A fuzzy logic based irrigation management system in arid regions applied to the State of Qatar

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Abstract

In arid and hyper arid regions like Qatar, the time and duration of irrigation is key to achieving sustainable irrigations. This paper proposes a practical solution based on artificial intelligence where all design and implementation phases are described. First, it describes a microcontroller-based system that collects soil moisture, ambient temperature, and solar radiation. Then the fuzzy logic controller takes these three inputs, and, based on the created rules table for a given crop, it produces the desired time and duration of irrigation. Also, ZigBee-based wireless monitoring is developed in-house in order to monitor the system operation and save sensor readings, irrigation time and during, and amount of water being dispensed. This constitutes the basis for future analysis and economic and environmental studies. Experimental results showed that the developed system rigorously compensates the amount of water that is lost through evapotranspiration as predicted by *Penman–Monteith* model, which is adapted by the FAO. The deployment of fuzzy control combined with wireless monitoring is found to have a great impact on irrigation management and planning in the near future.
Keywords: fuzzy logic, wireless monitoring, arid region, intelligent drip irrigation system.

1 Introduction

The importance of water is indisputable around the world and particularly in arid lands. Typically, arid areas receive *less than 250 mm* of rainfall annually [1, 2]. In the state of Qatar, the ground water (the main source of irrigation) is in a

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continuous state of depletion because the annual abstraction is always greater than the recharge from rainfall [3]. Waste water in irrigation is mainly caused by the use of traditional techniques in irrigation (basins and furrows irrigation techniques). To optimize the amount of water used, more efficient irrigation systems are required. Various types of irrigation systems have been developed, in all cases and with effective use of irrigation water, each plant must obtain the exact amount of water it needs. An intelligent system ensures setting the appropriate duration and time for irrigation as well as avoiding the high evaporation daytimes.

1.1 Traditional techniques

Surface irrigation is the oldest yet still the most common form of irrigation throughout the world [4]; it is based on the distribution of water by gravity over the soil. Many irrigation methods are frequently used: *Basin irrigation* applied to cover the entire area rapidly. In *furrow irrigation*, small channels are created along the field and pipes ensure the water distribution.

These techniques should consider the climatic factors that have a large effect on the irrigation process.

1.2 Modern techniques

Here, water needs of the crops depend on many factors [5]:

- The available water reserves.
- The type of the crop and growth stage.
- Nature and state of soil.
- Climatic information related to the growing area (temperature, rainfall, sunshine, wind, etc).
- The soil evaporation and plants transpiration (or evapotranspiration) processes.

Climatic conditions have direct influence on the evapotranspiration. The evapotranspiration as calculated with Penman–Monteith equation (1) and which has been adapted by the FAO so far [6] is given by:

$$Eto = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+237}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}. \tag{1}$$

where

ETo: reference evapotranspiration [mm.day^{-1}]
R_n: net radiation at the crop surface [MJ.m^{-2}.day^{-1}]
G: soil heat flux density [MJ.m^{-2}.day^{-1}]
T: mean daily air temperature at 2 m height [°C]
u_2: wind speed at 2 m height [m.s^{-1}]
e_s: saturation vapor pressure [kPa]

e_a: actual vapor pressure [kPa]
e_s-e_a: saturation vapor pressure deficit [kPa]
Δ: slope vapor pressure curve [kPa.°C^{-1}]
γ: psychometric constant [kPa.°C^{-1}].

In arid lands, *ETo* is at least 10 mm.day^{-1} [7–9], (equal to 10 liters every square meter per day). To minimize the evapotranspiration, the irrigation should be in the morning, around the time of sunrise, or sometimes even at night [10]. This strategy will reduce the amount of water wasted with the traditional techniques.

In this study, we will develop a system based on fuzzy control approach designed so that to reduce loss of water through evapotranspiration while providing the water needed by the crop. The system is enhanced with wireless monitoring of real-time critical factors (e.g., soil moisture, temperature, solar radiation and amount of water consumed).

2 System development

The system structure comprises two essential blocks, namely, control and monitoring as shown in Figure 1.

