RFID JOURNAL LIVE!

SEPTEMBER 26 - 28, 2021

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How to Take Inventory with Drones

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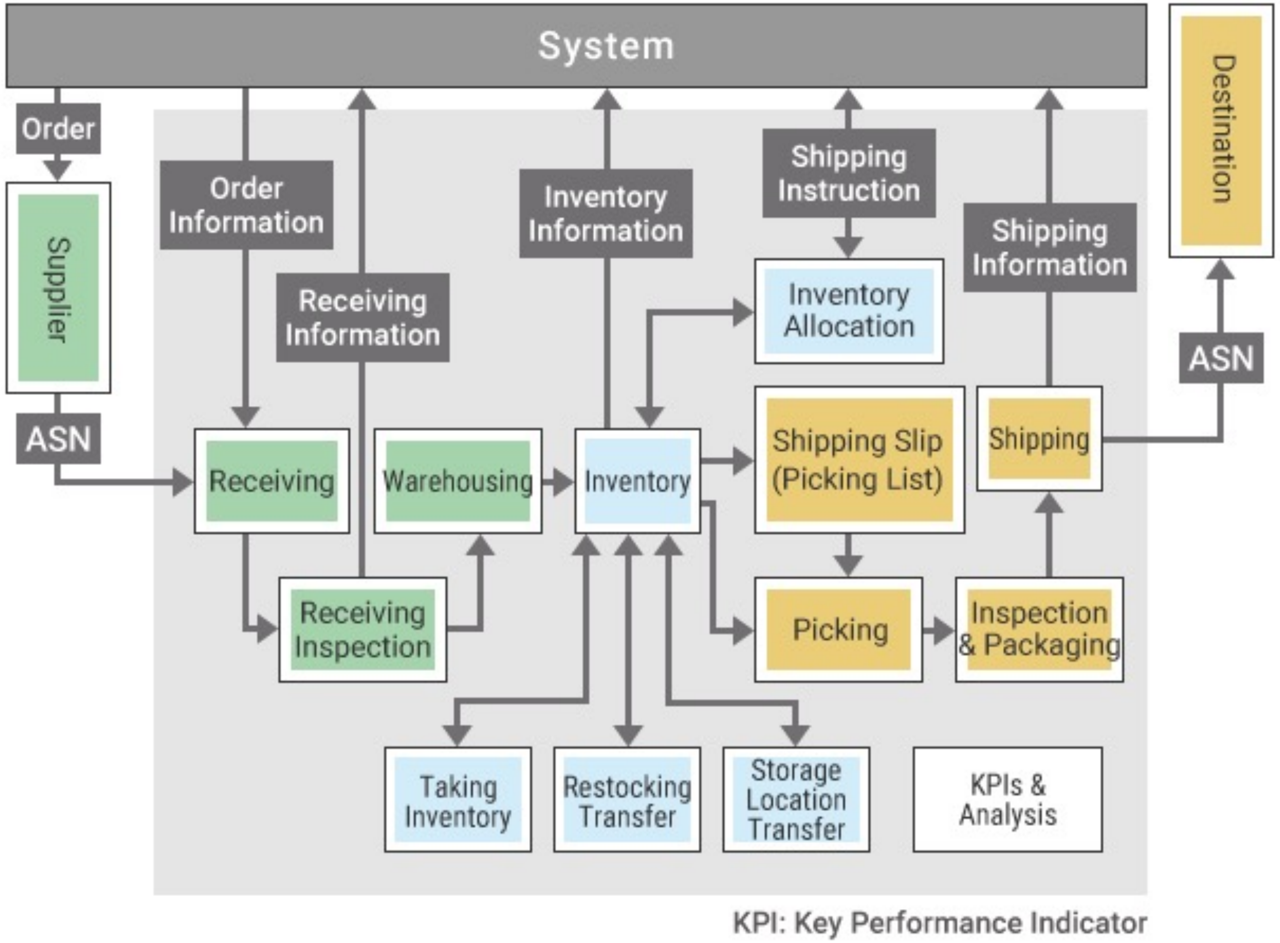
Agenda

- Introduction
- Warehousing and Inventory
  - Indoor Inventory
  - Outdoor Inventory
- Precision Agriculture
- Animal Tracking
- Conclusions
- References

Warehousing and Inventory

Complexity of Logistics Inventory



Importance of Inventory

Many business decisions and performance measures are related to inventory

- Purchasing
- Sales
- On Time Delivery
- Lot Sizing
- Safety Stock, shrinkage
- Depreciation
- Inventory Transport & Carrying Cost

Manufacturing: Types of Inventory

- Raw Materials
- Work In Progress
- Finished Goods
- Goods in Transport

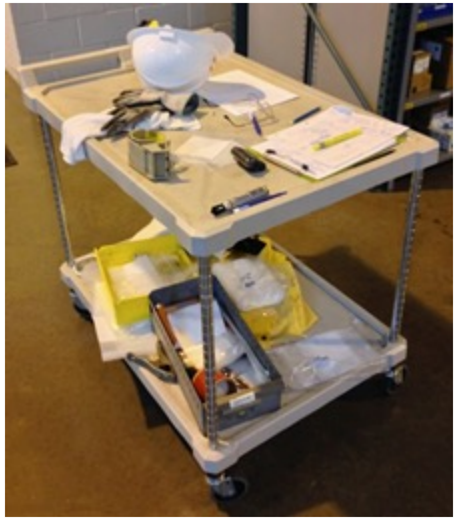
Inaccurate inventory causes customer complaints, lost sales, and penalties of various types.

