College of Engineering / Department of Computer Science and Engineering

Autonomic Computing Challenges in Fully Autonomous Precision Agriculture

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INTRODUCTION

- Earth's population by 2050: 9.7B
  - 1.7x more food needed
  - Food demands exacerbated by climate change
- Only 60-80% of seeds planted yield edible crops
- Precision Agriculture (PA) is used to improve crop yield
  - Uses aircraft, satellites, soil sensors, etc
- Yield Map: A PA report describing the yield of a crop field
- Yield Maps can be expensive to produce or inaccurate
  - Piloted aircraft are expensive to fly
  - Satellite images have very low spatial resolution
- FAAS can decrease the cost of yield map creation
- FAAS: edge and cloud systems and UAV that combine with deep object detection models and pathfinding logic to perform high level operations with little human interaction
- FAAS can be used to create Fully Autonomous Precision Agriculture (FAPA) systems

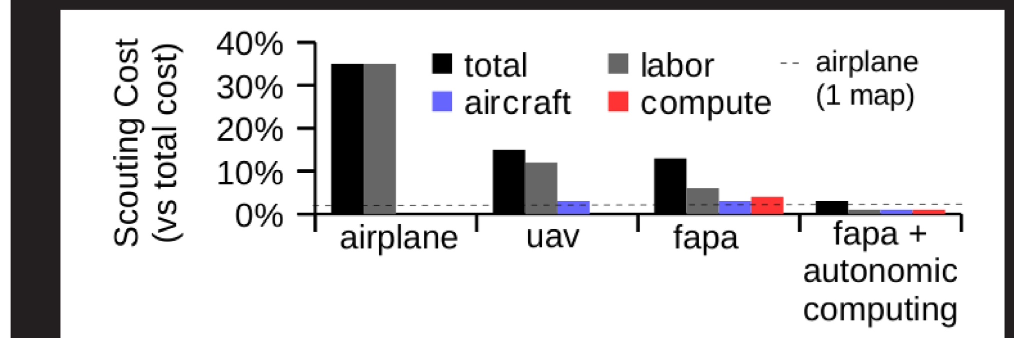
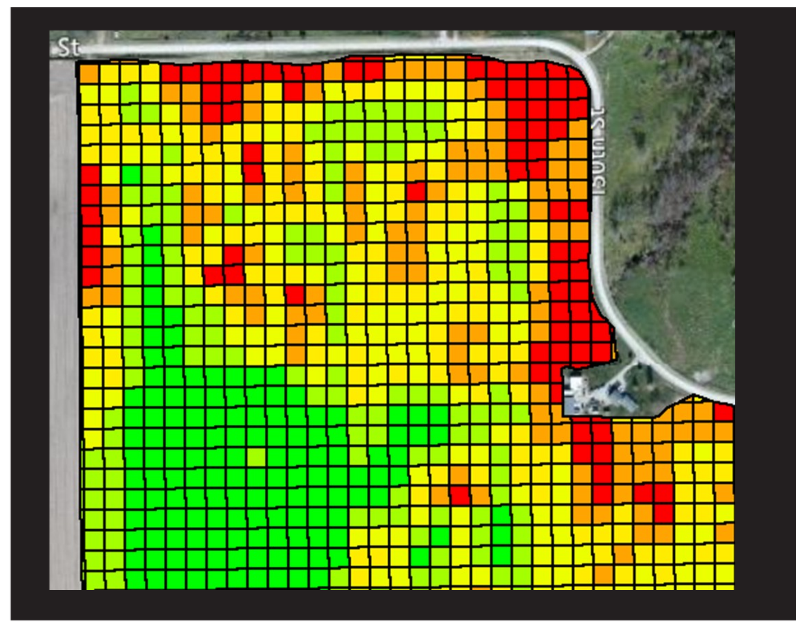


Fig. 1. Fully autonomous precision agriculture reduces and shifts costs.



