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Design and Implementation of Wireless Sensor Network for Monitoring and Controlling of Filter Backflush in Drip Irrigation System

Damla Sulama Sistemlerinde Geri Yıkamanın İzlenmesi ve Kontrolü için Kablosuz Sensör Ağı Tasarımı ve Uygulaması

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Key Words:

Drip irrigation, filtration, backflush, wireless sensor network, mobile application

ABSTRACT

Objective: Aim of this research was to design, prototype development and implement a wireless sensor network, which can provide data monitoring and enable the control of backflush in a drip irrigation system filtration unit equipped with four pairs of sand media and disc filter.

Material and Methods: Hardware material of the WSN consisted of a filtration control node (FCN), a coordinator and a GSM modem. Backflush was monitored and controlled by FCN. Firmware of the FCN and GSM modem, server-side communication, web based used interface and mobile application developed by ARM Mbed OS 2.0 with C/C++, Python 2.7, Node.js, Socket.IO, Javascript, HTML, CSS and Android Studio. Proposed system was tested in an agriculture enterprise in Salihli – Manisa.

Results: Backflush algorithm, web user interface and mobile application was presented. Filters were backflushed 70 times during the test period of 20 days. Backflush was initiated by the ΔP, periodic and manual control 34, 28 and 8 times, respectively. Backflush was more frequent as total water volume between two backflushes was lower than 72 m^3 for the first 15 backflushes which correspond to first two days of test. The results showed that, under the test conditions, the drip irrigation system was reached to stabilized operating conditions due to sufficient backflush duration after first 4 days of test.

Conclusion: Implemented wireless sensor network can provide efficient monitoring and control of backflush. Besides it can increase the performance of the drip irrigation system with providing more stable operating conditions and better water distribution.

Anahtar Sözcükler:

Damla sulama, filtrasyon, geri yıkama, kablosuz sensör ağı, mobil uygulama

ÖZ

Amaç: Bu araştırmada 4 kum-çakıl ve disk filtre çiftinden oluşan dama sulama sistemi filtrasyon ünitesinde geri yıkamanın kontrol edilmesini ve izlenmesini sağlayacak bir kablosuz sensor ağının tasarımı, prototiplemesi ve uygulaması amaçlanmıştır.

Materyal ve Metot: Araştırmanın donanım materyalini filtrasyon kontrol düğüm noktası (FCN), koordinatör ve GSM modem oluşturmaktadır. Geri yıkama FCN tarafından izlenmiş ve kontrol edilmiştir. FCN, GSM modem, sunucu tarafı haberleşmesi, web kullanıcı arayüzü ve mobil uygulama ARM Mbed OS 2.0 (C/C++), Python 2.7, Node.js, Socket.IO, Javascript, HTML, CSS ve Android Studio aracılığıyla hazırlanmıştır. Oluşturulan sistem Salihli – Manisa'da kurulu bir tarım işletmesinde test edilmiştir.

Bulgular: Geri yıkama algoritması, web kullanıcı arayüzü ve mobil uygulama sunulmuştur. 20 günlük test süresi boyunca filtreler 70 kez yıkanmıştır. Geri yıkama ΔP, periyodik ve elle olmak üzere 34, 28 ve 8 kez başlatılmıştır. Testin ilk iki gününde daha sık geri yıkama gözlemlenmiş ve bu süreçte iki geri yıkama arasında geçen su hacmi 72 m^3'den daha az bulunmuştur. Sonuçlar, test koşullarında, ilk 4 gün sonrasında, seçilen geri yıkama süresinin damla sulama sistemini stabil çalışma koşuluna ulaştırdığını göstermiştir.

Sonuç: Uygulamaya aktarılan kablosuz sensor ağı ile geri yıkama etkin şekilde izlenip kontrol edilebilmiştir. Sistem, daha stabil çalışma koşullarının oluşması ve daha iyi su dağıtımı sağlanarak sistemin performansının arttırılmasına katkıda bulunabilir.

INTRODUCTION

Dripper/emitter clogging is serious problem in drip irrigation systems especially in low water quality conditions (Bucks et al., 1979; Nakayama and Bucks, 1991, Ravina et al., 1997), since reduction in flow-rate negatively affects uniform water distribution and consequently lead to failure of drip irrigation (Nakayama and Bucks, 1991; Ravina et al., 1992; Tajrishy et al., 1994; Li et al., 2009). The main causes of emitter clogging originate from physical, chemical and biological factors (Nakayama and Bucks, 1991). Therefore, a filtration system is compulsory for all drip irrigation systems (Ravina et al., 1992, Bulancak et al., 2006).

Sand media filters are most common filter type used in drip irrigation particularly irrigating with low quality water (Ravina et al., 1997; Puig-Bargués et al., 2005; Burt and Styles, 2007; Capra and Scicolone, 2007). Performance of sand media filters decreases in time due to suspended materials. Backwashing is the critical and unavoidable operation to refresh the performance of sand media filters (Nakayama et al., 2007).