2.1 System description

The control part is developed to be near to the field and is centered on a Fuzzy Logic Controller (FLC) integrated in a microcontroller. As shown in Figure 1, sensors are used to log the environment and an eletrovalve to supply water.

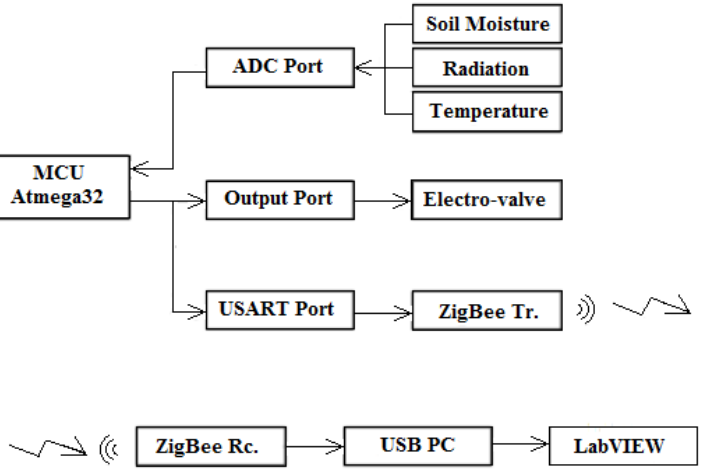


Figure 1: System structure (control and monitoring parts).

The microcontroller, ATmega32 from the Atmel manufacturer, has a 32 Kilobyte programmable flash memory, a microprocessor can operate with a frequency of 16 MHz, an Analog to Digital Converter port (ADC 10 bits with 8 inputs), and four (4) ports (8 bits) programmable as input or output.

The evapotranspiration in eqn (1) is adapted to devise the different fuzzy rules. Equation (1) includes temperature, relative humidity, insolation and wind speed. In arid lands like Qatar, evaporation losses caused by wind can be eliminated [11]. In this study, we used three sensors to measure ambient temperature, radiation (insolation) and soil moisture.

Temperature and radiation sensors collect the necessary information to compute the evapotranspiration rate. The soil moisture sensor provides an indication if irrigation is needed (moisture < 17% in this case study). These analogues signals are converted by the ADC into a digital data. The FLC carries out a fuzzy reasoning and a fuzzy decision according to that information from the sensors. The decision will be taken on the time and the duration of irrigation. The process of aspiration of water through the soil takes a considerable time, so the system will take 30 minutes waiting before restart the cycle from the beginning. The fuzzy logic is written in the C language and transferred to the microcontroller in the machine language (hex file). The program allocates 6.5 kilobytes in flash memory, equivalent to 20.3% of the total memory (32 kilobytes) only. All sensors' readings were sent wirelessly using ZigBee transceivers for record and later analysis.

The following chart in Figure 2 summarizes how the system operates.

2.2 Fuzzy logic controller

Fuzzy sets theory can handle real life uncertainties and therefore ideal for nonlinear, time varying and hysteretic system control [14, 15]. The membership functions are distributed according to the possible values of each variable after fuzzification. The rule base creates the transformation that links each input fuzzy sets with the appropriate output fuzzy sets using the suitable fuzzy logic operations.

Figure 3 explains the structure of FLC. All variables are fuzzified using trapezoidal and triangular membership functions as shown in Figure 4. Mamdani inference engine and rule base makes the best decision for each situation. After application of a centroid defuzzification, the controller gives a possible output. Three inputs (i/p) and one output (o/p) are used in this work:

- **Soil moisture (i/p#1):** This sensor measures the soil water and is critical in the whole decision. Outside temperature: To prevent water evaporation, the irrigation process will avoid when the outside temperature is high.
- **Ambient temperature** (i/p#2): temperature accelerates evapotranspiration.
- **Radiation (i/p#3):** it accelerates evapotranspiration also.
- **Duration (o/p):** the output of the FLC is the duration of irrigation.

