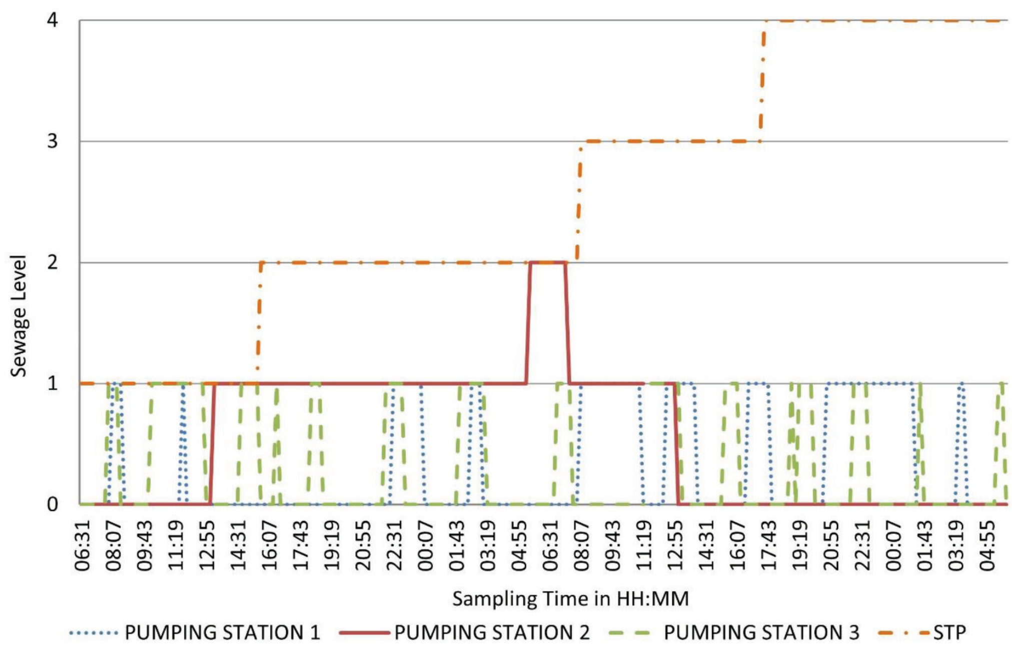

Figure 3: Sewage levels when operating pump motors in round robin fashion, every 12 minutes.

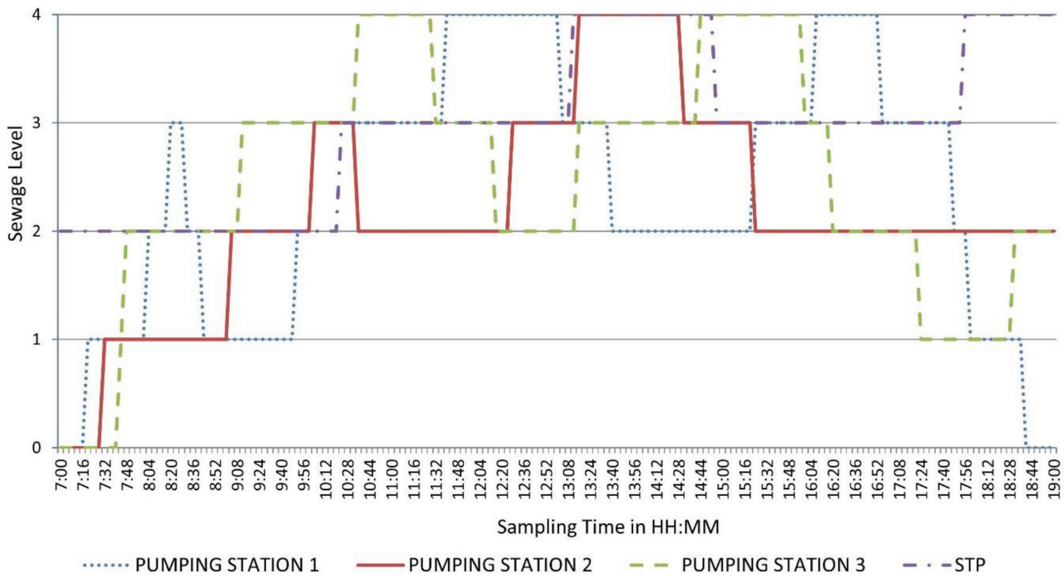

Figure 4: Sewage levels when operating pump motors in round robin fashion, every 1:30 hours.

