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Applying artificial intelligence modeling to optimize green roof irrigation

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ABSTRACT

Recent increase in green-roof installation has increased irrigation water consumption which could be wasteful using conventional watering management protocol. The knowledge gap in irrigation optimization to achieve water conservation could be filled. The complicated conventional approach uses weather and soil sensors to calculate watering needs, which is impractical and not cost-effective. This study employs artificial intelligence algorithms composed of artificial neural network and fuzzy logic, using weather data to simulate soil moisture changes to develop an optimal irrigation strategy. The artificial neural network is trained to predict soil moisture based on four daily weather variables: real-time air temperature, relative humidity, solar radiation, and wind speed. Fuzzy-neural network is applied to determine the irrigation time and watering volume. The simulation model successfully mimics the human brain in making irrigation decision. The artificial intelligence irrigation could maintain adequate soil moisture ranging from 0.13 to 0.22 m^3/m^3 and reduce 20% of water use with improved plant coverage. Since the evapotranspiration from living vegetation plays a key role in the passive cooling mechanism, better plant coverage could increase the thermal-energy performance of green roofs. The low-cost and effective technique can motivate the adoption of green roofs by alleviating the water consumption obstacle.

1. Introduction

Green roof offers a passive cooling technology to reduce electricity use for air-conditioning systems [1–4]. Typical green roofs are constituted by component layers laid from bottom to top in the following sequence: root barrier, drainage, filter, water-storage, growing substrate, and vegetation [5]. A wide range of vegetation growth forms, depending largely on substrate depth, can be planted [6,7]. The biomass structure, coverage and density of vegetation characterized by leaf-area index can regulate shading, evapotranspiration rate, and thermal cooling and insulation effect [8]. The role of the substrate in supporting plant growth is supplemented by the water storage layer. Rain or irrigation water is stored in the water-absorbing material to satisfy water demands between irrigation or rainfall episodes. Excess soil moisture can escape from green roof system through the drainage layer.

Modern green roofs can be categorized into extensive and intensive types [9]. They are differentiated by substrate depth and associated vegetation growth form. Intensive green roofs require >20 cm substrate to support shrubs and trees and offer more complex habitats for wildlife. In contrast, herbaceous plants including drought-tolerant species are often chosen for extensive green roofs with <20 cm substrate. Empirical research shows that both green roof types have good thermal insulation performance to reduce penetration of solar energy into buildings. They also offer high-quality green spaces which are often deficient in compact urban areas.

Fresh water has increasingly become a scarce resource in many places, including cities in different climatic zones. The efficient use and conservation of water are important to sustain economic growth and urban development. Despite the multiple economic and ecological benefits of green roofs, using scarce water for irrigation could be controversial particularly in semi-arid and arid regions [10]. There is a common tendency to apply an excessive amount of irrigation water to green roofs even if rain or weather sensors have been installed to regulate the irrigation time and volume. For instance, evapotranspiration is the lowest in warm-humid spring and the highest in cool-dry autumn in Hong Kong [11]. Irrigation schedule regulated by rain sensors without considering evapotranspiration loss may not deliver enough water in autumn. Rainfall data alone cannot tell the amount of available water stored in the soil pores [12], which may bring excessive application and wastage. The optimization of irrigation schedule for green roof remains a knowledge gap yet to be filled by research. It calls for the development of an intelligent irrigation model to improve water-use efficiency.