Backwashing is the operation of reversing (upward) the direction of water flow in filter tank (Haman et al., 2003). If sand media filters are not backwashing frequently or backwashing interval or duration is insufficient, irrigation system performance can decrease (Enciso-Medina et al., 2011). Backwashing can be controlled by pressure loss (pressure differential, ΔP) and/or by prescheduled intervals (Haman et al., 2003; Nakayama et al., 2007). When low quality water is used, it is required to use automatic cleaning devices since frequent backwashing is needed. With the frequent backwashing controlled by the pressure differential, pressure stabilization in the irrigation system is provided and system uniformity and efficiency are maintained (Haman et al., 2003; Burt, 2010).

Information and communication technologies (ICT) have shown rapid advancements in recent years. Because of this development, new technologies, solutions and services found large application areas (Ojha et al., 2015). The use of wireless sensor networks, as a branch of ICT, in agricultural domain are becoming more popular (Wang et al., 2006; Lea-Cox, 2012; ur-Rehman et al., 2014; Işık et al., 2017).

A wireless sensor network consists of nodes performing sensing, communication and computation operations. A node can act as source, sink or router node. Source nodes collect and send information, sink nodes gather information and routers nodes divert information to other nodes. (ur-Rehman et al., 2014). Since the source nodes are the main sensing point of the network, they include a microcontroller, radio module (communication module), sensor/actuator module and power module.

In recent years, some control devices and self-cleaning filters and control mechanisms (Smith et al., 2005; Jian and Chuan-xiang, 2006; Smith et al., 2006; Duran-Ros et al., 2008; Xiang et al., 2009; Quan-li et al., 2010; Earl, 2011; Liu et al., 2012; Duran-Ros et al., 2014) developed for the backflushing of filters. In general, filter backflush is initiated when the pressure difference exceeds 5 psi across the filter and backflush frequency should not exceed 30 minutes (Sanders, 1992).

The aim of this study is to design and implement an internet connected wireless sensor network providing backflush monitoring and control in filtration unit of drip irrigation system. The presented system allows real-time data and backflush monitoring, remote control and remote setup operations. It enables the monitoring of collected sensor data and alarm conditions with web-based user interface or mobile application.

MATERIAL and METHOD

Wireless Sensor Network Topology

Topology of the wireless sensor network (WSN) was star network with repeater functionality operating at 868 MHz ISM band and closely related to selected radio modules. (Telit Star Network Protocol Stack User Guide, 2015).

Hardware

WSN consisted of a filtration control node (FCN), a coordinator and a GSM modem (Figure 1). Backflush was monitored and controlled by FCN. FCN consist of main and sub-main hardware layers. Main hardware layer (MHL) included a 32-bit ARM microcontroller (STM32F401RE, ST Microelectronics), a short-range radio module (LE70-868, Telit), a two-wire serial eeprom (AT24C512, Atmel) for saving backflush configuration parameters, a serial TTL connection (Rx/Tx) and other electronic components such as resistors, diodes and a crystal. Sub-main hardware layer (S-MHL) included power regulation components which provided required voltage to system and sensors, a motor control IC (DRV8800, Texas Instruments) for the activation of 3-way solenoid valves and 9 GPIOs (general purpose input/output) for analog and digital sensor connections. MHL was pluggable to S-MHL with male and female row headers. Custom printed circuit and definition of GPIO's are presented in Figure 1 and Table 1, respectively.

Serial TTL connection on MHL of FCN (master) allowed the connection of other FCNs (slaves) in case of more than backflushing of 4 filters required. In this case, all monitoring and controlling mechanism would be carried out by master FCN, while slave FCNs only controls relevant 3-way solenoid valves according to received on/off control commands from master FCN over serial connection.

Energy requirement of the FCN met by mains or solar energy. To maintain the data transmission and valve operation during power cut or failure, a 12 VDC 14000 mAh gel-battery with suitable charge unit was added (Figure 2).

Coordinator (Figure 2) included a short-range radio module (LE70-868, Telit) and other electronic components. It collected the data sent by the FCN and transmitted to GSM modem over RS-232 serial connection and vice versa.

Modem hosted an embedded 3G module (HE910, Telit) (Figure 2). Similar to coordinator, it transreceived data between coordinator and Linux server with static IP.

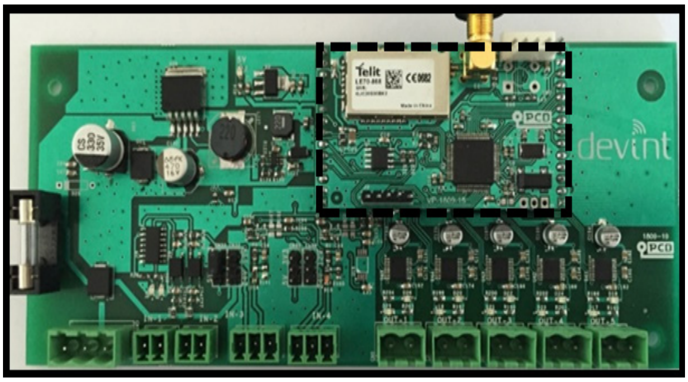

Figure 1. Main (dashed rectangle) and sub-main (solid rectangle) hardware layers of filtration control node.
Şekil 1. *Filtrasyon kontrol düğümünün ana (kesik çizgili dikdörtgen) ve alt (düz çizgili dikdörtgen) donanım katmanları.*