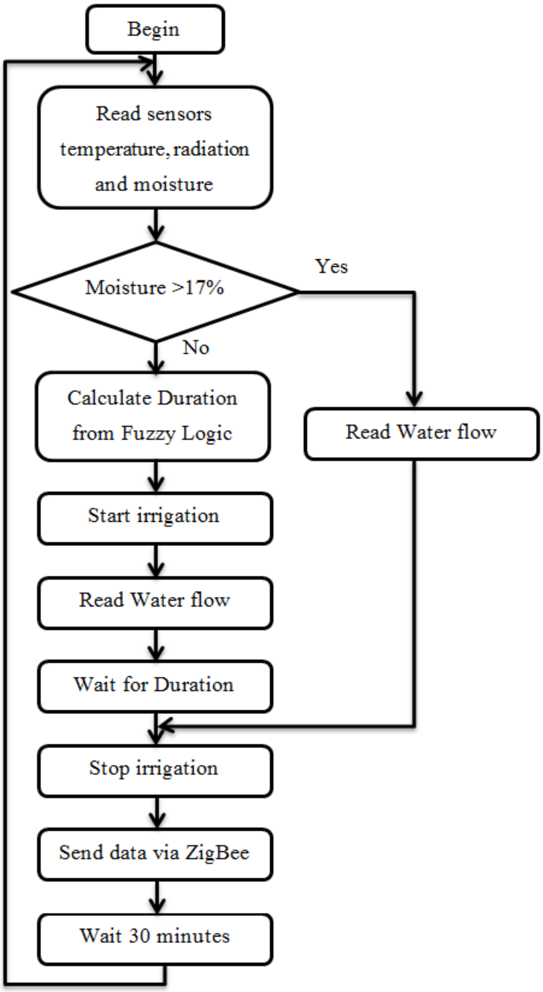


Figure 2: Flow chart software.

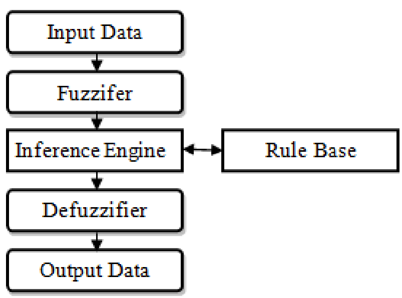
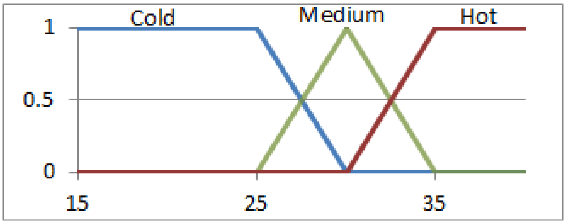


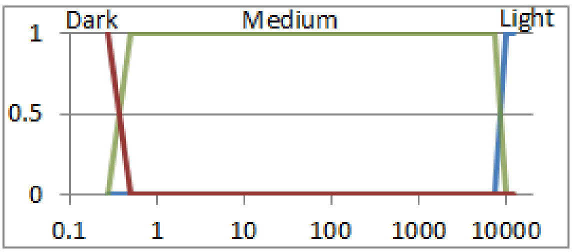
Figure 3: Fuzzy logic controller structure.

Inputs and output membership functions are shown below in Figure 4.

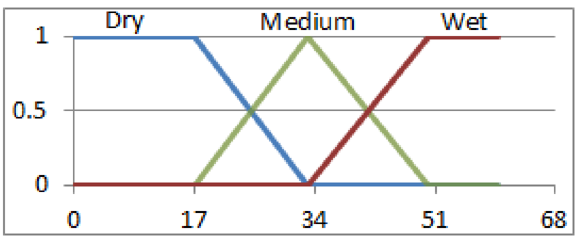
The variables are fuzzified using trapezoidal and triangular membership functions. For the purpose of avoiding memory leaks and improving the program execution speed, three significant membership functions are used for each input



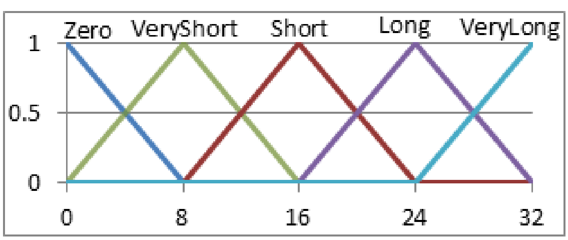
Temperature membership function (ºC)



Solar radiation membership function (Lux)



Soil moisture membership function (%)



Duration, output membership function (Minute)

Figure 4: Inputs and output membership functions.

variable. The output variable need to be more extended, with five membership functions, to cover the variation of the water need.