DESIGN

- FAAS can be used to create yield maps
- Hardware Architecture:
  - UAV
  - Bae Station
  - Edge Server
  - Data Center
- Software Architecture:
  - Feature Extraction
  - State Modeling
  - Reinforcement Learning

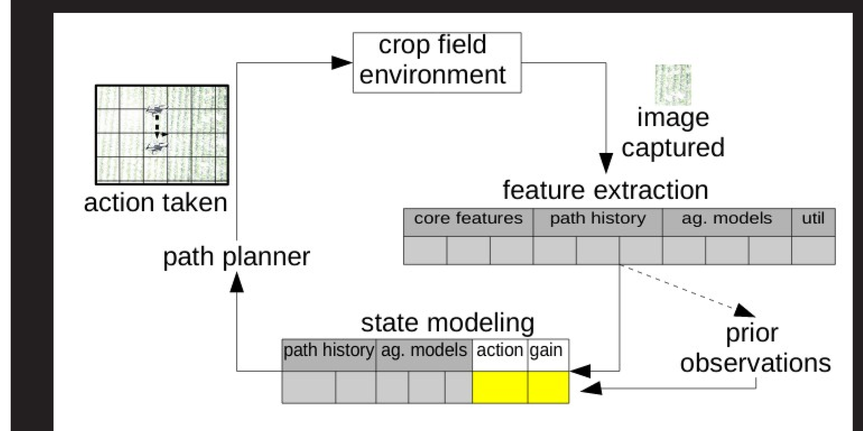


Fig. 3. Reinforcement learning underlies our approach.

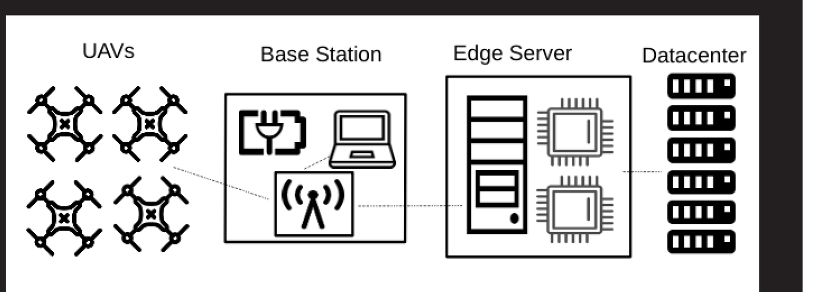


Fig. 2. Core agricultural FAAS system components.

- FAPA Design:
  - Collect data using UAV
  - Add to partial yield map
  - Once all data is collected:
    - Construct total yield map
    - Return results to farmer

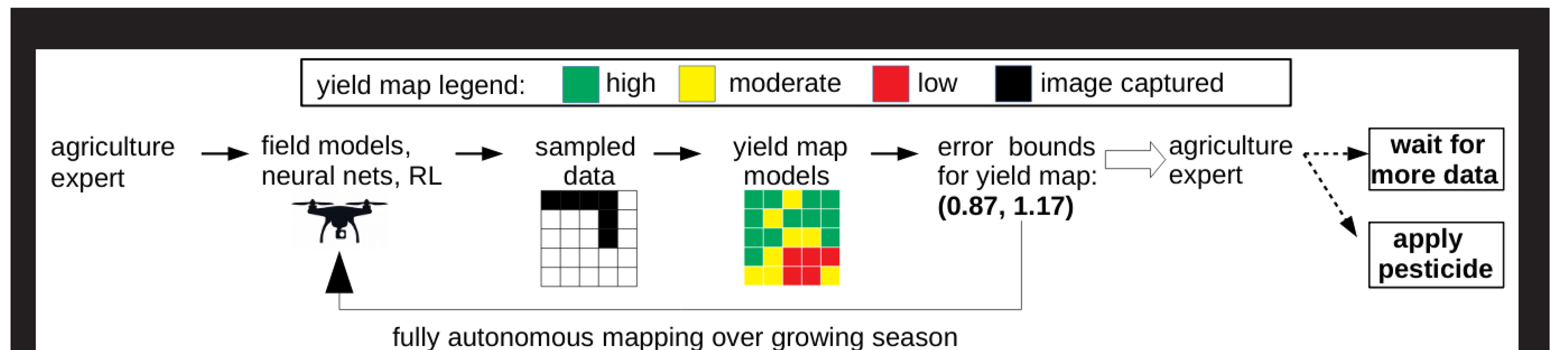
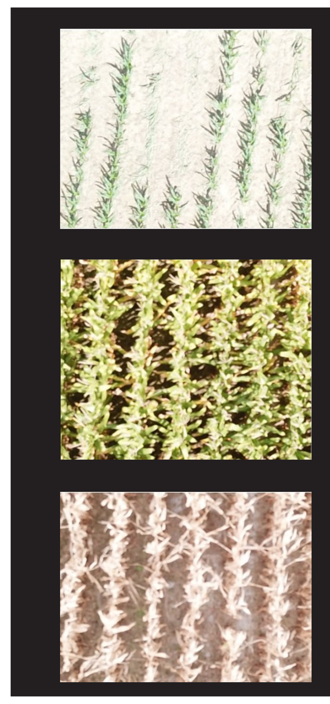


