Poster Abstract: MICO: Model-Based Irrigation Control Optimization

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ABSTRACT

Lawns, both public and private, make up the largest irrigated crop in North America by surface area. Although there have been improvements in sprinkler head technology and weather assimilation, state-of-the-art irrigation systems do nothing to adjust for heterogeneous terrain or varying lawn environments. In this work, a computationally lightweight soil moisture movement model is developed, which allows the computation of optimal irrigation valve scheduling using standard optimization techniques. A prototype sprinkler head is produced with the ability to sense local soil moisture conditions, wirelessly communicate, and independently actuate based on the optimal schedule centrally computed. This prototype is then deployed to control two parallel irrigation systems covering a total of more than 10,000 ft^2 for a duration of 5 weeks. It is shown that lawn health can be maintained by using the topography of the space to take advantage of runoff to provide improved coverage while using an average of 23.4% less water. We also show that the initial capital and operating costs of our system could be amortized by our water savings in 13 months while maintaining and/or improving quality of irrigation and lawn health.

Categories and Subject Descriptors

J.7 [**Computers In Other Systems**]: Command & control; C.3 [**Special-Purpose and Application-Based Systems**]: Real-time and embedded systems

Keywords

Irrigation; Monitoring; Control

1. INTRODUCTION AND MOTIVATION

As the western United States suffers its fourth year of a historical drought, coming on the heels of a similar drought in the south-east United States, resources have become widely available to promote efficient use of freshwater. In spite of this, lawn (turf) irrigation systems continue to operate inefficiently. As turf makes up North America's largest irrigated crop by surface area [1], improved efficiency will help to alleviate the freshwater shortages the nation is experiencing.

Efficient watering is critical to the health of the turf and surrounding environment. Insufficient irrigation will cause turf to lose its healthy look, and eventually cause plant death. Generally, groundskeepers and homeowners prevent this by over-irrigating, but over time this can lead to root rot, soil instability, and in extreme cases the leeching of harmful chemicals into the groundwater, as examined in [3].

In this work, we identify the cause of these issues to be an incorrect amount of irrigation applied to the soil surface and create an irrigation system that benefits from two main contributions. The first is the development of a sprinkler node with the ability to sense its environment using a soil moisture sensor, actuate independently based on a centrally-computed schedule, and communicate wirelessly with sister nodes in the environment. The second contribution is the development of a computationally-efficient moisture movement model that incorporates the fundamental sources of water movement in an irrigated environment, which is used in coordination with an optimization framework to determine optimal valve scheduling for the distributed sprinkler nodes. Using this model-driven approach, we are able to provide more precise irrigation control to turf areas, and demonstrate over a five-week deployment that quality of service can be improved, while reducing system water consumption.

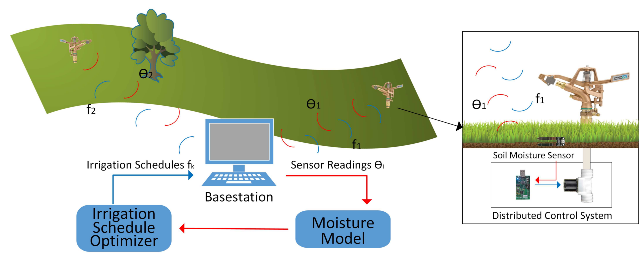

Figure 1: MICO System Architecture Overview

2. SYSTEM OVERVIEW

The MICO system architecture can be seen in Figure 1. The MICO nodes are integrated into the irrigation system's

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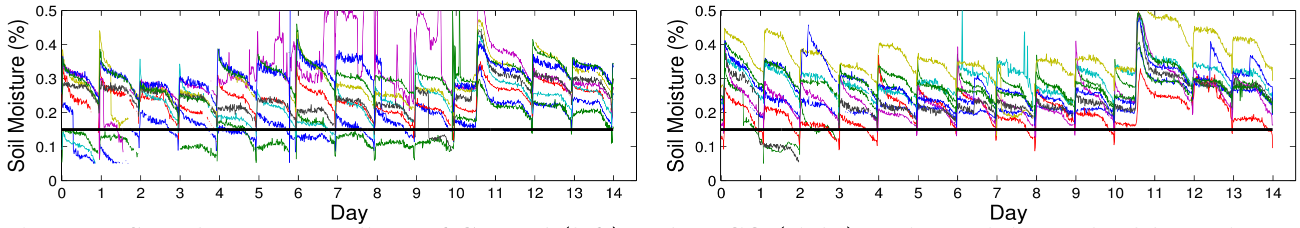

Figure 2: Sample sensor readings of Control (left) and MICO (right) against minimum healthy moisture

architecture, each equipped with a soil moisture sensor, a solenoid to control water flow to the attached sprinkler, and a tmote sky for radio communication. To react to environmental conditions, soil moisture data is collected by each MICO node in the space and routed to the *Basestation*, interfacing between the 802.15.4 network and another communication medium, such as an ethernet or 4g network.