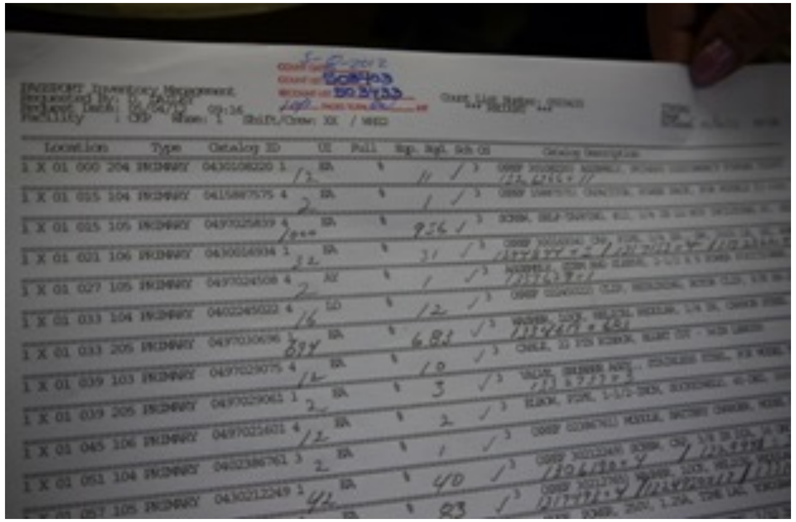
The cost to keep accurate inventory is VERY HIGH!

Manual Inventory Count

Common Set-Up:

- Packages labeled with barcode
- Worker/Sales Rep equipped with barcode scanner/printed sheets






24
Digit
EPC
Database
24
Digit
EPC

Semi-Automating Inventory Tasks

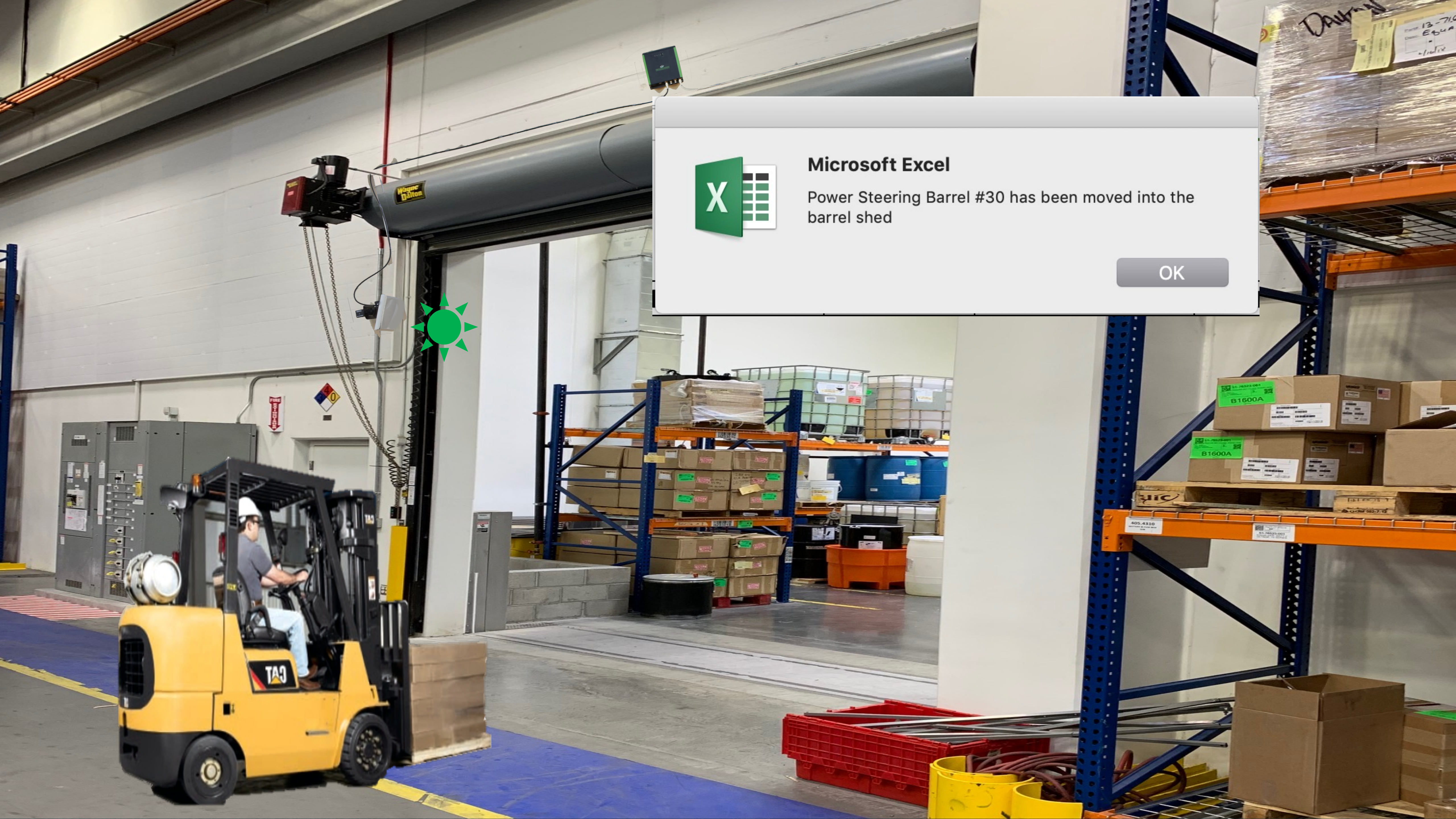
Set-Up:

