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Soil moisture Fuzzy Estimation Approach based on Decision-Making

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ABSTRACT

This paper presents a Fuzzy Estimation Approach based on Decision Making (*FEADM*) to estimate point soil moisture, in order to develop a regional soil moisture estimate. This keeps the advantages of an automatic irrigation system but avoiding their operational complexity. In the *FEADM* 's first stage, the Fuzzy Analytical Process weigh five fuzzified environmental inputs used as assessment criteria. These criteria are used by a selective assessment stage, where only the relevant criteria for each alternative are assessed. As result, the best assessments of each alternative and the best assessed alternative are obtained. In the second stage, an output membership function is assigned to every alternative for its forward aggregation and defuzzification. This process reaches a soil moisture estimate. Unlike other models, *FEADM* allows estimating a quantitative value from a decision making process. Furthermore, its computational cost is lower than conventional fuzzy estimation models due to the selective assessment.

1. Introduction

The current issues presented by the shortage of usable water for human tasks (Al-Seekh and Mohammad, 2009; Girona et al., 2010), the changes in behavior of weather events and the rising demand for agricultural products for human consumption (Ferraro, 2009; Postel, 1998), have led research and development of innovative scientific methods to improve the production of agricultural crops (Sheikh et al., 2009; Ustaoglu et al., 2016). One of the main topics of research is the development of models and intelligent systems for automatic irrigation since automatic farmland irrigation increases agricultural production as well as allowing an appropriate exploitation of agricultural resources.

It is essential to properly exploit agricultural resources to prevent overuse and unnecessary use of them. Irrigation water is one of the most important agricultural resources in the process. In this sense automatic irrigation systems play an important role. These systems generally measure the soil moisture, using a single measuring instrument as well as a network (Phillips et al., 2014). These measurements determine whether the irrigation water supply is required at the point or region where the measurement is made, improving the use of irrigation water.

Despite the advantages of automatic irrigation systems, there are certain limitations: implementation complexity and maintenance of these systems given the need to intercommunicate large number of sensors and measuring instruments. Also, little importance has been assigned to weather conditions and as well as to the crop and soil features, which are important factors for irrigation process (Romero et al., 2012; Sheikh et al., 2009).

The problems associated with automatic irrigation systems could be solved preserving its inherent advantages by means of soil moisture estimation (Gill et al., 2006; Liu et al., 2010). In this regard, a soil moisture estimation approach is expected to be used in automatic irrigation systems to avoid measuring soil moisture at any checkpoint within the irrigation area. A soil moisture estimation performed at any checkpoint within the region can be called *Point Estimate*, meanwhile the set of point estimates performed within the region can be referred as *Regional Estimate*.

The hypothetical conventional irrigation region from in Fig. 1a presents $R = 8$ checkpoints $Z^{r=1,2,\ldots,R}$ where the soil moisture must be measured in order to determine irrigation demands in the area. Each zone close to a checkpoint Z^r has spatial features, which characterize it, as well as certain soil and crop features. These

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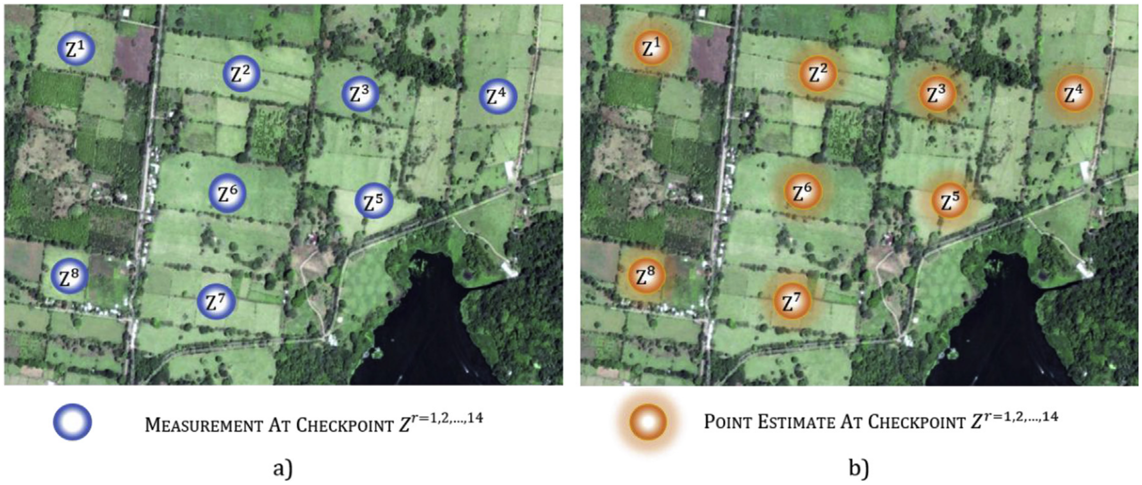

Fig. 1. Soil moisture data acquisition in a hypothetical irrigation region: a) Measurement, b) Point Estimates.

features as well as the soil moisture measurements performed at each checkpoint Z^r, define the water supply requirements in that zone. However, instead of measuring the soil moisture at each Z^r location, which could be not suitable for small and medium farms, a *Point Estimate* can be performed at every checkpoint $Z^{r=1,2,\ldots,R}$, as is depicted in Fig. 1.