Under a set of valve schedules, the *Moisture Model* is used to calculate movement of moisture across the surface and through the sub-surface. Sensitive to diffusion, gravity, and soil physics, it determines where water travels after being distributed by sprinklers. However, a discretized moisture movement model may consist of millions of variables and take minutes to solve one problem. As an optimizer may need to evaluate the model thousands of times to converge on a solution, we approximate the model as a linear system to make optimization practical. Once discretized in time and space for numerical evaluation, the model is fed into the *Irrigation Schedule Optimizer* to be converted into a constrained optimization problem. With current sensor readings as initial conditions and a minimum saturation level as a goal state, the *Irrigation Schedule Optimizer* solves the problem to determine an activation schedule for each MICO node in the space that provides sufficient moisture to all turf in the space while minimizing system water consumption.

Computed schedules are then disseminated by the *Basestation* through the wireless sensor network to their respective MICO node. Once received, the *Distributed Control System* then steps through the received schedule and routes power to the attached solenoid to activate the sprinkler.

3. CASE STUDY: LIVE DEPLOYMENT

As all-inclusive models for our application have not been researched, we must deploy an irrigation system that can compare our control modifications to existing systems. Ideally, existing irrigation infrastructure can be used to test our control strategies. However, we found that the granularity of irrigation control on our campus was poor, with regions spanning over 10,000 ft^2 actuated by a single valve. As such, we chose to deploy our own parallel infrastructure to run our experiments. We developed two identical irrigation systems, 70'x70' each, each with 9 MICO nodes uniformly distributed across each. One system uses the control schedules used by the university (Control), and the other uses the control schedules generated by the *Irrigation Schedule Optimizer*. As the two side-by-side irrigation systems have identical topography, lawn type, and irrigation infrastructure, any differences in water consumption and service quality can be attributed to the schedules run by each.

4. EXPERIMENTAL RESULTS

4.1 Quality of Service

To determine if the MICO system maintains lawn health, we compare sensor readings from both systems to the volumetric water content threshold known as the permanent wilting point (θ_{pwp}), where the soil becomes too dry for the plant to extract moisture. Sustained moisture below θ_{pwp} will result in wilting and death of the plant. θ_{pwp} is generally found to be between 10-15% [2], so we assign θ_{pwp} to be a conservative 15%. Figure 2 shows the sensor readings from each of the 9 sprinkler nodes from Control and MICO systems compared to the minimum moisture threshold θ_{pwp}. Across the deployment, the Control system spends a combined 1362 hours beneath θ_{pwp}, in comparison to 417 hours with the MICO system. Although this shows MICO is not perfect, the reduced time spent with insufficient moisture demonstrates that more precise watering strategies by modeling the environment and system can provide an improved quality of service, despite using less water.

4.2 Water Consumption Analysis

Throughout the deployment, actuation was closely monitored to keep track of the total on-time for each sprinkler in both systems. This actuation time is used to calculate each system's total water consumption, based on each sprinkler's regulated flow rate. The water consumption from the Control system is representative of the schedules used by campus groundskeepers. In comparison, the water consumption of the experimental system is found to reduce water consumption over the Control by 9-38% each day, with an average of 23.4% water savings over the span of the deployment.

5. CONCLUSIONS

In this work, we created a computationally-light irrigation moisture movement model that can be analyzed using standard optimization techniques to determine optimal valve scheduling based on environmental conditions and irrigation system. We then develop a prototype sprinkler head with soil moisture sensing, actuation, and wireless communication capability to determine system efficiency improvements with higher granularity of control. These sprinkler nodes are then deployed to irrigate an area of turf covering 10,000ft^2 for 5 weeks. Analysis of the data collected shows that, although the MICO system consumed 23.4% less water, the lawn sustained unhealthy moisture levels 3.23× less than with the Control system, demonstrating an improved quality of service over standard irrigation systems. As a system, MICO is estimated to pay for itself in ∼13 months based on water savings alone.

6. REFERENCES

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