- Packages tagged with RFID
- Vehicle equipped with RFID reader, antennas, tag printer

- MAIN ADVANTAGE: VEHICLE RECORDS INVENTORY RFID WHILE PERFORMING PICK & PLACE TASKS


24 Digit RFID EPC Number
24 Digit Barcode Number
Database
SEPTEMBER 26 - 28, 2021


THIS ROW: MAXIMUM PERMISSIBLE LOADING
WARNING
FIRE
FLAMMABLE
KEEP FIRE AWAY
THIS ROW: MAXIMUM PERMISSIBLE LOADING


Microsoft Excel
Power Steering Barrel #30 has been moved into the barrel shed
OK
B1600A
B1600A

Dock Door Scan & Display

- Captures inventory moved into truck
- Compares to shipping plan
- Displays items
- Touch screen allows modifications

Refresh Filter

Tag Management > SGTIN's

105104 Records

1 2 3 4 5 ... 1052

SGTIN	Filter	Quantity	Catalog ID with Quality Level and Serial Number
204020.0091194.0	Item	1	0402009119-4-0000000000
204020.0091204.1	Item	1	0402009120-4-0000000001
204020.0091204.2	Item	1	0402009120-4-0000000002
204020.0091214.1	Item	1	0402009121-4-0000000001
204020.0091214.2	Item	1	0402009121-4-0000000002
204020.0091214.3	Item	1	0402009121-4-0000000003
204020.0091214.4	Item	1	0402009121-4-0000000004
204020.0260504.1	Item	1	0402026050-4-0000000001
204020.0260514.1	Item	1	0402026051-4-0000000001
204020.0260524.1	Item	1	0402026052-4-0000000001
204020.0260534.1	Item	1	0402026053-4-0000000001
204020.0260964.1	Item	1	0402026096-4-0000000001
204020.0260964.2	Item	1	0402026096-4-0000000002
204020.0263264.1	Item	1	0402026326-4-0000000001
204020.0263264.2	Item	1	0402026326-4-0000000002
204020.0263264.3	Item	1	0402026326-4-0000000003
204020.0263854.1	Item	1	0402026385-4-0000000001
204020.0263854.2	Item	1	0402026385-4-0000000002
204020.0263934.1	Item	1	0402026393-4-0000000001

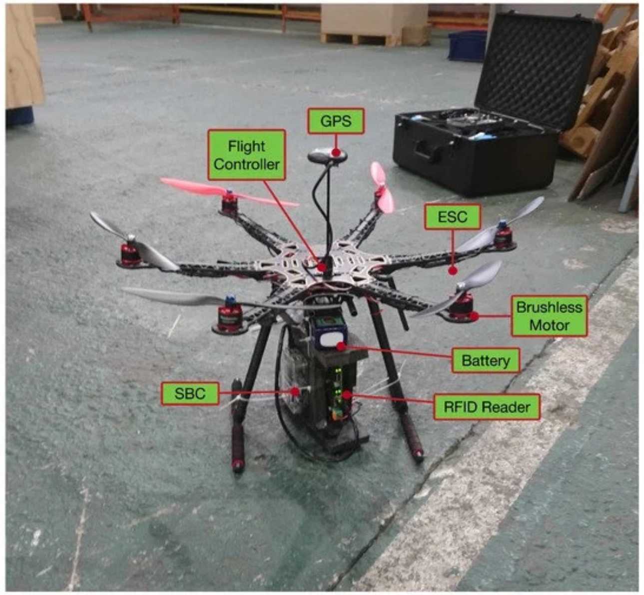
Automating Inventory Tasks

Common Set-Up:

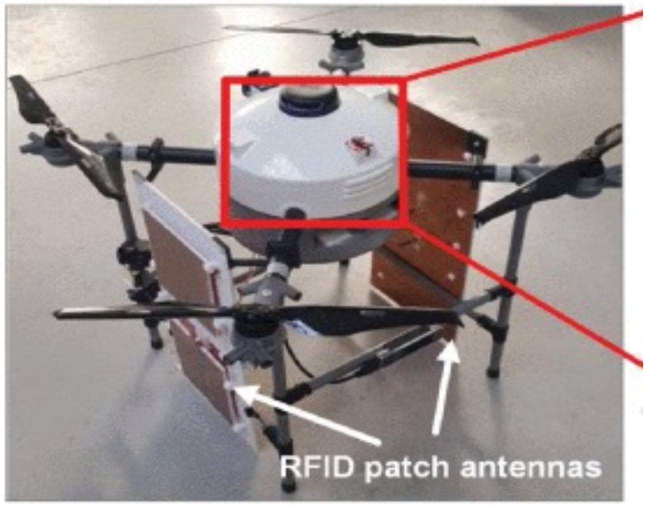
- Packages tagged with RFID
- Vehicle equipped with RFID reader, antennas, tag printer

Inventory tasks can be automated using RFID and UAV [8]

- Study conducted by Universidade de Coruña, Spain Research
- RFID tags placed on various packaging materials
- Tag location read by UAV
- Data stored in a blockchain-based system
- Allows data validation and security
- Collects and processes inventory data in real time

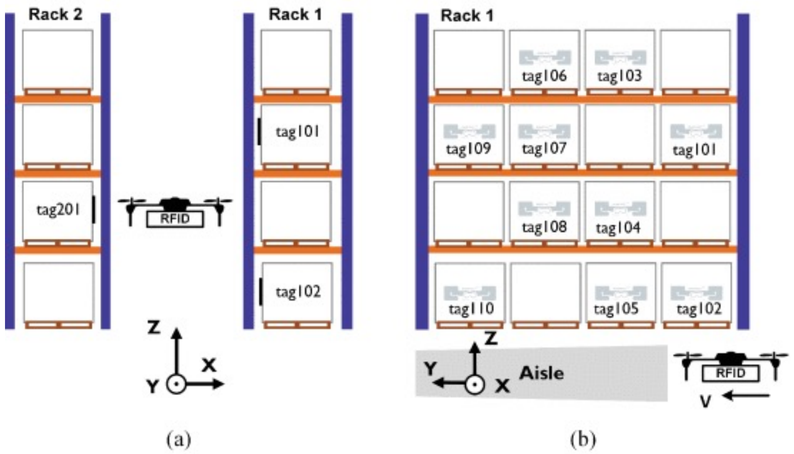


Identification of Packages



Received Signal Strength Identification (RSSI) [14]

- Strength of RFID tag reading is used to locate its position
- Signal strength maps can potentially be created



ReLoc 2.0, IEEE Research (Lab tested) [14]

- Onboard antennas can have interference from environment
- ID factors: rack number, tag lateral location, rack-level distinguishing
    - Measured phase, RSSI, readability

Conceptual Possibilities (Simulated)

Tracking of perishable items [7]

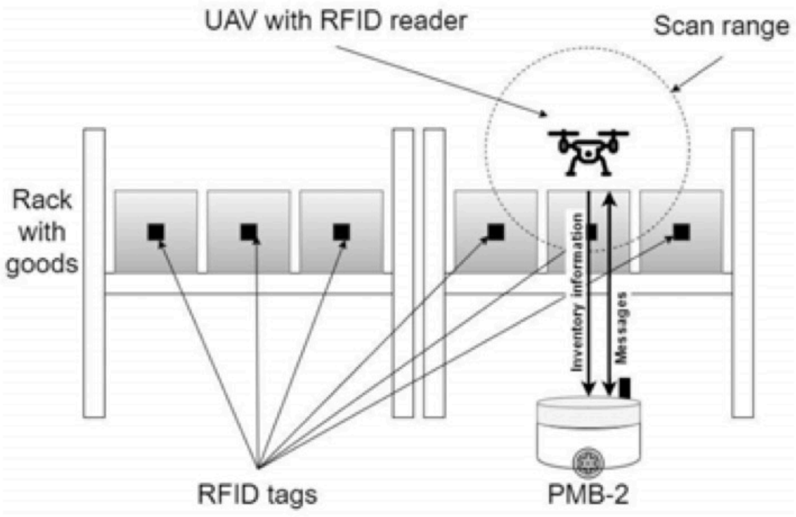
- Utilizing RFID and dielectric tags in tandem to check freshness of bottled items when conducting inventory

Autonomous path planning and decision making [11]

- UAV path planning utilizing RFID tag-based localization algorithms

Cooperative robotic missions [12]

- Unmanned ground vehicles (UGV) working in tandem with UAVs for faster RFID inventory



Outdoor Inventory Management

Open storage areas

- Stockyards and construction sites often have greater horizontal area to cover
- Inventory location won't always be as predictable as indoor shelves
- Wide open areas make precise positioning systems infeasible, so rough GPS data must be used

Environmental Hazards

- Drones and Readers/Antennas subject to rough weather

Current Technologies

Squadrone System: Apach Drone with RFID Load [6]

Andromeda Systems Incorporated: ADVISOR Drone [1]

