FarmBeats: An IoT System for Data-Driven Agriculture

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Why Agriculture?

Agricultural output needs to **double by 2050** to meet the demands

– United Nations\(^1\)

\(\begin{array}{c|c|c|c}
1950 & 2000 & 2050 \\
\hline
0 & 6 & 8 \\
\end{array}\)

\(^1\): United Nations Second Committee (Economic & Financial), 2009
Agriculture output needs to **double by 2050** to meet the demands – United Nations

But...

- Water levels are receding
- Arable land is shrinking
- Environment is being degraded

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Number of World’s Hungry People

**Source:** FAO.
Solution: Data-Driven Agriculture

Ag researchers have shown that it:
• Reduces waste
• Increases productivity
• Ensures sustainability
But...

According to USDA, **high cost of manual data collection** prevents farmers from using data-driven agriculture.
IoT System for Agriculture
Problem 1: No Internet Connectivity

• Most farms don’t have any internet coverage

• Even if connectivity exists, weather related outages can disable networks for weeks
Problem 2: No Power on the Farm

• Farms do not have direct power sources

• Solar power is highly prone to weather variability
Problem 3: Limited Resources

• Need to work with sparse sensor deployments
  • Physical constraints due to farming practices

• Too expensive to deploy and maintain
Beyond Agriculture

How can one design an IoT system in challenging resource-constrained environments?
In this talk

- FarmBeats: An end-to-end IoT system that enables seamless data collection for agriculture
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• FarmBeats: An end-to-end IoT system that enables seamless data collection for agriculture

• Solves three key challenges:
  • Internet Connectivity
  • Power Availability
  • Limited Sensor Placement

• Deployed in two farms in NY and WA for over six months
Challenge: Internet Connectivity

(Farmer’s home/office)  Cloud

Microsoft Azure
Challenge: Internet Connectivity

Sensors

(Farmer’s home/office)

• Few miles away
• Obstructed by crops, canopies, etc

Cloud
Idea: Use TV White Spaces

• Can provide long-range connectivity

• Can travel through crops and canopies, because of low frequencies

• Large chunks are available in rural areas=> can support large bandwidth
Idea: Use TV White Spaces

- **Base Station**
  - TV White Spaces
  - Few miles
  - (Farmer’s home/office)

- **Cloud**
  - Weak Connectivity
  - Prone to outages

- **Wi-Fi, BLE**

- **Sensors**
Idea: Compute Locally and Send Summaries

• PC on the farm delivers time-sensitive services locally

• Combines all the sensor data into summaries

• 2-3 orders of magnitude smaller than raw data

• Cloud delivers long-term analytics and cross-farm analytics
FarmBeats Design

Base Station

Sensors

TV White Spaces
Few miles

Gateway PC
(Farmer’s home/office)

Cloud

Microsoft Azure
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Challenge: Limited Resources

• Need to work with sparse sensor deployments
  • Physical constraints due to farming practices
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• How do we get coverage with a sparse sensor deployment?
Idea: Use Drones to Enhance Spatial Coverage

• Drones are cheap and automatic

• Can cover large areas quickly

• Can collect visual data

Combine visual data from the drones with the sensor data from the farm
Idea: Use Drones to Enhance Spatial Coverage

Drone Video → Panoramic Overview → Precision Map

Sparse Sensor Data
Formulate as a Learning Problem

Panoramic Overview

Training Data

Prediction
Model Insights

• **Spatial Smoothness:** Areas close to each other have similar sensor values

• **Visual Smoothness:** Areas that look similar have similar sensor values
Model

Features (visual)

Kernel (Model visual similarity)

Output (say, moisture)

Spatial Smoothness

\[ i = 1 \text{ to } N \]

\[ x_i \]

\[ y_i \]

\[ W \]

\[ K \]

- **Training Phase**: Learn \( K \) and \( W \)
- **Test Phase**: Generate outputs for unknown areas
FarmBeats can use drones to expand the sparse sensor data and create summaries for the farm.
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  • Power Availability

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Challenge: Power Availability is Variable

Battery dies due to cloudy/rainy/snowy weather
TV White Spaces

Gateway
(Farmer's home/office)

Cloud
Challenge: Power Availability is Variable

• Solar powered battery saw up to 30% downtime in cloudy months

• Miss important data like flood monitoring

How do we deal with weather-based power variability?
Idea: Weather is Predictable

• Use weather forecasts to predict solar energy output

• Ration the load to fit within power budget
Idea: Weather is Predictable

- $\gamma$: Duty Cycle ratio, $T_{on}$: On time in each cycle, $T_{off}$: Off time

- $\gamma = \frac{T_{on}}{T_{off}}$

- Constraints:
  - Power Neutrality: $\gamma P \leq C$
  - Minimum Transfer Time: $T_{on} \geq T_{connect} + T_{transfer}$
Solution: Weather is predictable

Minimum Transfer Time: $T_{on} = \gamma T_{off} \geq T_{connect} + T_{transfer}$

Optimal for minimum latency

Power Neutrality: $\gamma P \leq C$

FarmBeats can use weather forecasts to duty cycle the base station, with minimum latency
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Deployment

• Six months deployment in two farms: Upstate NY (Essex), WA (Carnation)
• The farm sizes were 100 acres and 5 acres respectively
• Sensors:
  • DJI Drones
  • Particle Photons with Moisture, Temperature, pH Sensors
  • IP Cameras to capture IR imagery as well as monitoring
• Cloud Components: Azure Storage and IoT Suite
Deployment Statistics

• Used 10 sensor types, 3 camera types and 3 drone versions

• Deployed >100 sensors and ~10 cameras

• Collected >10 million sensor measurements, >0.5 million images, 100 drone surveys

• Resilient to week long outage from a thunderstorm
FarmBeats: Usage

TV White Spaces

Gateway
(Farmer’s home/office)

Cloud

Farm
Example: Panorama

- Water puddle
- Cow excreta
- Cow Herd
- Stray cow
Precision Map: Panorama Generation
Precision Map: Moisture
Precision Map: pH
FarmBeats can accurately expand coverage by orders of magnitude using a sparse sensor deployment.
Weather-Aware Duty Cycling

Reduced downtime from 30% to 0% for month long data (September)
Related Work

• **Wireless Sensor Networks:** Sensor networks for agriculture (Baggio `05, Sanchez et al `11, Lee et al `10,…), LPWAN technologies (LoRA, SIGFOX, …)

• **Agriculture:** Precision agriculture (Bratney et al `99, Mueller et al `12, Cassman et al `99,…), Nutrient measurement (Kim et al `09, Hanson et al `07)

• **ICTD:** Information access and user interfaces (Zhao et al `10, Doerflinger et al 2012)
Conclusion

• FarmBeats: First end to end IoT system for environments constrained by:
  • Limited internet connectivity
  • Power Variability
  • Sparse Sensor Deployment

• Acts as a tool to enhance farm and farmer productivity

• Used by farmers for applications beyond precision farming
Thank you!

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