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A fuzzy logic based irrigation system enhanced with wireless data logging applied to the state of Qatar

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ABSTRACT

In arid regions, developing environment and crop-specific irrigation scheduling that reduces water lost via evapotranspiration is a key to a sustainable and better managed irrigation. This paper presents a practical solution based on intelligent and effective system for a field of hyper aridity in Doha–Qatar. The system consists of a feedback fuzzy logic controller that logs key field parameters through specific sensors and a Zigbee–GPRS remote monitoring and database platform. The system is easy to deploy in existing drip irrigation systems without any physical modification. For a given crop, the fuzzy logic controller acquires data from these sensors and then applies well-devised fuzzy rules to produce appropriate time and duration for irrigation. All variables are fuzzified using trapezoidal and triangular membership functions. In this fuzzification, Max–Min inference engine and Mamdani-type rule base is adopted in order to make the best decision for each situation. Typical data in summer and winter showed that the controller ensures maintaining the soil moisture above a pre-defined value with non-abrupt oscillations. The system compensates the amount of water that is lost through evapotranspiration as predicted by *Penman–Monteith* model and hence allows predicting future water consumption. A local station first processes and saves real-time data received from the field controller via wireless Zigbee protocol to finally transmit these data to a remote station via a GPRS link. This enhancement enables tracking system performance in real time and creating a database for analysis and improvement. It follows that the deployment of fuzzy control combined with remote data logging would foster better management of irrigation and water resources in hyper-arid lands such as Qatar.

1. Introduction

The importance of water is indisputable around the world and particularly in arid and hyper arid lands. With the rapid industrial and social development, and the massive increase in Qatar's population, conventional water resources have become seriously depleted. With an average of less than 250 m^3 available per person per year, Qatar falls far below the internationally recognized 'water poverty line' of 1000 m^3 per person per year (Al-Mohannadi et al., 2003; Hasim, 2009; Prakash and Chenb, 2010; Kanzari et al., 2012). Without proper management, water will become a severe constraining factor in the socio-economic development of the country. Currently, agriculture accounts for about 60% of the total net demand on fresh water in Qatar (Alexandridis et al., 2008; FAO Water Reports, 2008; Feliu-Batlle et al., 2009; John, 2011). This demand is expected to increase even further while ground water is continuously in depletion. It is thus obvious that any measure taken to improve the efficiency of water usage in agriculture will have a significant impact towards achieving water supply sustainability, and secure the availability of this very valuable resource to the community.

In Qatar, wastage of water in irrigation is mainly caused by; first: the use of traditional techniques which are based on timers such as basins and furrows irrigation (Gillies and Smith, 2005), and second: the water loss through ground evaporation and crop transpiration (so-called evapotranspiration *ET*). In the first case, research has shown that people over-irrigate crops due to the misunderstanding of seasonal water need or the impracticality of updating the irrigation schedule to reflect actual water needs of the landscape (Haley et al., 2007). In this scenario, people generally adjust timers by observing the crop and irrigating when it looks stressed (qualitative). On the other hand, the loss by evapotranspiration is inevitable and accentuated by the hyper-arid environment under untapped ambient temperature and solar radiation of 6 kW h/m^2/day where daylight is about 4449 h/year (Touati et al., 2013). Here, there is a need for automated irrigation systems that are able to deliver the exact quantity of water required by the crop for proper irrigation while reducing *ET* losses.

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There are several studies discussing the pros and cons of open-loop and closed-loop control systems (McCreadya et al., 2009; Rahangadale and Choudhary, 2011; Obota and Inyama, 2013). According to (Wade and Waltz, 2004; Jaume et al., 2012), the most deployed method of irrigation control is the closed-loop which splits into two categories; feed-forward and feedback control. In the feedback control, the idea is to maintain soil moisture (i.e. plant's water stress) within a specific range by measuring crop's needs from soil moisture levels using instruments such as tensiometers or dielectric probes (Javadi et al., 2009). However, in the feed-forward control (known as *ET* control), controllers use the crop's reference evapotranspiration (*ETo*) to schedule irrigation compensating then for *ET* water loss through the water balance technique. Climatic conditions have direct influence on *ETo* (Davis and Dukes, 2010), which can be calculated by using Penman Monteith model as this has been officially adopted by the FAO (Allen et al., 1998; Roy et al., 2009; Yang et al., 2010). In hyper-arid lands like Qatar for example, *ETo* can reach 10 mm day^{-1} in summer which corresponds to 10 L per square meter per day (Hasim, 2009). For both feedback and feed-forward approaches, in order to minimize *ET* losses and hence system's overrunning that would result in wastage of water and energy, the controllers should schedule irrigation either in the morning, around sunrise, or even at night (Speetjens et al., 2008; Car et al., 2012). This reveals the complexity of the irrigation decision and stresses the need for a robust and effective irrigation strategy especially in harsh environments where evapotranspiration is acute. To address this complexity, much attention has been paid to fuzzy theory in order to improve the ability to make correct decisions.