Localization Techniques

Recurrent Neural Network[23]

- Predicts tag position using the independent variables on the right and neural network with a short-term memory of previous variables

K-Nearest Neighbors algorithm[24]

- Predicts position with machine learning algorithm that assumes similar independent variables indicate similar tag positions

SARFID[4]

- Uses precise drone position, RSSI readings and the assumption of immobile tags to calculate position on the scale of centimeters

Dependent Variables	
Tag Position	Estimated coordinates of the targeted tag
Independent Variables	
Drone Position	Position of Drone taken from GPS
Drone Rotation	Rotation of the drone, as rotation can affect RSSI
RSSI	Measured returned signal strength of RFID tag

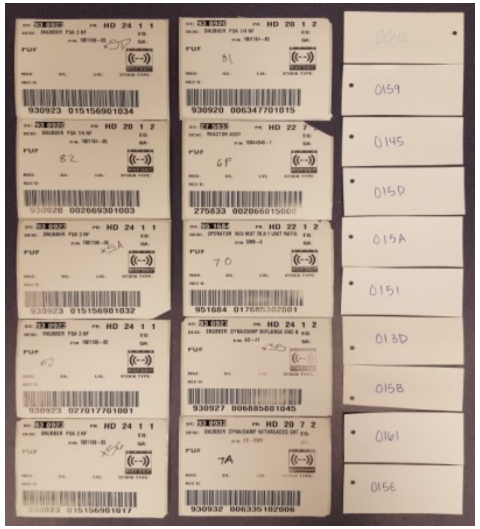
Inventory of Oilfield Tubulars

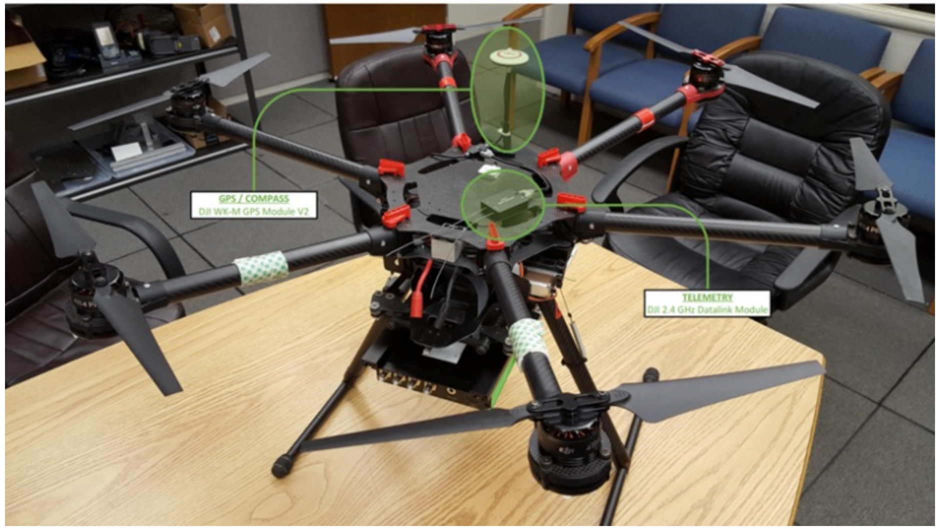
Hundreds or thousands tubulars

Across large fields

Labor Intensive Inventory

RFID to the Rescue





Passive UHF RFID

Tag cost = $0.15

Adhered to pipe cap
or to foam insulator

RFID reader on UAV

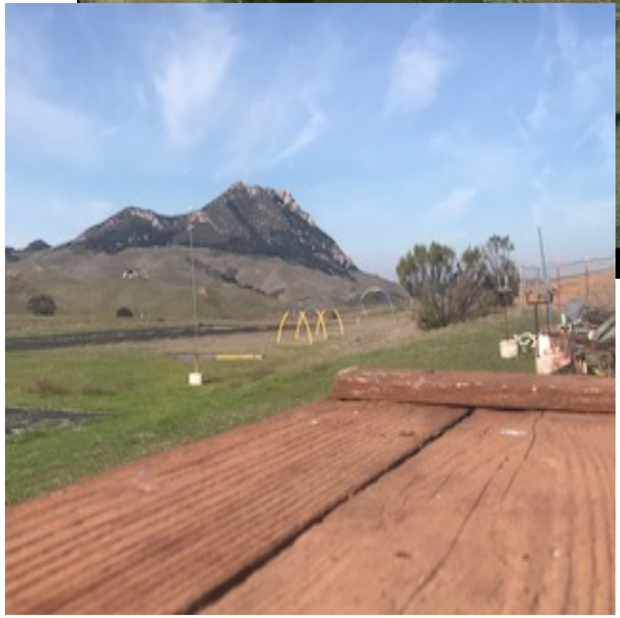
Experiment #1 – Establish Base Read Range

Experimental Flight Range

Read range testing

Zip ties for tag attachment

Promising results – 12’