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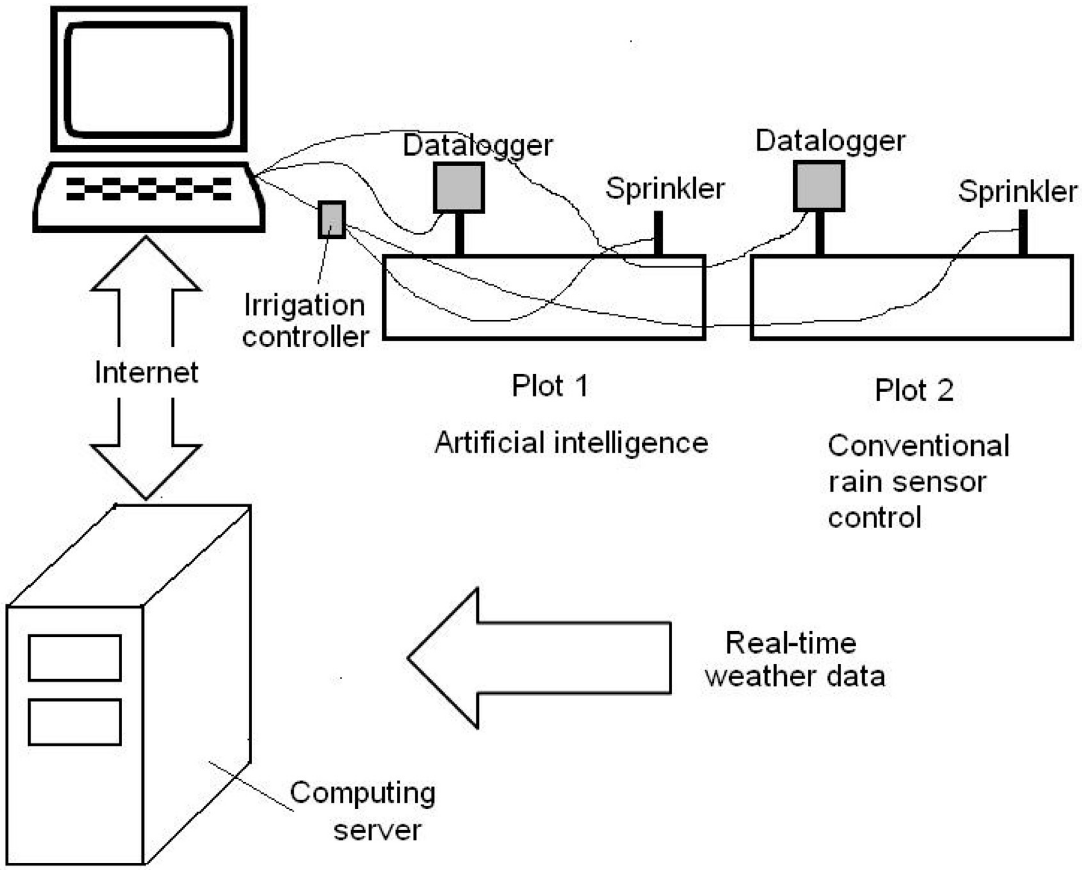

Fig. 1. Schematic drawing of the experimental setup.

2. Artificial intelligence models for irrigation control

Many successful applications of artificial intelligence (AI) models have been reported, such as irrigation scheduling (e.g. [13,14]), water management (e.g. [15,16]), and weather forecast (e.g. [17,18]). The AI computation, namely genetic algorithm (GA), artificial neural network (ANN), and fuzzy logic (FL), could provide flexibility for irrigation researchers to handle real-world complex problems.

GA can be used to optimize the farmland irrigation constraints, such as economic profits, water demand, crop yields, and planted area by minimizing or maximizing objective functions (e.g. [19–22]). The computing flexibility permits researchers to examine many complex problems that are difficult to solve using traditional mathematical and computational methods such as linear and nonlinear programming [23,24]. Analogous to the biological mechanisms of genes, the rules of GA are governed by four basic operations: parent selection, crossover, replacement, and mutation [25,26]. The possible solutions are defined as chromosomes. The objective functions are translated into fitness functions that measure the performance of chromosomes according to the study objectives. New chromosomes are created in crossover and mutation. The chromosomes with the highest fitness values in successive populations can survive. The best set of chromosomes is obtained by iterating the possible solutions until convergence.

ANN is a complex non-linear process that connects the inputs to the outputs of a system. It often provides satisfactory results in scientific and engineering researches. The artificial neurons in ANN resemble the biological ones by forming networks during the learning process. Patterns are recognized from their interactions with the environment [14]. The learning process can be classified into supervised and unsupervised types [13]. ANN acquires knowledge by comparing the simulated output with the real output in supervised learning. The weights associated with neurons at different layers are obtained by training the network [27]. For unsupervised learning, ANN does not require the knowledge of the real output. The weights are found by iterating the network to reflect the output characteristics. Based on the non-linearity properties of ANN, the input-and-output mapping capabilities can be applied to predict water use for green roofs.

ANN is often used with FL in decision making. If the input data are less accurate, ANN would encounter difficulty handling the interactions between inputs and outputs. An integration of ANN with FL (or fuzzy-neural algorithm) presents a better choice to

Table 1
Technical information and accuracy of the soil temperature and moisture sensors installed at the experimental plots.

Sensor position[a]	Sensor model and type	Source	Accuracy & unit
Substrate temperature	8160.TF (PT100)	Lufft, Fellbach, Germany	±0.4 °C
Substrate moisture	S-SMC (Dielectric)	Hobo, Bourne, MA	±3% m^3/m^3
Data logger[b]	Opus 200	Lufft, Fellbach, Germany	n.a.

[a] A weather station was set up near the experimental plots.
[b] The data loggers were programmed to acquire data at 10-min interval.