of pumping stations from 4 to 100 under all possible scenarios. To start with, the simulation was run with 4 pumping stations. The communication modes assumed for sensor nodes in each of the pumping stations and the priority assigned to the pumping stations are shown in Table 2. The working of the proposed algorithm under different scenarios was captured in Table 3, Scenarios S1 to S5 show the operations of motors by checking the sewage level, the constraints on MTTE, minimum and maximum running time and resting time of motors, and the priority of pumping stations. The last scenario shows the motor operations when the treatment plant sump is full. It is assumed that at a given point in time, 2 pump motors alone can be switched ON. It was observed that the sewage level did not raise to level 4 in any of the pumping stations, which indicates that the proposed algorithm prevents overflow of sewage. Further, it is verified that the proposed algorithm is robust with 100 pumping stations preventing the sewage from reaching level 4.

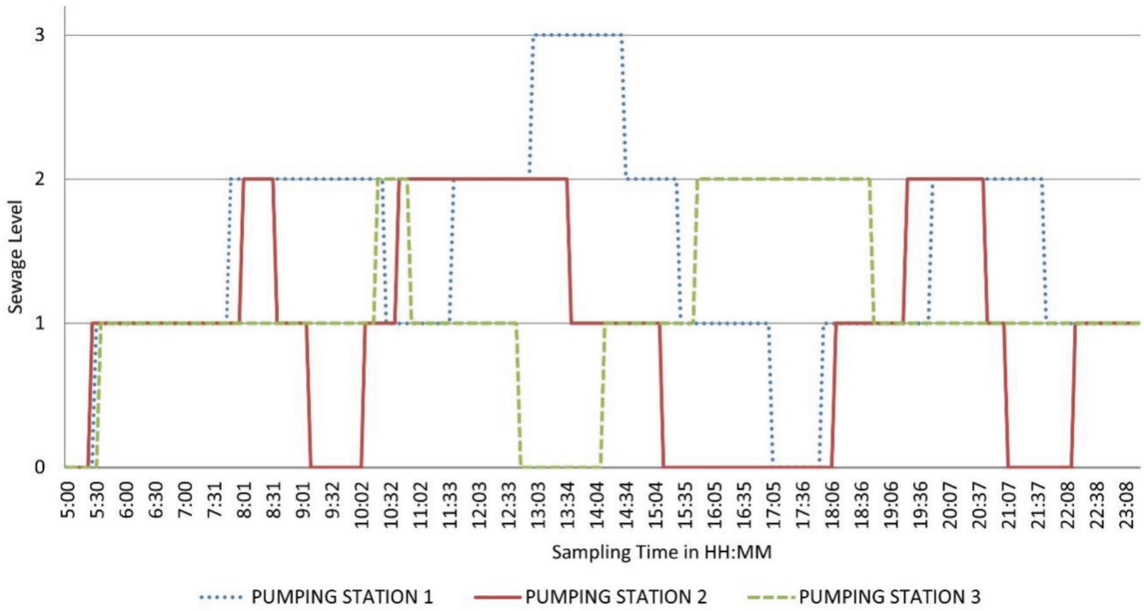

Figure 5: Sewage levels while controlling pump motors based on sewage level and priority.