Fig. 4. Fully autonomous precision agriculture

IMPLEMENTATION

- Dataset: Over 10,000 images from Ohio Corn Fields
  - 75 acre corn field
  - 12 megapixel images
  - 4mm spatial resolution
  - Data captured at 3 points in the growth cycle
- Simulated 1350 FAAS yield mapping missions using the algorithm below

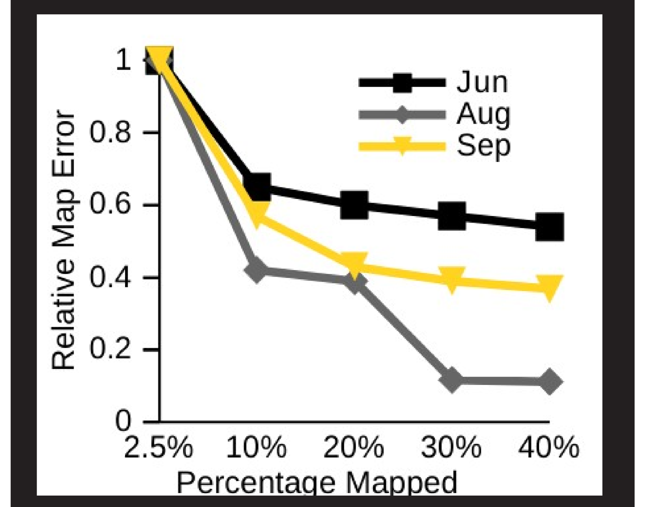


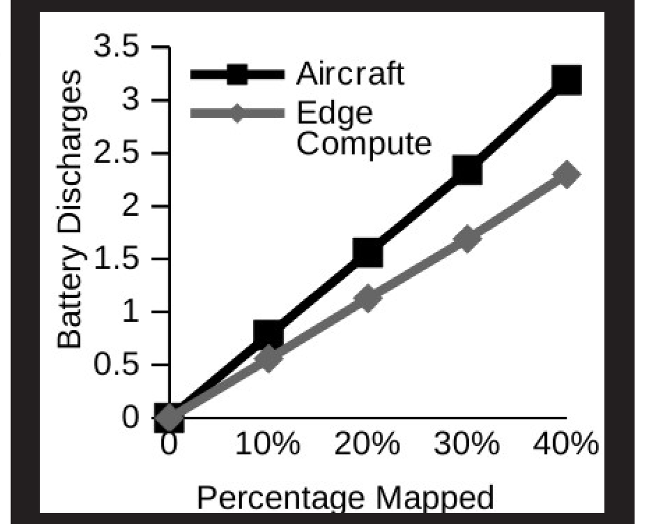
Algorithm 1 FAPA Simulation

1: *yieldmap* ← empty
2: *i* ← starting image
3: *ensembleError* ← ∞
4: **while** *ensembleError* > threshold **do**
5: *featVec* ← extract(i)
6: yieldmap[featVec[lat],featVec[lon]] = featVec[GE]
7: *errVector* ← findNextFlightAction(featVec)
8: *dir* = min(errVector)
9: *i* = nextImage(i, dir)
10: *imagesMapped* ← error(dir)
11: return extrapolate(yieldmap)

