Comosum: An Extensible, Reconfigurable, and Fault-Tolerant IoT Platform for Digital Agriculture

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Comosum Technical Contributions

- Distilled black-box SOTA down to a single interface
- Applied strong systems approaches to new contexts
- Deployed across different farm types and cloud providers

4 Years 18 months 1M+ sensor readings
Background

DA Challenges & State of the art

Comosum Design & Implementation

Deployment Experiences, Insights & Limitations

Conclusion
What is Digital Agriculture (DA)?

Growing ability to… convert precise data… into actionable knowledge to … support complex decision-making on farms

Priorities for Science to Overcome Hurdles Thwarting the Full Promise of the ‘Digital Agriculture’ Revolution. Shepherd et al. 2018
What is Digital Agriculture (DA)?
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[Diagram showing components of Digital Agriculture including sensors, networking, processing software, cloud, application programming interfaces (API), and artificial intelligence (AI).]

Farm House
What is Digital Agriculture (DA)?
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Motivating Challenges in DA

Greenhouse: KB/hour

The Effects of Light-emitting Diode Lighting on Greenhouse Plant Growth and Quality. Olle & Viršile. 2013
Motivating Challenges in DA

Greenhouse: KB/hour  Dairy Farm: MB/day

Image Credit: Martin Perez

Effect of Automating Health Monitoring on Detection of Health Disorders and Performance of Lactating Dairy Cows. Perez et al. 2021
Motivating Challenges in DA

Greenhouse: KB/hour

Dairy Farm: MB/day

Vineyards: TB/year

Scalable early detection of grapevine virus infection with airborne imaging spectroscopy. Romero Galvan et. al. 2023
Rural Infrastructure Challenges

- Sparse population & geography
  - Internet connectivity
  - Public transportation
  - Power
Rural Infrastructure Challenges

• Sparse population & geography

• Scale & distance limit access to:
  • Provider maintenance and repair
  • Repair parts for self-repair

5G, Uber, and Chromebooks should solve this

Image Credit: https://knowyourmeme.com/memes/mocking-spongebob

Thinking Relationally about Digital Inequality in Rural Regions of the U.S. Jenna Burrell. 2018
Rural Infrastructure Challenges

- Sparse population & geography

- Scale & distance

- Service provider tactics lead to:
  - Closed system and manuals
  - Reselling sensor data and resulting insights
Rural Infrastructure Challenges

- Sparse population & geography
- Scale & distance
- Vendor lock-in
Research Question:
How do we build data-intensive IoT apps on top of unreliable rural infrastructure?
Infrastructure Challenges ➡ Desired Technical Features

• Sparse population & geography ➡ • Reconfigurable networks
  • Energy efficiency

• Scale & distance ➡ • Fault tolerance
  • Failure detection
  • Independent failures
  • Off-the-shelf (OTS) parts

• Vendor lock-in ➡ • Open-source X-ware
  • Accessible data analytics
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State of the art: Sensing

Bandwidth: 50kbps - 10Mbps

State of the art: Sensing
State of the art: Cloud computing

Cloud computing
Ubiquitous, convenient, on-demand network access to storage media and compute devices.

State of the art: Edge computing

Cloud computing
Ubiquitous, convenient, on-demand network access to storage media and compute devices.

Edge computing
A distributed computing framework that brings applications closer to data sources.

What is Edge Computing. IBM. 2022.
The distributed cloud avoids vendor lock-in
Revised Research Question: How do we build an *extensible*, *reconfigurable*, and *fault tolerant* IoT platform on top of *unreliable* base infrastructure?
Building **Comosum** on unreliable base infrastructure

**Research Contribution**: Design, implementation, and deployments of a reconfigurable platform for DA experimentation
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Conclusion
Backyard deployment  
Oct 2020

TVWS config  
Mar 2021

Dairy farm visit  
Feb 2023
Comosum Design aka The Software Defined Farm (SDF)
Comosum Design: The Analytics Module
Comosum Design: The Actuation Module
Comosum Design: Extensible Data Plane
FarmBIOS: A Comosum Implementation
FarmBIOS: A Comosum Implementation

