Poster Abstract: Unifying Modeling Substrate for Irrigation Cyber-Physical Systems

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CPS's multi-domain nature is difficult to capture using existing modeling approaches, which produce compartmentalized and complex system simulation models. Unifying models of multi-domain physical phenomena and processes, and man-made artifacts into a single modeling substrate will enable enhanced design of intelligent control algorithms and analytics. Moreover, with use of known modeling abstractions, which describe the physical ordinary differential equation (ODE) relationships by introducing model components, such as those found in Electronic Design Automation (EDA) tools, models of the physical world, e.g. *irrigation systems*, integrated with models of cyber world, e.g. *electrical circuits*, can be analyzed using existing tools. This can be done by using analogies between hydraulic, electrical, mechanical, etc. (e.g Table 1). For example, we developed *soil moisture transient electrical circuit model* for the next generation of Irrigation CPS.

The most important component in smart irrigation system design are the knowledge of water transport in the soil, or percolation, and water uptake by plants or transpiration and evaporation, or combined evapotranspiration (ET) (Figure 1). Main analytical ODEs that describe water transport in soil are Richard's Equation: $\frac{\partial\theta}{\partial t} = \frac{\partial\theta}{\partial z}[K(\frac{\partial\psi}{\partial z}+1)]$ and Darcy's Law: $q = K\nabla\psi$, where θ is water content, K is the hydraulic conductivity function, z is the elevation, t is time, ψ is the pressure head or water potential, q is the flux or the discharge per square area. However, these equations do not have closed form solutions, thus, we chose to model and simulate the phenomena using electrical circuit components.

To expose the underlying soil physics, we modeled vertical segment of soil by layers of water storage, or capacitive, and transport, or resistive, components. Starting with a single layer of storage, model is tuned and evolved. At each successful stage of evolution, a storage component is divided into two storage elements and connected by a transport component. Meanwhile, model parameters are tuned by quadratic optimization with respect to experimental data split into training and validation segments, which were gathered from outdoor soil moisture sensor in a 16 day duration with 15 min sampling period. Finally, experimental results show that model order 3 (Figure 1) has the best fit of experimental data with $R^2 = 0.923$. Thus, this ODE based simulation methodology describes transient behavior of vertical moisture transport in soil, and enables CPS model-based design and control.

Electric	Hydraulic
Charge	Water Content
Current	Flux/Discharge
Potential	Pressure Head
Capacitance	Storage
Resistance	Transfer

Table 1: Domain Analogies

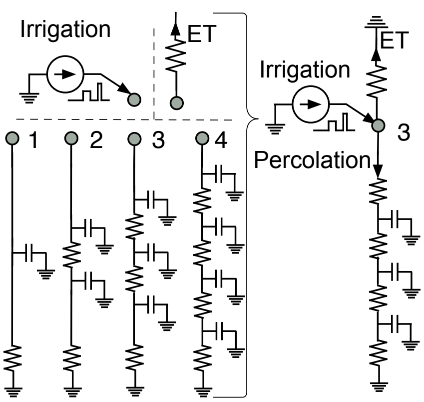

Figure 1: Model Evolution

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