Fuzzy logic interprets real uncertainties and becomes ideal for nonlinear, time-varying and heuristic knowledge to control a system. As contrasted to conventional feedback control systems, it is gaining importance due to its flexibility in handling imprecise subjective data and hence very effective for real-world decision-making problems (Zhang et al., 1996; Mirabbasi et al., 2008). The functionality of fuzzy logic has been extensively tested in a wide range of applications. Jia et al. (2011) designed a field integrative irrigation controller based on fuzzy logic and programmable logic controller. A fuzzy logic-based multi-criterion decision making approach was applied for selecting the best-performing irrigation subsystem in India (Raju and Kumar, 2005). A Fuzzy Logic Feedback Controller (FLC) prototype based on a Mamdani controller and simulated on MATLAB software was shown to be more effective when compared to feedback controllers of simple on/off and on/off with hysterics (Javadi et al., 2009). A fuzzy logic based benefit-cost approach proved to be very suitable in decision making between three alternative irrigation projects (Anagnostopoulosa and Petalasb, 2011). In Mexico, the development of a fuzzy irrigation control system using a field programmable gate array (FPGA) to control greenhouse fertigation was found cost-effective and easy to implement (Melendez et al., 2011). Rahangadale et al. (2011) reported that fuzzy logic control improves the performance of automatic irrigation systems by smoothing system ON/OFF and having the potential for saving water when compared to conventional controllers. Fuzzy logic was used to develop a model for crop water stress index (Al-Faraj et al., 2011). In Qiu et al. (2007), a fuzzy irrigation decision-making system established by using virtual instrumentation platform of sensors, test instruments, data logger, and LabView was presented. Generally, published studies use ON/OFF controllers where the inherent complexity of irrigation process made it difficult to achieve optimal results. Few studies used *ET* controllers, however, inputs for such systems which are used to calculate the theoretical irrigation requirement (scheduling) are complex and subject to a lot of uncertainties rendering the scheduling efficiency and irrigation adequacy a difficult task (Davis and Dukes, 2010). Systems using feedback (or soil moisture) controllers have been used successfully. For example, an irrigation controller which has been developed based on controlling soil moisture (Muñoz-Carpena et al., 2004) reduced irrigation water by 70% on drip irrigated tomato in South Florida. Research shows that feedback control based systems give promising results in terms of water savings as high as 70% compared to drip approach with no negative impact on crop yields (Nogueira et al., 2003; Dukes et al., 2003; Dukes and Scholberg, 2005).

Most commercialized systems are "on/off with hysteresis" systems, where the controller continually compares one input with two preset values to provide a decision either start or stop irrigating. This approach is simple but cannot handle efficiently complex systems with multiple inputs like irrigation. As discussed above, fuzzy logic is very flexible, robust by nature, has a clear reasoning logic mimicking human brain (Domingo et al., 2011) and hence well fit to this application.

In this study, we developed a site-specific standalone smart irrigation system (SIS) which uses FLC-based feedback ON/OFF control. The SIS is designed to efficiently schedule irrigation for cucumber under drip irrigation system in open fields in order to keep the soil moisture above 17% and avoid times where evapotranspiration is high. In Qatar, the soil moisture that is adequate for cucumber is around 66%, however, it should not go below 17% to avoid water stress (shortage) and bitter taste in the yield (Hasim, 2009). The FLC is supposed to provide the time and duration of irrigation as needed by the crop in a 100-m^2 field in Doha (coordinates: 25.375°N, 51.490°E). Various sensors were deployed to log critical factors, such as soil moisture, ambient temperature, solar radiation and amount of water consumed. The readings from the various sensors were then fed to the FLC to apply well-devised fuzzy rules to control irrigation. In order to monitor and save measured data in real time for further analysis, the system was also enhanced with ZigBee–GPRS module for wide-range wireless monitoring and data logging platform. To the authors' knowledge, this is the first study published on designing such irrigation system applied to Qatar.

2. System design

The system structure of SIS is shown in Fig. 1. It consists of two main subsystems: (1) the sensing and control, and (2) long-range

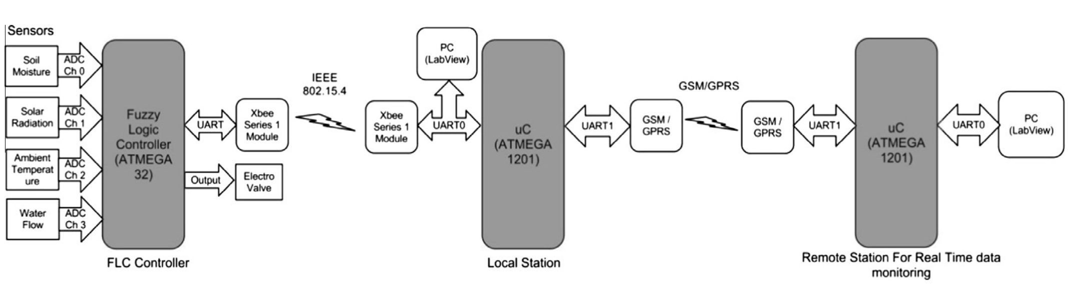

Fig. 1. Block diagram of smart irrigation system.