Experiment #2 – Reading Reliability on Oilfield Tubulars

Santa Maria Holdings Site

Oil drilling pipes

Tags on insulation strips

Results: 3m 100% read 2 minute hover time

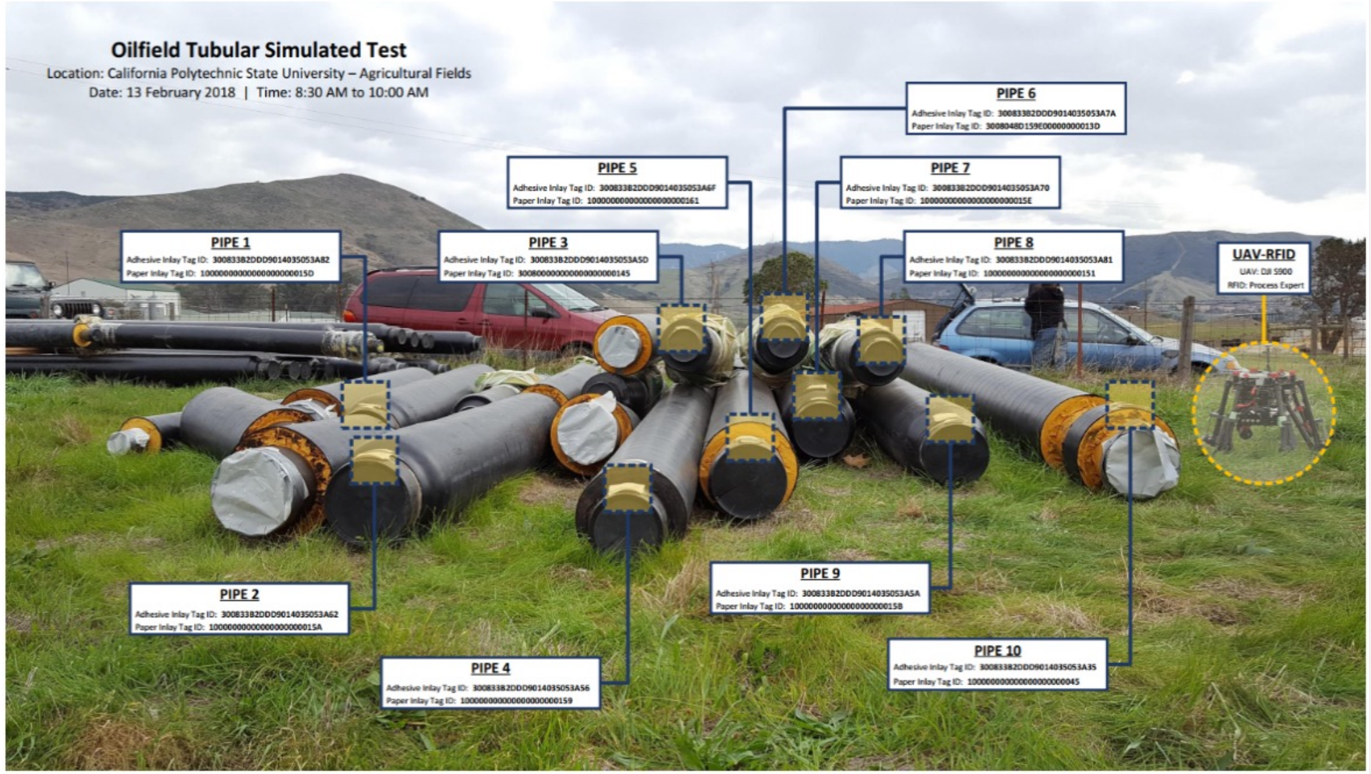
Experiment #3 – Reading 2 Tag Types

Cal Poly Experimental Site

Insulated hot water pipes

Insulated tags on metal
Labels on pipe insulation

Results: 2.5m 95% read
2 minute hover time



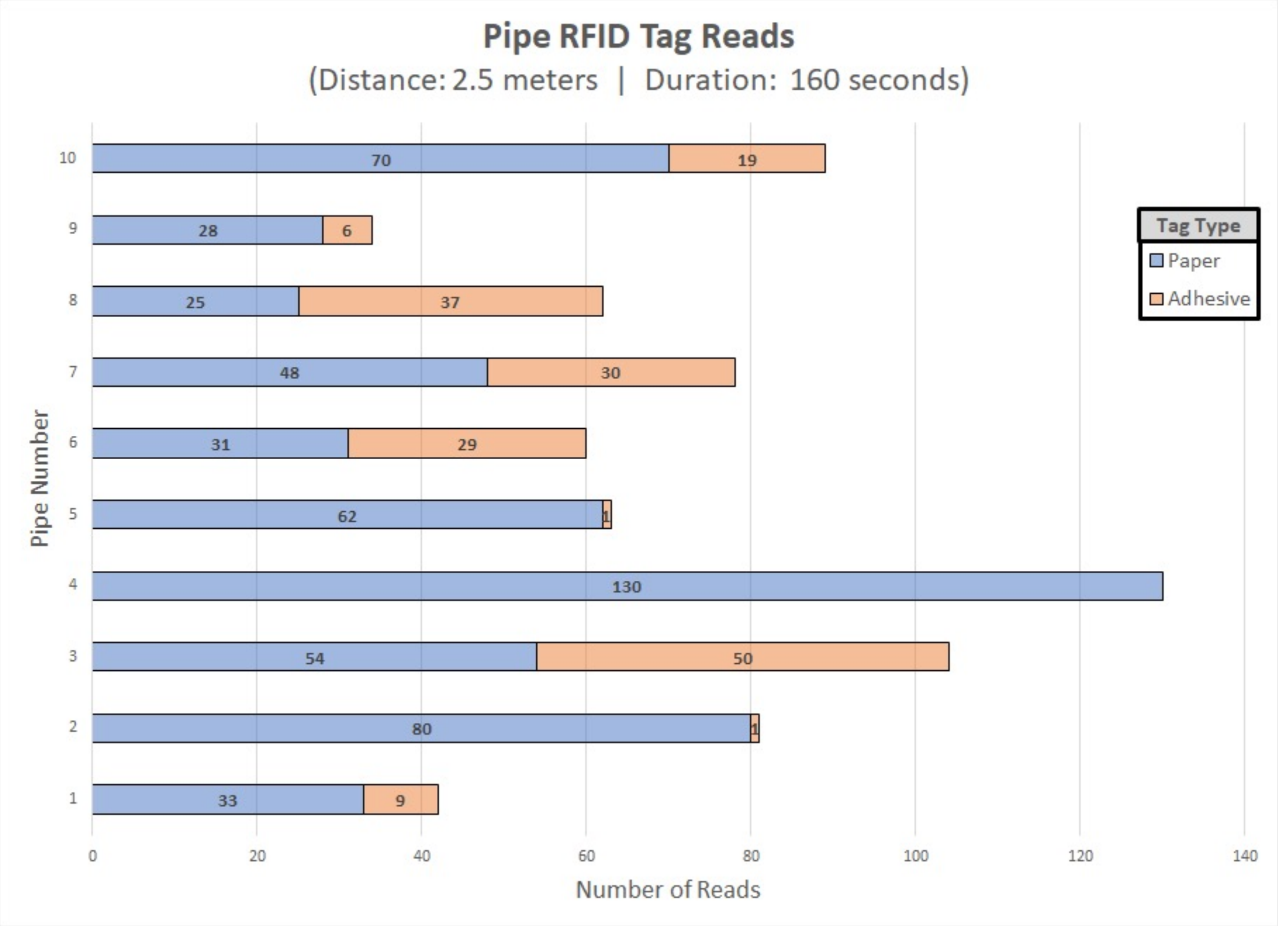
Number of Tag Reads – Reading Reliability

Variability is common

Experiment with tag types

Experiment with insulation

Results: 2.5m 95% read with adhesive,
100% read of paper tags



UAV and RFID Reader, Antenna & Tags Information

Process Expert’s DroneStock

Oil Drilling Pipe Tags

DroneStock hovers above pipes

Reader & Antenna

Outdoor Equipment Inventory

Using

Artificial Intelligence

and

Machine Learning

Link to Video

Autonomous Navigation, e.g., Mission Planner

Mission Planner

ARDUPILOT
Versatile, Trusted, Open

Search docs

Donate

- Individual
- Partners
- SWAG Shop