One possible soil moisture estimation approach is a hydrological model, in which, land surface models, meteorological data and other parameters are used as inputs (Clark et al., 2008; Kumar et al., 2008a, 2008b). Despite the accurate predictions of soil moisture, these models present a high development complexity due to the inputs acquisition complexity and the assumptions required in order to apply the model in the absence of actual data as well as their spatial relationships (Al-Hamdan and Cruise, 2010; Crosson et al., 2002). Additionally, Artificial Neural Networks (ANNs) have been employed for soil moisture estimation (Elshorbagy and Parasuraman, 2008; Liou et al., 2001; Zanetti et al., 2015) as well as Supported Vector Machines (SVM) (Gill et al., 2006; Yu et al., 2012). In literature, SVM has proved better performance than the ANN (Kashif Gill et al., 2007), especially when an ensemble Kalman filter (EnKF) is used, (Liu et al., 2010, 2016). However, ANNs and SVMs require a high number of data observations to avoid uncertainties in soil moisture estimates (Asefa et al., 2006), which could not be suitable for small and medium farms where a prompt estimation is required.

In this paper a Fuzzy Estimation Approach based on Decision Making (*FEADM*) for obtaining a *Point Estimate* of soil moisture is proposed. *FEADM* is a fuzzy model complemented by a decision-making algorithm proposed herein to choose the best alternative assessed (soil moisture level) under current environmental conditions. The proposed model is not limited to decision-making because *FEADM* also allows the quantitative estimation of the soil moisture using fuzzy operations. Moreover, it is not limited to a conventional fuzzy estimation system, because all possible combinations of the input variables are not needed given the evaluators expertise for selecting and assessing only those relevant for each soil moisture level established.

FEADM only requires current environmental conditions as well as the soil and the crop features of the checkpoint zone where the *Point Estimate* is being performed. Therefore a limited number of measurements is required. Also, the decision makers expertise modeled within *FEADM* allows to correlate relevant factors of a given zone such as the weather conditions as well as the soil, the crop and the spatial features in order to determine the soil moisture content.

This paper is presented in seven sections. In Section 2 the importance of a soil moisture point estimate is highlighted in order to conduct a soil moisture regional estimate. In Section 3, a review of some decision-making methods and their applications is presented. Section 4 describes the methodology of work presenting the proposed model and its different stages. In Section 5, the experiments for obtaining *Point Estimates* of the soil moisture based on measured environmental conditions are presented while Section 6 discusses results of several tests including the comparison with its measured counterpart. Finally, Section 7 contains the conclusions.

2. Point estimate significance for a regional estimate of soil moisture

Soil moisture at different checkpoints within the region of interest is measured when conventional automatic irrigation systems are used (Goumopoulos et al., 2014; Phillips et al., 2014). However, the physical and operational complexity of these systems is high. In addition, current models for obtaining soil moisture estimates are not suitable for using in small and medium farms given their complex requirements. Therefore, *FEADM* endeavors to replace the checkpoint measurements of soil moisture with estimations based on the climatic conditions of the environment as well as soil, crop and spatial features of the zone where the checkpoints are located.

Fig. 2 presents a hypothetical regional estimation based on *Point Estimates* of the soil moisture. The abovementioned *Point Estimates* could be computed using the *FEADM* proposed herein. The hypothetical regional estimation model would require to know weather conditions at any checkpoint within the estimation region as well as soil, crop and spatial features of the zone where the checkpoint is located. In order to conduct the hypothetical regional estimation, the weather conditions $C^0_{i=1,2,\ldots,I}$ of the primary checkpoint Z^0 must be measured. These weather conditions $C^0_{i=1,2,\ldots,I}$ as well as the soil, crop and spatial features of the primary checkpoint Z^0 are a requirement to obtain *Point Estimate* P^0_e by means of *FEADM*. Any other *Point Estimate* $P_e^{r=1,2,\ldots,R}$ for a checkpoint $Z^{r=1,2,\ldots R}$, where R is the number of checkpoints within the region of interest, can be computed using weather conditions $C^{r=1,2,\ldots,R}_{i=1,2,\ldots,I}$ as well as soil, crop and spatial features of checkpoint $Z^{r=1,2,\ldots R}$.

Soil, crop and spatial features of checkpoint $Z^{r=1,2,\ldots R}$ are well known. However, weather conditions $C^{r=1,2,\ldots,R}_{i=1,2,\ldots,I}$ at checkpoint $Z^{r=1,2,\ldots R}$ are unknown. That is, no weather conditions would be