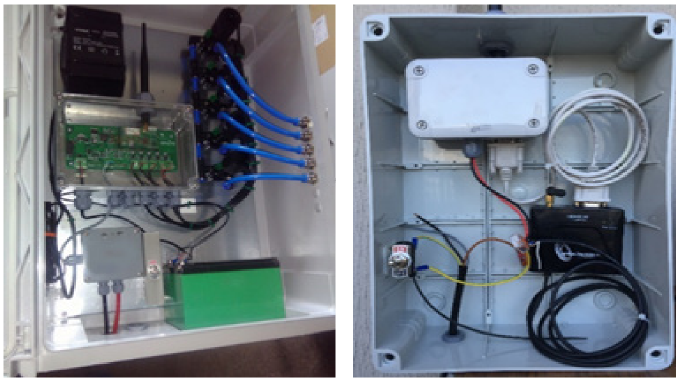

Figure 2. Filtration control node (a), with coordinator (upper-left) and GSM Modem (lower-right) (b).
Şekil 2. *Filtrasyon kontrol düğümü (a) ile koordinatör (sol üst) ve GSM modemin (sağ alt) (b) görünümü.*

Table 1. Definition of general purpose input/outputs (GPIO).
Çizelge 1. *Genel amaçlı giriş çıkış noktalarının (GPIO) tanımlamaları.*

Hardware Layer	GPIO name	Property	Supported sensor/device
Main	Serial 1	TTL Rx/Tx	Connection to slave FCNs
	IN-1	Digital input	Pulse watermeter
	IN-2	Digital input	Flow sensor
	IN-3	0-3.3 VDC analog input	Differential pressure (ΔP) sensor
	IN-4	4-20 mA analog input	Pressure sensor
Sub-main	OUT-1	12VDC output	3-way latching solenoid valve
	OUT-2	12VDC output	3-way latching solenoid valve
	OUT-3	12VDC output	3-way latching solenoid valve
	OUT-4	12VDC output	3-way latching solenoid valve
	OUT-5	12VDC output	3-way latching solenoid valve

Software

The firmware of the FCN was developed by ARM Mbed OS 2.0 with C/C++ language. For this purpose, ARM Mbed online IDE was used (https://os.mbed.com). FCN firmware allowed to change of control and monitor parameters of backflush operation that sent by server (Table 2).

The firmware of the modem was coded with Python 2.7. Connection between modem and server was established over TCP-IP socket. After successful socket connection, IMEI query was sent to modem by the server to prevent any undesired entry to system.

Modem firmware, also, checked GSM network and socket connection status with constant intervals to maintain healthy connection with server. If required, it refreshes socket connection or restarts itself.

Server-side communication with modem was developed with Node.js and Socket.IO libraries. Transmitted data and generated alarms from FCN together with predefined set commands sent to FCN by the user was recorded into MySQL database installed on Linux server with PHP.

Web based interface for user was prepared with HTML, CSS and JavaScript. DevExtreme, echarts and google materialize libraries were used for table and chart presentation of data. Backend, i.e. server connection, of this interface was prepared with PHP.

The required calculations for the data visualization for the web was implemented on RabbitMQ message broker. Thus, it was possible to carry out complex calculations and reduce the visualization response time since calculations are performed on the background and prepared for visualization before user interaction.

Mobile application for Android operating system was developed with Android Studio (Google Inc.) by using Java.

Table 2. Backflush control parameters.
Çizelge 2. *Geri yıkama kontrol parametreleri.*

	No	Parameter	Value	Field Test Value
Device Parameters	S1	Differential pressure (ΔP) sensor	Available / Not available	Available
	S2	Pressure sensor	Available / Not available	Available
	S3	Flow sensor	Available / Not available	Available
	S4	Watermeter	Available / Not available	Available
Control Parameters	S5	Total filter number	-	4
	S6	Watermeter coefficient	Liter/pulse	100 Liter/pulse
	S7	Pressure sensor max. value	Bar	16 bar
	S8	Pressure sensor type	0-3.3VDC / 4-20 mA	4-20 mA
	S9	ΔP for backflush start	Bar	1 bar
	S10	Pressure control interval	Seconds	30 seconds
	S11	Flush duration for 1 filter	Seconds	90 seconds
	S12	Wait time between 2 filter flushes	Seconds	30 seconds
	S13	Flow control latency	Seconds	20 seconds
	S14	Backflush enabled	Yes / No	Yes
	S15	Pressure sensor position	Before ΔP sensor / After ΔP sensor	Before ΔP sensor
	S16	If any error occurs	Stop backflush / Don't stop backflush	Don't stop backflush
	S17	Inlet pressure alarm high threshold	Bar	6 bar
	S18	Inlet pressure alarm low threshold	Bar	2 bar
	S19	Inlet pressure alarm	On / Off	On
	S20	ΔP alarm high threshold	Bar	1.5 bar
	S21	Sense of irrigation pressure in inlet point	Bar	1 bar
	S22	Outlet pressure for start of ΔP control	Bar	2 bar
	S23	Periodic backflush interval	Hour	4 hours
	S24	Wait time between two ΔP based backflush	Minutes	5 minutes
	S25	Automatic data transmission	On / Off	On
	S26	Data transmission interval during irrigation	Minutes	10 – 15 minutes
	S27	Data transmission interval during no-irrigation	Minutes	10 – 15 minutes

Sensors

Board mount analog sensor (SSCSHHT004BDAA3, Honeywell) was used for ΔP measurement. Following transfer function was used to calculate ΔP (Honeywell Tru-Stability Board Mount Pressure Sensors Datasheet, 2014):

$$V_o = \left(\frac{0.8 \times V_s}{P_{max} - P_{min}} \times (\Delta P - P_{min})\right) + (0.1 \times V_s)$$

Where; V_o: Output voltage of the sensor (0-3300 mV), P_{max}: Maximum ΔP value that sensor can measure (+4 bar), P_{min}: Minimum ΔP value that sensor can measure (-4 bar), Vs: Supply voltage (3300 mV), ΔP: Differential pressure (bar).