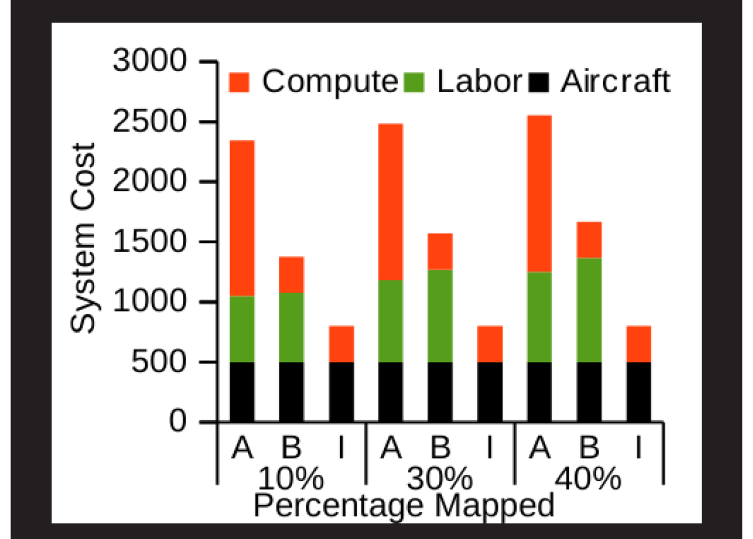
RESULTS

- Simulator was fed 7,000 corn field images in 1350 sample executions
- Energy demands were tested offline using real UAV and mapped to simulator actions
- Our yield map creation algorithm produces relatively low error maps by viewing just 40% or less of the field
- We found that aircraft battery discharge slightly outpaces edge discharge using our setup
- While edge systems are easy to provision, UAV battery life is hard to increase
- An ideal FAPA system would include a highly provisioned edge system controlling multiple UAV





- Decreasing system cost is paramount to FAPA
- Current system requires labor
- Ideal system would require no labor, relying instead on autonomic software components



DISCUSSION

- Many autonomic concepts could be included in FAPA systems to improve performance and decrease cost
- Autonomic Management Layer:
  - A new layer between middleware and application
  - Utilizes and ensemble of autonomic models to manage system components
- Required to implement autonomic components like edge to cloud bursting and adaptive power management

Topic	Systems Layer	Adaptive Computing Challenges
Self-Aware Integration	Autonomic Management	Seamlessly integrate features extracted by other devices on nearby fields
Quality-Adaptive Models	Autonomic Management	Speedup feature extraction when accuracy does not degrade outcome
Load Balancing	Middleware	In swarms, dynamically re-partition fields to avoid long recharging delays
Adaptive Power Management	OS/ Architecture	Duty cycle power hungry devices while keeping execution time low
Edge to Cloud Bursting	OS/ Architecture	Use cloud resources to multiplex thin edge clients across multiple fields
Micro-UAV Swarms	Cyber physical	Reuse smaller, cheaper aircraft over multiple mapping missions and fields
Performance Modeling	Pervasive	Model end-to-end execution time of mapping missions

CONCLUSIONS

- PA can help close the yield gap and feed our growing population
- We propose a FAAS approach to precision agriculture we call FAPA
- We demonstrate that our system can produce low-error yield maps by sampling 40% or less of a crop field
- We identify future autonomic computing challenges that face FAPA which can decrease labor and hardware costs

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