Tables 1, 2 and 3 show the fuzzy rule-based system. As an example of these rules:

- "If the Moisture is Wet and regardless of the Temperature and the Radiation THEN the Duration is Zero".
- "If the Moisture is Medium and the Temperature Medium and the Radiation is Light THEN the Duration is Very Short".
- "If the Moisture is Medium and the Temperature Hot and the Radiation is Light THEN the Duration is Zero".

Table 1: Rules for duration of irrigation (in minutes) at wet soil moisture.

Temperature (^oC)	Radiation (Lux)		
	Light	Medium	Dark
Cold	Zero		
Medium			
Hot			

Table 2: Rules for duration of irrigation (in minutes) at medium soil moisture.

Temperature (^oC)	Radiation (Lux)		
	Light	Medium	Dark
Cold	Short		
Medium	Very Short	Short	
Hot	Zero	Very Short	Long

Table 3: Rules for duration of irrigation (in minutes) at dry soil moisture.

Temperature (^oC)	Radiation (Lux)		
	Light	Medium	Dark
Cold	Very Long		
Medium	Short	Long	
Hot	Zero	Very Short	Very Long

The system is enhanced with a flow meter sensor which measures the water flow in liters/minute. By recording the duration of irrigation, one can compute the amount of water being consumed. The flow meter also alerts in case of shortage of water. The electro-valve is controlled by the microcontroller via a driver power adapter. It serves to switch the water ON and OFF and is connected to a drip irrigation pipe line.

The hardware part is developed over a small pcb circuit and consumes a low current (max of 0.5 Amp) under a 12 Volts.

2.3 Monitoring part

The monitoring part uses LabVIEW which is installed on a pc and whose front panel is depicted in Figure 5. The program monitors all data being sent and received remotely in real time through ZigBee transceivers.

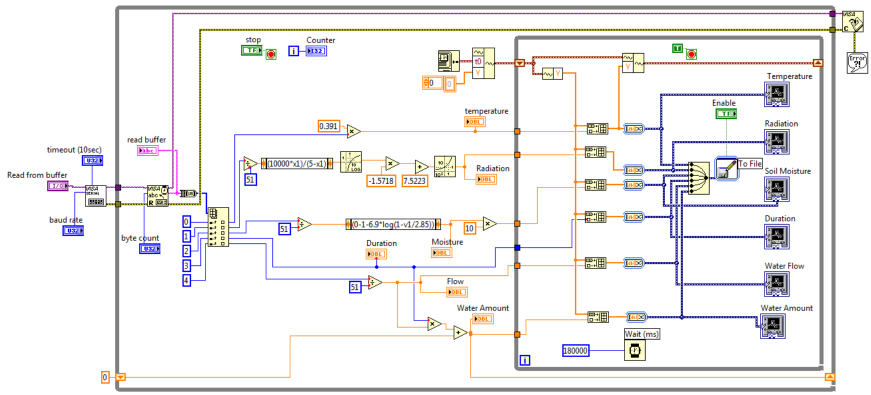


Figure 5: LABVIEW front-panel acquisition block.

Various wireless standards for monitoring and automation applications have been established, of which are the standards for wireless LAN, IEEE 802.11b “Wi-Fi”, wireless PAN (personal area networking), IEEE 802.15.1 “Bluetooth”, and IEEE 802.5.4 “ZigBee” [12]. However, ZigBee presents unique features for conventional and precision agriculture [13] such as low-cost, low-power consumption and similar communication range.

3 Experimental results

The system is implemented on a printed circuit board and connected to the various sensors. The remote experimental results received and displayed in real-time by LABVIEW are illustrated in Figures 6–8.

The system was operated continuously for six working days. The results presented above show actual measurements of a field plant in Qatar. The fuzzy controller avoids operating the system during high temperatures throughout the day in order to reduce evapotranspiration. It also selects the appropriate time by referring to the base of fuzzy rules. The last curve is the total water amount being consumed.