Pressure was measured with 4-20 mA two wire current loop pressure transmitter. Supply voltage of the sensor was 8-30 VDC. Pressure range was 0-16 bar. Received 4-20 mA current signal of the sensor was linearly converted and scaled (mapped) to 595.8-2978.9 mV range with following equation:

$$P = \frac{(V_a - V_{min}) \times (P_{max} - P_{min})}{(V_{max} - V_{min}) + P_{min}}$$

Where; V_a: Output voltage of the sensor (0- 3300 mV), V_{min}: Minimum voltage value (corresponding to 4 mA) that sensor can send (595.8 mV), V_{max}: Maximum voltage value (corresponding to 20 mA) that sensor can send (2978.9 mV), P_{min}: Minimum pressure that sensor can read (0 bar), P_{max}: Maximum pressure that sensor can read (defined with S7 parameter in Table 2, in this case 16 bar), P: Calculated pressure (bar).

Even though one pressure sensor could be installed, both inlet and outlet pressures could be achieved depending on the position of pressure sensor to ΔP sensor that was defined with S15 parameter in Table 2. If the pressure sensor was positioned before the ΔP sensor, measured pressure sensor value accepted as inlet pressure and outlet pressure was calculated with the following equation:

$$Outlet\ pressure = Inlet\ pressure - \Delta P$$

In the contrary, if the pressure sensor was positioned after the ΔP sensor, measured pressure sensor value accepted as outlet pressure and inlet pressure was calculated with the following equation:

$$Inlet\ pressure = Outlet\ pressure + \Delta P$$

A dry contact (1 and 0) flow sensor (Ayvaz, AK-100) was used to determine the existence of flow during backflush.

Water volume was measured with a woltman type watermeter (WS10, Alfa Su) with 100 liter/pulse. When a pulse was sent by the watermeter to MCU, an interrupt service routine (ISR) caught the incoming pulse and increased the value of water volume variable by one and multiplied the new value by watermeter coefficient defined with S6 parameter in Table 2. Each data transmission reset the value of water volume variable. The cumulative water volume was calculated by server using RabbitMQ.

Field Test

The proposed WSN was tested in walnut growing agricultural enterprise established at Salihli-Manisa between 28.04.2018 and 17.05.2018 (20 days). Total area of the enterprise was about 1000 da. 70% of the total area was drip irrigated and irrigations were carried out by the personnel of the enterprise.

Backflush of 4 sand and disc filter pair was controlled with FCN (Figure 3). Setup parameters and values for backflush control are given in Table 2. Due to head loss across the filtration unit and to prevent frequent backflushes, ΔP threshold for the initialization of backflush was selected as 1 bar. Periodic backflush interval was 4 hours. Flush duration of each filter pair was 120 seconds and total backflush duration was 480 seconds.

a b c

Figure 3. Filtration unit (a), FCN (b) and coordinator & modem point (c).
Şekil 3. *Filtrasyon ünitesi (a), FCN (b) ve koordinatör ile modem noktası (c).*

Backflush Algorithm

Developed backflush algorithm is given in Figure 4. When the FCN is powered-up, it reads current backflush control settings from eeprom (Table 2) and initializes pressure control, data transmission and periodic backflush procedures (timers and ISRs) according to pressure control (S10), data transmission (S26 and S27) and periodic backflush interval (S23) settings in Table 2. The availability of ΔP sensor, pressure sensor, flow sensor, watermeter and total filter number is also determined in initialization procedure according to values of S1, S2, S3, S4 and S5 in Table 2, respectively. After the initialization procedure, ISRs are triggered by the MCU to send data to coordinator, to check inlet, outlet and differential pressure and periodic flush interval.

Differential pressure (ΔP), manual and periodic control of backflush was implemented for backflush operation. ΔP control algorithm was prepared so that backflush operation can only be executed during irrigation and above the predefined outlet pressure. For this purpose, sense of irrigation was determined by the S21 parameter in Table 2. When the inlet pressure is above the value of S21, it is assumed that the irrigation has started. ΔP control is started only if irrigation has started and outlet pressure has reached the value of S22 parameter. Eventually, if these two conditions are met and ΔP sensor value reaches the value of S9 parameter backflush is started. The time between two consecutive ΔP controlled backflush cannot be less than the time given in S24 parameter. In manual control algorithm, backflush can be started any time during irrigation by the user. In periodic control algorithm, if the total elapsed time in irrigation period since the last ΔP, manual or periodic backflush is greater than the value of S23 parameter, system initializes a backflush. Any backflush operation resets elapsed time counter in MCU.