Reconfigurable Control Plane

Hardware Devices

Sensors

Networking

Vendor Cloud

1a

REST, FTP

2a

1b

1c

Software

Analytics

Telemetry

Storage

Compute

Actuation

FarmBIOS Lib

FarmBIOS RPC Protocol (register, read, notify, etc)

FarmBIOS Message Format

Network (TCP Sockets)
FarmBIOS: A Comosum Implementation

Extensible Data Plane
FarmBIOS: A Comosum Implementation

Network-agnostic dispatcher
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FarmBIOS Applications

WaterGuard

CowsOnFitbits

WineGuard

Image Credit: Martin Perez

Image Credit: Fernando Romero Galvan
FarmBIOS Deployments: WineGuard

<table>
<thead>
<tr>
<th>Training</th>
<th>Data Location</th>
<th>Data Size</th>
<th>Compute</th>
<th>Storage</th>
<th>Runtime</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge</td>
<td>Local</td>
<td>4MB</td>
<td>8 CPUs</td>
<td>256GB</td>
<td>27.1s</td>
<td>82%</td>
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<tr>
<td>Edge</td>
<td>Cloud</td>
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<td>8 CPUs</td>
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<tr>
<td>Azure ML</td>
<td>Cloud</td>
<td>-</td>
<td>2 vCPUs</td>
<td>100GB</td>
<td>86.5s</td>
<td>84%</td>
</tr>
</tbody>
</table>
FarmBIOS Deployments: WaterGuard

9 sensors hubs
1 **TVWS** client/base station
2 **LoRa** antennas
2 Edge devices (4GB RAM, 32GB storage)
FarmBIOS Deployments: WaterGuard

Networking: Campus Fiber Optic

TVWS Base Station

Edge Cloud 1: LoRa + TVWS

Base station

TVWS Client

LoRa module

Sensor Hubs

Edge Cloud 2: LoRa + 4G

Base station

4G hotspot

LoRa module

Sensor Hubs

Sensor Hubs

Base Station

LoRa antenna

dBi hotspot

TVWS Base Station

TVWS Client

FarmBeats: An IoT Platform for Data-Driven Agriculture. Vasisht et al. 2017
Adapting to the wild: offline data collection

Total deployment: **18 months**
Average deployment: **223 days**
**1M+** sensor readings
Faulty sensors and config errors affect data analytics
Active digital twin notifies human operators if a sensor hub twin diverges from its physical twin.
**Active digital twin** notifies human operators if a sensor hub twin diverges from its physical twin.
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DA Challenges & State of the art
Comosum Design & Implementation
Deployment Experiences, **Insights & Limitations**
Conclusion
Practical Insights & Limitations

- Extending to new vendors comes with minor costs
  - New scripts for each vendor (50 LoCs)
Practical Insights & Limitations

● Extending to new vendors comes with minor costs
  ○ New scripts for each vendor (50 LoCs)

● The cloud complicates reconfigurability
  ○ Treat incoming parameters as abstract data types (ADTs)
Practical Insights & Limitations

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  ○ New scripts for each vendor (50 LoCs)
● The cloud complicates reconfigurability
  ○ Treat incoming parameters as abstract data types (ADTs)
● **Failure in DA is the norm, not the exception**
  ○ Active digital twins detect divergence
Practical Insights & Limitations

- Extending to new vendors comes with minor costs
  - New scripts for each vendor (50 LoCs)
- The cloud complicates reconfigurability
  - Treat incoming parameters as abstract data types (ADTs)
- Failure in DA is the norm, not the exception
  - Active digital twins detect divergence
- **No automated migrations during permanent outages**
  - Future work
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Comosum Experiences, Insights, Limitations

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Comosum Experiences, Insights, Limitations

https://github.com/Cornell-CIDA-Dev/Software-Defined-Farm

Total deployment: **18 months**
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Thanks
Thank You

Questions?

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