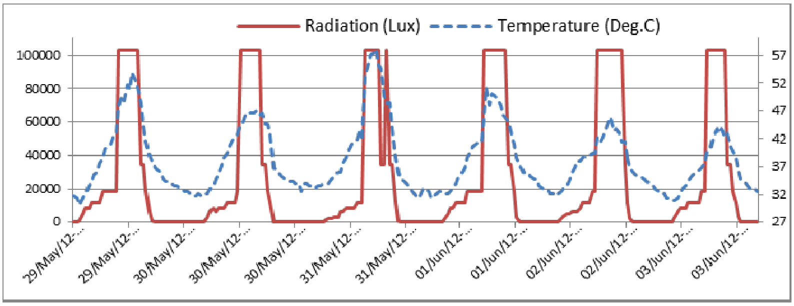


Figure 6: Real-time remote temperature and radiation data.

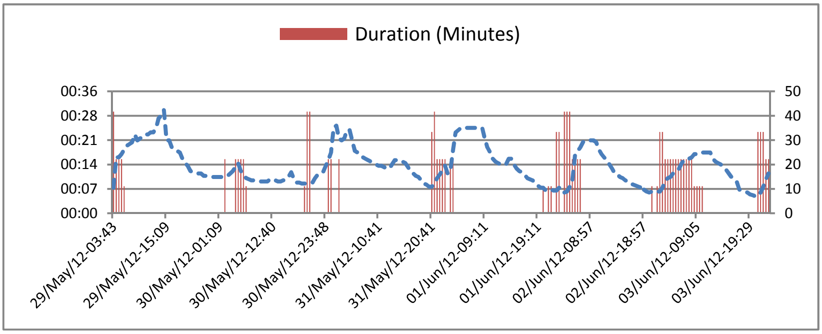


Figure 7: Real-time remote soil moisture and duration of irrigation data.

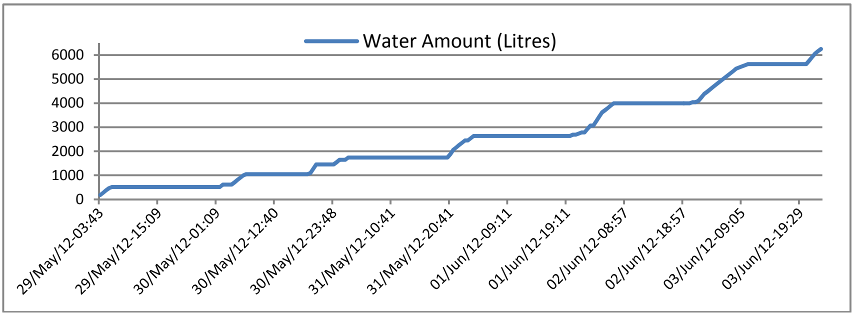


Figure 8: Real-time remote water amount data.

As shown in Figure 8, in 6 days the total amount of water consumed is 6252 Liters, that is, an average of 1042 Liters per day over an area of 100 square meters. It follows that our control system irrigated the field with an average of 10.42 mm.day^{-1}. This is similar to the value calculated by the evapotranspiration in eqn (1) for arid lands, that is, 10 mm.day^{-1} as reported in [3]. This indicates that the fuzzy control-based irrigation system developed here compensates perfectly the amount of water that the soil and crop loose due to evapotranspiration in arid regions like Qatar.

4 Conclusion

In this paper, fuzzy control and wireless monitoring were presented as a strategy to develop an irrigation approach that fosters sustainable improvement in management of irrigation. The developed fuzzy control strategy optimized the time and duration of irrigation for a given crop. In order to monitor system performance in real time and keep record of key data, a ZigBee wireless system was developed. Key environmental and climatic real-time factors along with the time and during of irrigation as well as the amount of water being sourced were wirelessly recorded. The developed system rigorously compensated the amount of water that was lost by evapotranspiration as predicted by Penman–Monteith model (adapted by the FAO). Experimental results showed that the deployment of fuzzy control approach combined with wireless monitoring has a great impact on irrigation sustainability through better management and planning.

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