Backflush operation was considered as 4 phase state-machine for each filter (Figure 5). Specific alarms are sent to server to notify user in mobile application at the start and the end of irrigation and backflush (Table 3). Total backflush duration of a filter is sum of 4 phases. In the first two phase, i.e. phase 1 and 2, flush operation is executed according to S11 parameter in Table 2. In the last two phase, i.e. phase 3 and 4, flush operation is stopped according to S12 parameter in Table 2, also. Two different flow control procedures are also executed in the phase 2 and 4 during each filter backflush. In these phases, flow sensor is controlled to determine the water flow in backflush discharge line. Two different alarm conditions, namely alarm code 3 and 4, occurs if there is no water flow in phase 2 or there is water flow in phase 4 (Table 3, Figure 5). Latency of phase 2 and 4, i.e. duration of phase 1 and 3, is configured with S13 parameter in Table 2. If any alarm occurs during flow control phases (phase 2 and 4) backflush is stopped or continued relating to value of S16 parameter in Table 2.

If the ΔP value exceeds the value of S20 parameter during backflush, alarm notification with code 5 is sent to user. Occurrence of this alarm indicates the in-effectiveness of backflush operation due to low water quality and backflush duration.

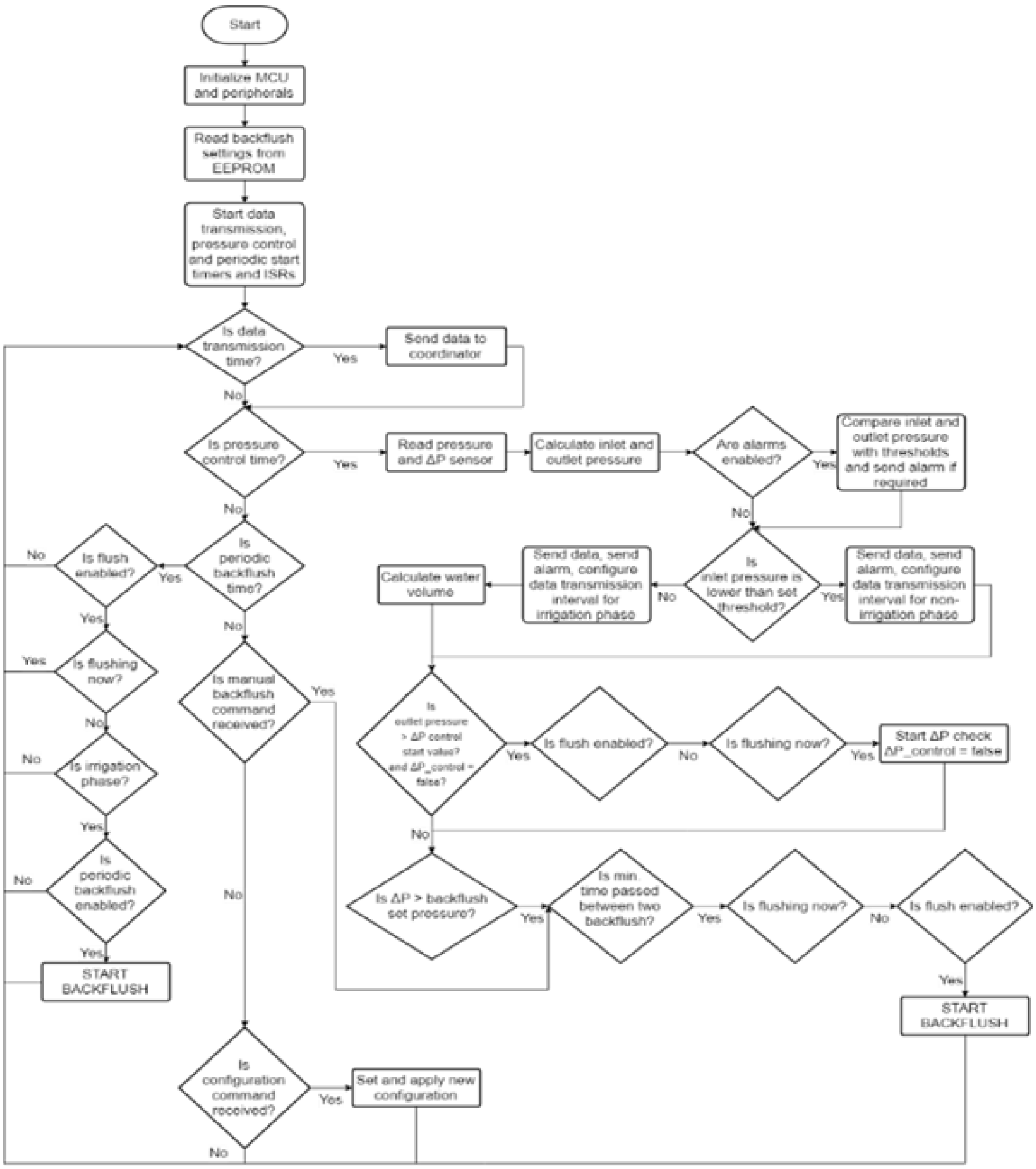

Figure 4. Backflush algorithm.
Şekil 4. *Geri yıkama algoritması.*

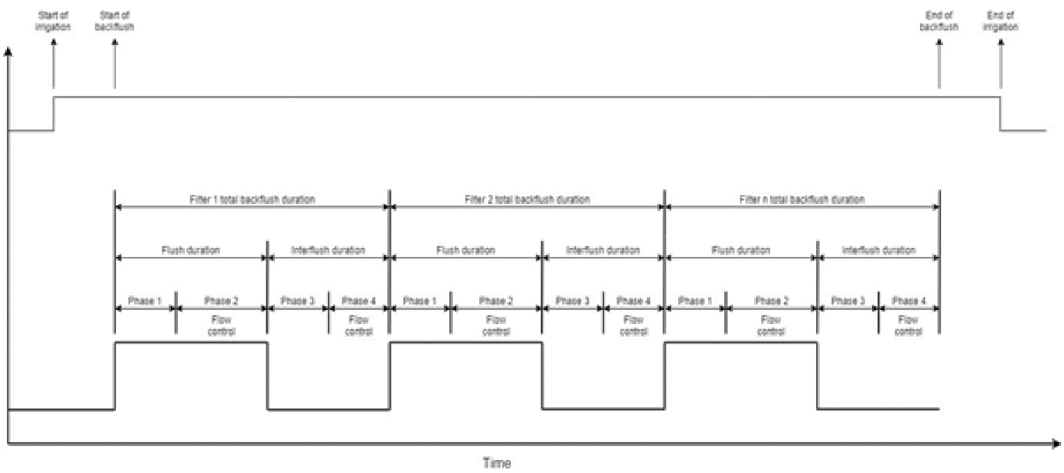

Figure 5. Backflush state machine.
Şekil 5. Geri yıkama hal makinası.