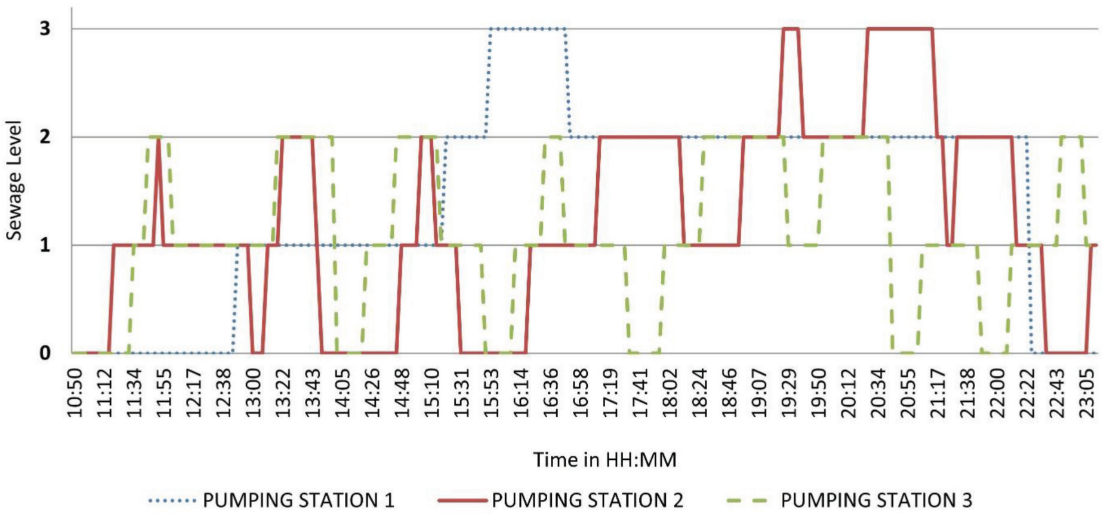

Figure 6: Sewage levels with automated controlling of motors based on sewage level, priority and constraints.

Table 2: Configuration of communication mode and priority of sensor nodes

Sensor node ID	*Communication mode of the sensor node*	*Pumping station priority*
1	GPRS	High
2	RF	Medium
3	WiFi	Low
4	ETHERNET	Medium
5	BLUETOOTH	High

Conclusion

The proposed approach IS2P was successfully implemented in our academic institution to control the sewage flow from the pumping station sumps to the STP sump, preventing sewage overflows. IS2P considered the sewage level in the collection sump, incoming sewage to the sump, priority of pumping stations, and various constraints on the pump motor. With three pumping stations and an STP, it was verified that IS2P prevents sewage overflows by automating pump motor

Table 3: Operation of pump motors by IS2P approach under the simulated scenarios*

Scenario		*Pumping Stations (PS)*				*STP Motor Status*	*Explanation*
		PS1	*PS2*	*PS3*	*PS4*		
S1	I	X	X	X	X	ON	Though PS2 is at level 1, it is not switched on as MTTE <MinRT (Minimum Running Time)
	L	0	1 MTTE <MinRT	0	0		
	O	OFF	OFF	OFF	OFF		
S2	I	X	X	X	X	ON	PS2 has highest water level, hence, ON. Between PS 1, 3 & 4, PS 1 has highest priority; hence, ON
	L	1 MTTE >MinRT	2 MTTE >MinRT	1 MTTE >MinRT	1 MTTE >MinRT		
	O	ON	ON	OFF	OFF		
S3	I	ON	X	X	X	ON	PS1 has exceeded its MRT, so OFF. PS 2 has highest water level, hence ON. Between PS 3 & 4, PS 4 has higher priority, hence ON
	L	1 MTTE >MinRT RD >MaxRT	2 MTTE >MinRT	1 MTTE >MinRT	1 MTTE >MinRT		
	O	OFF	ON	OFF	ON		
S4	I	X	OFF	X	X	ON	PS2 is not available as the motor's resting time has not elapsed. Between PS 1, 3 & 4, PS 1 & 4 with higher priorities are ON
	L	1 MTTE >MinRT	2 MTTE >MinRT; Resting Time <CoolingTime	1 MTTE >MinRT	1 MTTE >MinRT		
	O	ON	OFF	OFF	ON		
S5	I	X	X	X	X	ON	PS 2 is not switched ON as MTTE<MinRT, PS 3 with higher water level switched ON. PS 1 has higher priority than PS 4; hence ON.
	L	1 MTTE >MinRT	1 MTTE <MinRT	2 MTTE >MinRT	1 MTTE >MinRT		
	O	ON	OFF	ON	OFF		
S6	I	X	X	X	X	OFF	Since TP is full, Switch OFF
	L	3 MTTE <MinRT	3 MTTE <MinRT	3 MTTE <MinRT	3 MTTE <MinRT		
	O	OFF	OFF	OFF	OFF		

* I: Input status of pump motors.
L: Sewage level and constraints.
O: Observed output status of pump motors
X: Don't care

operations and the sewage level did not raise to level 4. IS2P accommodates five different communication modes of the sensor node. Based on the availability of the network and the communication mode near the pumping station, the sensor node with the respective modem was installed in the pumping station.

A test bed was simulated with four pumping stations and the STP. All possible scenarios with respect to sewage level and constraints were simulated and it was verified that the proposed approach prevents sewage overflows. Furthermore, simulation experiments were repeated by varying the number of pumping stations from 4 to 100 and the scalability of the proposed approach was also verified. The automated operations of the pump motor have resulted in a smart sewage collection system that maximises the sewage and thus treated water. As a future work, the priority of each pumping station can be determined dynamically, based on varying incoming sewage flows. Further, issues like finding the pumping station from where the maximum sewage has been collected, etc., can be analysed.

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