WaterGuard: Toward Cheap Automated Irrigation Systems Powered by the Cloud and TV White Spaces

Gloire Rubambiza
Cornell University, CS
Ithaca, NY, 14853
gloire@cs.cornell.edu

Hakim Weatherspoon
Cornell University, CS
Ithaca, NY, 14853
hweather@cs.cornell.edu

José Martínez
Cornell University, ECE
Ithaca, NY, 14853
martinez@cornell.edu

Abraham Stroock
Cornell University, CBE
Ithaca, NY, 14853
abe.stroock@cornell.edu

1. INTRODUCTION

1.1 Motivation

Global food security in 2050 requires a radical change to current food production approaches. In the US in particular, the United States Department of Agriculture National Institute of Food and Agriculture (USDA NIFA) estimates that crop loss to environmental stresses must be reduced by 20% [8]. Further, USDA NIFA's Agriculture and Food Research Initiative suggests that water use efficiency must improve by 50% [8]. Globally, we must increase farm productivity by 67% to feed billions despite shrinking arable land and receding water levels [5]. Data-driven farming shows promise in achieving this formidable goal. For instance, Almarshadi *et. al* demonstrate that precision irrigation (using sensor measurements) can increase productivity by as much as 45% while reducing water intake by 35% [7].

1.2 Problem Statement

Agriculture constitutes approximately 70% of global water usage, with a good portion dedicated to irrigation. Yet, 50% of the water is wasted to over-watering [9]. In most contexts, data-driven farming techniques consist of a pipelined system: sensing the environment, data transfer from the field to a processing hub, and data actuation. Deploying data-driven irrigation at a rural farm faces three main challenges: *inaccurate sensing*, *poor network connectivity*, and *expensive data processing/actuation*. First, accurate sensing is impeded by soil variability, cost, and other factors [2]. Second, the network connectivity challenge stems from cellular carriers having no incentive to cover sparsely populated rural areas where most farmers operate [6]. Moreover, shipping large amounts (GBs) of data collected from farm sensors, drones, and other inputs in the face of limited network connectivity is daunting. Lastly, irrigation schedules are largely based on farmers' prior knowledge of their fields and recent past climactic patterns, with little to no foresight into future weather forecasts [1].

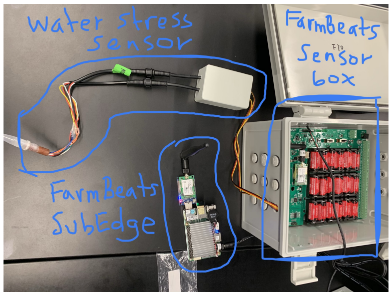

Figure 1: Sample FarmBeats components including a sensor box and SubEdge. The MEMS sensor is wired to a sensor box to detect water stress in the trunk of plants.

2. APPROACH AND CONTRIBUTIONS

We are investigating the feasibility of a cloud-backed network of micro-scale sensors to maximize water use efficiency of automated irrigation systems. With that in mind, this paper presents three contributions:

- **MEMS Water Stress Sensor**: We explore water potential as an alternative to soil moisture to predict water stress and healthy growth of a plant. We measure water potential through a microtensionmeter embedded inside a microelectromechanical sensor (MEMS) emitting millivolt signals indicative of water stress. The measurements are combined and analyzed with other inputs such as weather forecasts to build a predictive model that gives a pulse on the state of a plant.
- **Leveraging free, farmwide connectivity with TV White Spaces (TVWS)**: We demonstrate the limitations, both technical and financial, of a MEMS-based automated irrigation system employing 3G as a relay to a cloud service. Instead, we build upon FarmBeats - a state of the art IoT framework for precision agriculture [2]. Specifically, we propose an architecture where a MEMS sensor attached to a FarmBeats sensor box relays sensor readings to the Azure Cloud (See figure 1). Farm-

ACM ISBN 978-1-4503-2138-9.
DOI: 10.1145/1235

Table 1: Startup and maintenance costs for a 3G-based, baseline system and WaterGuard. The data transmission costs for the Hologram Nova modem assume 255-byte water stress signal transmitted every 6 minutes. The human labor costs for the baseline assume a $16 per hour pay rate where the human operator performs water stress checks every 4 hours on ubidots [10] dashboards.