Web-based User Interface

General view of user interface (UI) is given in Figure 6. Backflush UI is divided into general information, graphic and table parts.

Backflush settings, irrigation status, total irrigation water, average flow rate and backflush numbers in the last week, in the last month and in the season is presented in general information tab. Inlet pressure, outlet pressure, ΔP and flow rate since last data transmission was shown with gauge type graphics, also.

Backflush data is grouped under 3 charts in graphic tab (Figure 7). Water volume between two backflushes and ΔP after backflush; flow rate and cumulative water volume; inlet pressure, outlet pressure and ΔP is presented in the first, second and third chart respectively (Figure 8 and 9).

Backflush data is also presented as table in the table tab (Figure 10). Moreover, user can monitor irrigation status from the irrigation status column of this table. An additional button to export all data or selected rows into excel format (.xls) is placed top of the table.

Figure 6. Web-based backflush user interface.
Şekil 6. *Web tabanlı geri yıkama kullanıcı arayüzü.*

Figure 7. Backflush graphic interface.
Şekil 7. *Geri yıkama grafik arayüzü.*

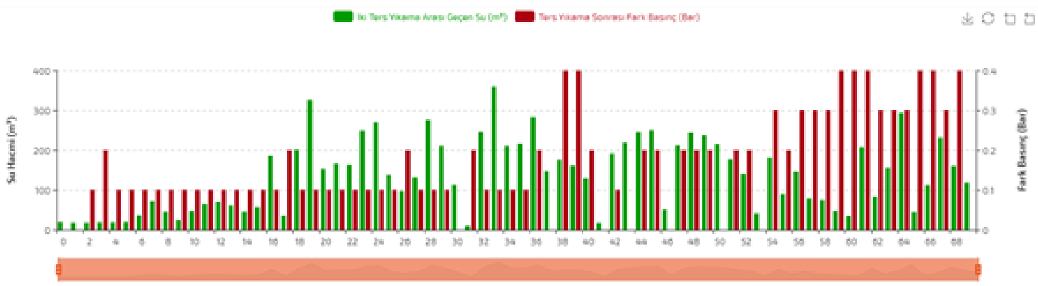

Figure 8. Water volume between two backflushes and ΔP after backflush.
Şekil 8. *İki geri yıkama arasındaki su hacmi ve yıkama sonrası ΔP.*

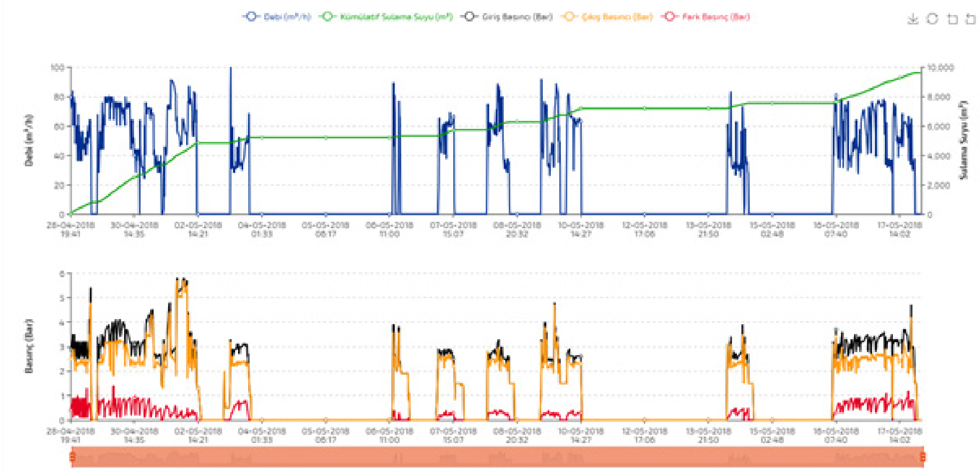

Figure 9. Flow rate, cumulative water volume and pressures.
Şekil 9. *Debi, kümülatif su hacmi ve basınçlar.*

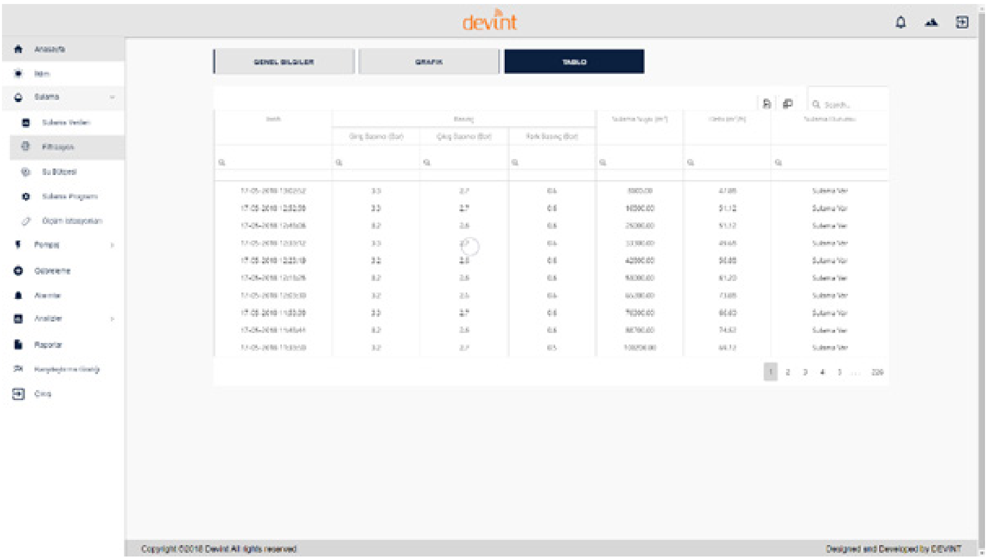

Figure 10. Table representation of backflush data.
Şekil 10. *Geri yıkama verilerinin tablo şeklinde görüntülenmesi.*

Mobile application

UI of mobile application is given in Figure 11. Inlet pressure, outlet pressure, ΔP, flow rate, irrigation-backflush status and last received data time can be monitored by the user. Values are updated automatically when a new data received or any status change in irrigation or backflush occurred. Backflush can be started manually by the user with a button, if there is no backflush at the moment and system is in irrigation phase.

Alarms

Generated alarms in FCN (Table 3) are listed as table under the alarms menu of web user interface and sent to mobile application as notification. Alarms are categorized as info, fault and critical type (Figure 12). Only the flow control alarms during backflush are categorized as critical type which means user action required as soon as possible.

Figure 11. Mobile application user interface.
Şekil 11. *Mobil uygulama kullanıcı arayüzü.*

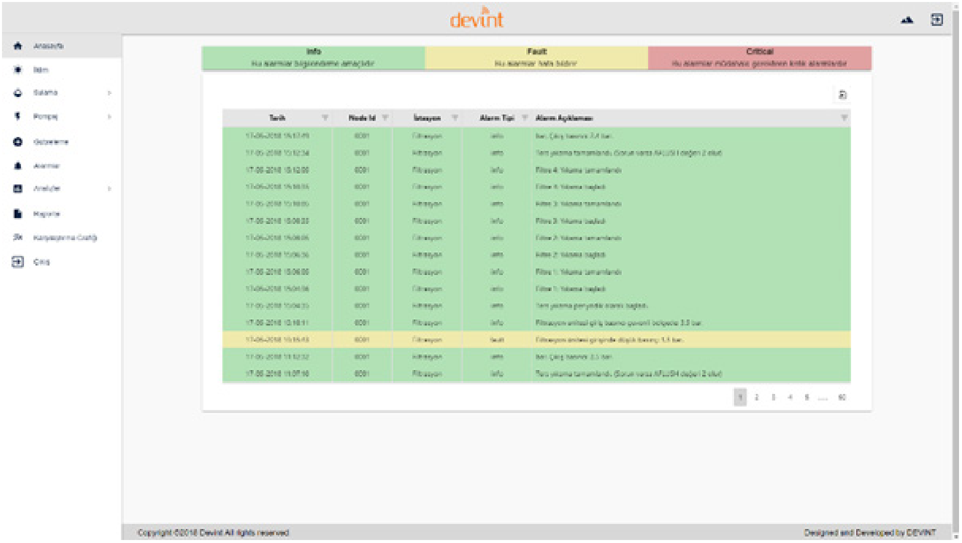

Figure 12. Alarm interface of web application.
Şekil 12. *Web uygulaması alarm arayüzü.*

Table 3. Generated alarm codes in FCN.
Çizelge 3. *FCN'de üretilen alarm kodları.*