	Baseline	WaterGuard
Analog-to-Digital (A2D) Converter	CR6 ($1500)	Sensor Box (Approx. $200)
Farmhouse Wi-Fi	$0	$44/month from Spectrum
Farm-wide connectivity	Hologram Nova 3G Modem [3] ($69 up front cost, $1.50 per device per month + 40 cents per MB transferred)	LoRa Radio ($104) and SubEdge ($225)
Raspberry Pi Kits	$146 * 1 ($146)	$146 * 2 ($292)
Analytics	ubidots ($49/month for IoT entrepreneur subscription)	Azure Functions ($8/month assuming 10 executions per hour)
Human labor	$1920/month	$0/month
Total Startup Cost	**$1715**	**$821**
Total Monthly Cost	**$1971**	**$52**

Beats overcomes rural networking limitations by leveraging unlicensed TV white spaces (TVWS) [2] and long range radio (LoRa). Our deployment leverages FarmBeats' LoRa communication cability. In essence, FarmBeats constitutes the forward path from the farm to edge/cloud computing resources.

- **WaterGuard**: A fully automated irrigation system leveraging cheap serverless computing in the cloud, Raspberry Pis optimally placed across a farm, and existing (free) wireless protocols to drive precision irrigation of crops. Therefore, WaterGuard is the backward path from the cloud to the farm. By leveraging the cloud, Waterguard integrates water stress measurements from the MEMS sensor and other inputs such as weather forecasts to produce efficient irrigation schedules based on robust model predictive control [1].

3. EVALUATION

We evaluate WaterGuard via a startup/maintenance cost comparison between a cellular-based (with ubidots [10] cloud service) and a LoRa-based (with Azure cloud) irrigation system. The 3G-based model represents the state of the art in automated irrigation. The results are shown in Table 1. In summary, WaterGuard requires two orders of magnitude less computational and analytical resources (e.g. cloud service subscriptions). A large scale system evaluation of WaterGuard is in progress this Spring.

4. RELATED WORK

As the world grapples with an increasingly limited water supply, considerable research is being devoted to improving water use efficiency, especially in agriculture. Gutierrez *et al.* developed an automated irrigation system using the ZigBee wireless protocol for sensor nodes and a General Packet Radio Service Module (GPRS) for receivers [4]. The system, composed of wireless sensor units (WSU) and wireless information units (WIU), promises up to 90% in water savings compared to traditional open loop and on-off control. Similar to our baseline system, the automated irrigation system exposes a web interface for users to program irrigation remotely. Thus, it suffers from the aforementioned limitations of a human in the loop. Unlike WaterGuard, Gutierrez *et al.* rely on soil moisture and temperature sensors to detect irrigation needs of plants. Both our baseline system and Gutierrez *et al.*'s work are served by GSM-based technologies that do not guarantee neither availability nor scalability in rural areas where most farmers operate.

Acknowledgements
This research was partially supported by NSF (No. 1704742 and 1922551), Cornell Institute for Digital Agriculture (CIDA), and Microsoft.

5. REFERENCES

[1] S. C., C. W., S. A., and Y. F. Robust Model Predictive Control of Irrigation Systems with Active Uncertainty Learning and Data Analytics. In *IEEE Transactions on Control Systems Technology*, pages 1–12, 2019.
[2] V. D., W. J., J. X., C. R., K. A., S. S., S. M., and S. S. Farmbeats: An IoT Platform for Data-Driven Agriculture. In *Proceedings of the 14th USENIX Symposium on Networked Systems Design and Implementation (NSDI '17)*, pages 515–529, Boston, MA, USA, 2017.
[3] Hologram. Hologram Nova. *Hologram*, 2019.
[4] G. J., V.-M. J. F., N.-G. A., and P.-G. M. A. Automated Irrigation Systems Using a Wireless Sensor Network and GPRS Module. *IEEE Transactions on Instrumentation and Measurement*, 63(1), Jan. 2014.
[5] G. H. C. J., B. J. R., C. I. R., H. L., L. D., M. J. F., P. J., R. S., T. S. M., and T. C. Food Security: The Challenge of Feeding 9 Billion People. *Science*, 327(5967):812 – 818, 2010.
[6] L. J. and B. V. Rural America Is Stranded in the Dial-up Age. *The Wall Street Journal*, 2017.
[7] A. M. and I. S. Effects of Precision Irrigation on Productivity and Water Use Efficiency of Alfafa under Different Irrigation Methods in Arid Climates. *Journal of Applied Sciences Research*, 7(3):299 – 308, 2011.
[8] N. K. P. USDA NIFA AFRI Sustainable Agricultural Systems Program Accepting Applications.
[9] U. N. W. W. A. Program. The United Nations World Water Development Report 2018: Nature-Based Solutions for Water. March 2018.
[10] ubidots. Connecting the Dots to the Internet of Things. 2019.