Alarm Code	Explanation	Category
1	Filter N flush started (N: Filter number)	Info
2	Filter N flush completed (N: Filter number)	Info
3	No flow during filter flush	Critical
4	Flow during filter flush	Critical
5	High ΔP	Critical
243	Periodic backflush started	Info
244	Manual backflush can't start since backflush disabled	Fault
245	Manual backflush can't start since no water flow at inlet (No irrigation)	Fault
246	Manual backflush can't start since already backflushing	Fault
247	Manual backflush started	Info
248	High inlet pressure	Fault
249	Safe inlet pressure	Info
250	Low inlet pressure	Fault
251	Filtration inlet pressure is below irrigation pressure threshold (Irrigation ended)	Info
252	Filtration inlet pressure is above irrigation pressure threshold (Irrigation started)	Info
253	Outlet pressure is stabilized, and ΔP control started	Info
254	Backflush completed	Info
255	ΔP backflush started	Info

Field Test

Filters were backflushed 70 times during the test period of 20 days. Backflush was initiated by the ΔP, periodic and manual control 34, 28 and 8 times, respectively. Total irrigation water and average flowrate were 9594.4 m^3 and 55.62 m^3/h for the test duration.

Highest inlet and outlet pressure was observed in 5th day as 5.8 and 5.7 bar, respectively. ΔP was fluctuated between 0 and 1 bar.

Backflush was more frequent as total water volume between two backflushes was lower than 72 m^3 for the first 15 backflushes which correspond to first two days of test. Later, it was fluctuated between 10-360 m^3 (Figure 8). As the drip irrigation system has been operated first time since installation, lower water volume between two backflushes in day 1 and 2 can be attained to residue of denser physical particles in main irrigation pipeline.

Daily categorized backflush numbers are given in Figure 13. Since plants were not irrigated in day 7, 8, 14, 15, 16 and 18, there was no backflush in these days. The backflush numbers were higher in the first 4 days of test and generally initiated by the ΔP in the first 3 days and last 2 days of test. Total daily backflush number was 2-3 between day 5 and 17. During this period all the backflushes were initiated by periodic control and ΔP was around 0.2 bar (Figure 9). Haman et al. (2003) reported that ΔP increases with time as contaminants accumulate and partially plug the filter. Observed ΔP results showed that periodic backflush with 4 hours provided adequate filter flushing especially in this period.

By combining the results of daily categorized backflush numbers and water volume between two backflushes, it can be said that, under the test conditions, the drip irrigation system was reached to stabilized operating conditions due to sufficient backflush duration after first 4 days of test.

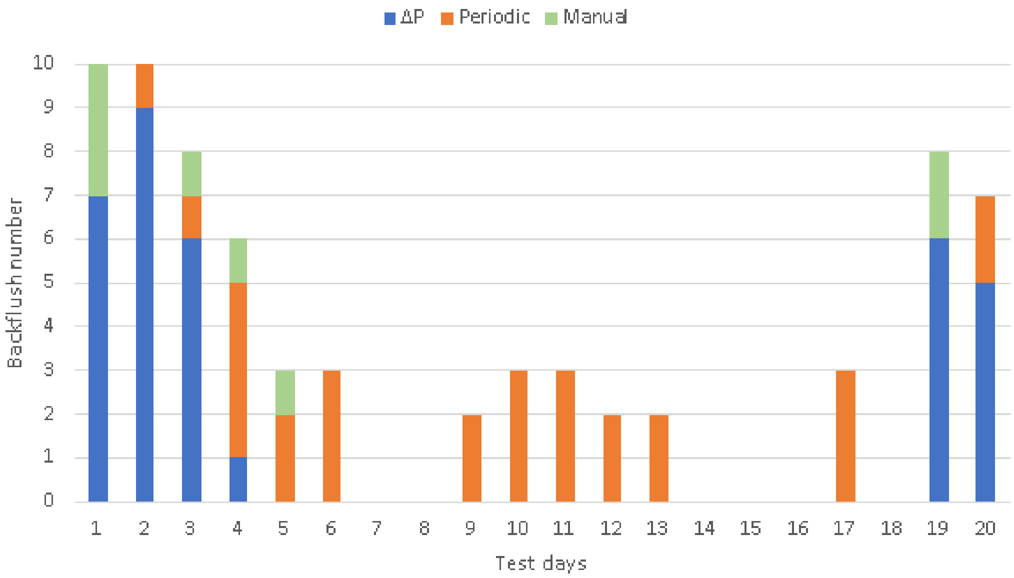

Figure 13. Daily categorized backflush numbers.
Şekil 13. *Günlük sınıflandırılmış ters yıkama sayıları.*

After backflush, ΔP changed between 0-0.4 bar during the test period. However, in the first 30 backflushes it was more stable (~0.2 bar). After that point it fluctuated and reached to 0.4 bar at the end of the test. Since the pressure differential of 0.2-0.8 bar was considered as clean filter conditions (Haman et al., 2003; Hanson et al., 2008), achieved results indicates the efficient backflush conditions.

CONCLUSION

From this study it is concluded that the implemented wireless sensor network can provide efficient monitoring and control of backflush by using ΔP, periodic and manual control strategies. Besides it can increase the performance of the drip irrigation system with providing more stable operating conditions and better water distribution.

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