Mission Planner Home

The Mission Planner, created by Michael Oborne, does a lot more than its name. Here are some of the features:

- Point-and-click waypoint/fence/rally point entry, using Google Maps/Bing/Open street maps/Custom WMS.
- Select mission commands from drop-down menus
- Download mission log files and analyze them
- Configure autopilot settings for your vehicle
- Interface with a PC flight simulator to create a full software-in-the-loop (SITL) UAV simulator.
- Run its own SITL simulation of many frames types for all the ArduPilot vehicles.

Optimized Route

Similar to Autonomous Robot

Collision Avoidance

Low Battery Crash Prevention

Route Design

Background
System Constraints

RFID scanning radius

350 ft ≈ 106m

RFID scanning area

35753 m2

UAV Flight Speed

16 m/s

UAV Flight Time per Charge

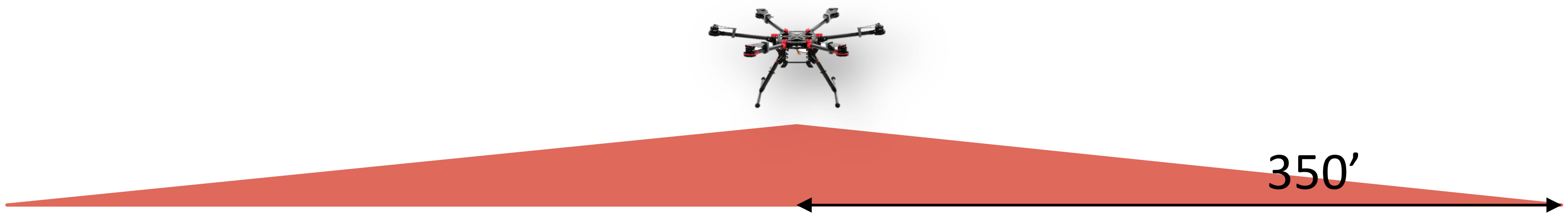
15 min

Ranch Area

2,562 acres

Intesive Grazing Pasture Area

up to 293 acres



Problem

To utilize the RFID-UAV system for cattle tracking, the following must be considered:

- *The location of each cow is unknown within the pasture.*
- *The UAV must fly within 350’ of each cow.*
- *The UAV flight time is limited to 15 minutes.*

Alternatives Considered
System Adjustments

- Increase the flight time
- Enhance read range
- Additional UAV + RFID interrogator
- Reduce the flight path

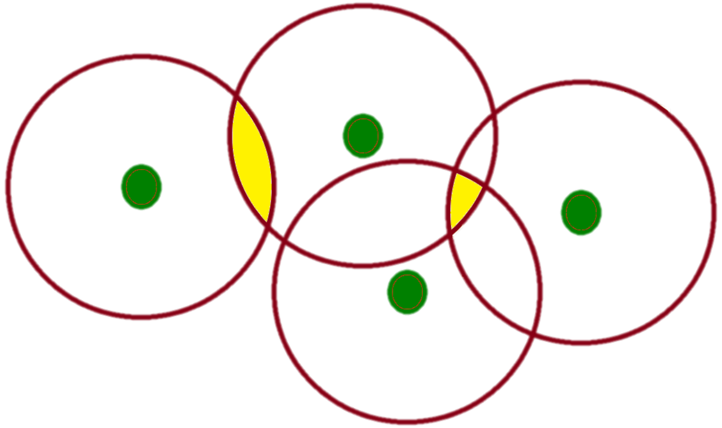
Path Optimization Method – *Close Enough Traveling Salesman Problem*

1. Identify Nodes
2. Heuristic Approach to Minimize Number of Nodes
3. Traditional TSP Solution

Identify the Nodes

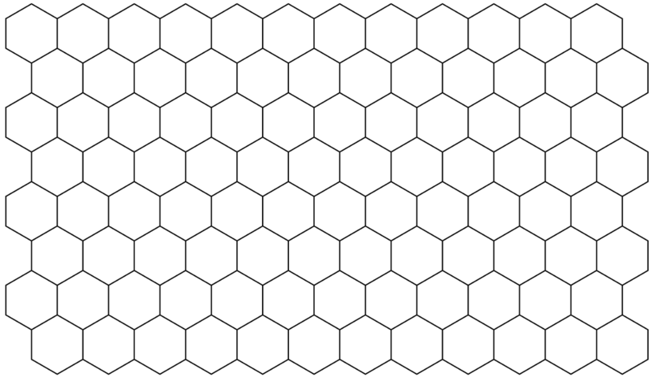
STEINER ZONE

- Circle drawn around each target
- Supernode set defined by overlapping circles
- Target location must be known



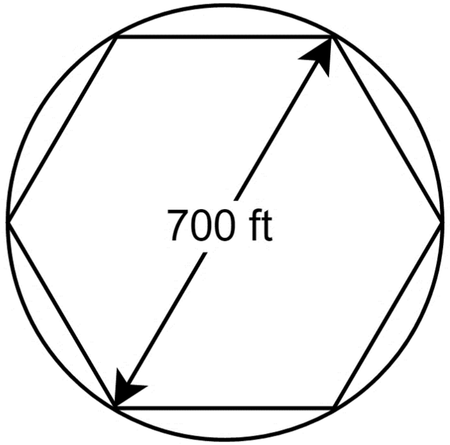
TILING

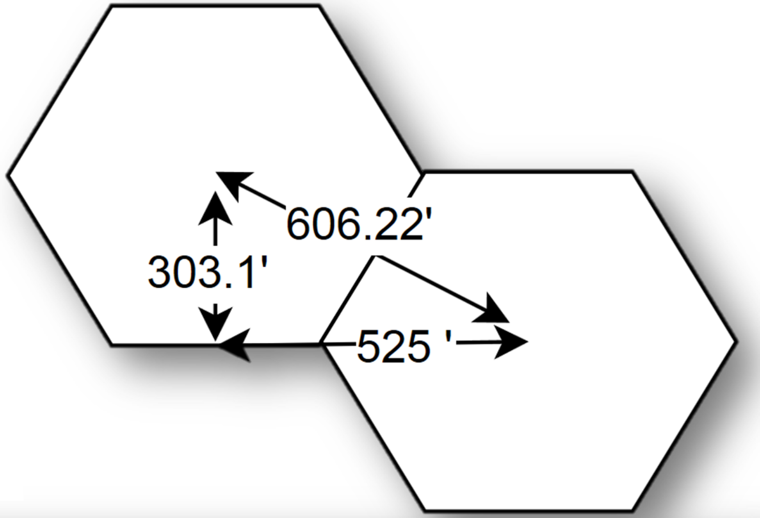
- Discretization of area
- Nodes defined by midpoint of each area
- Target location may be unknown

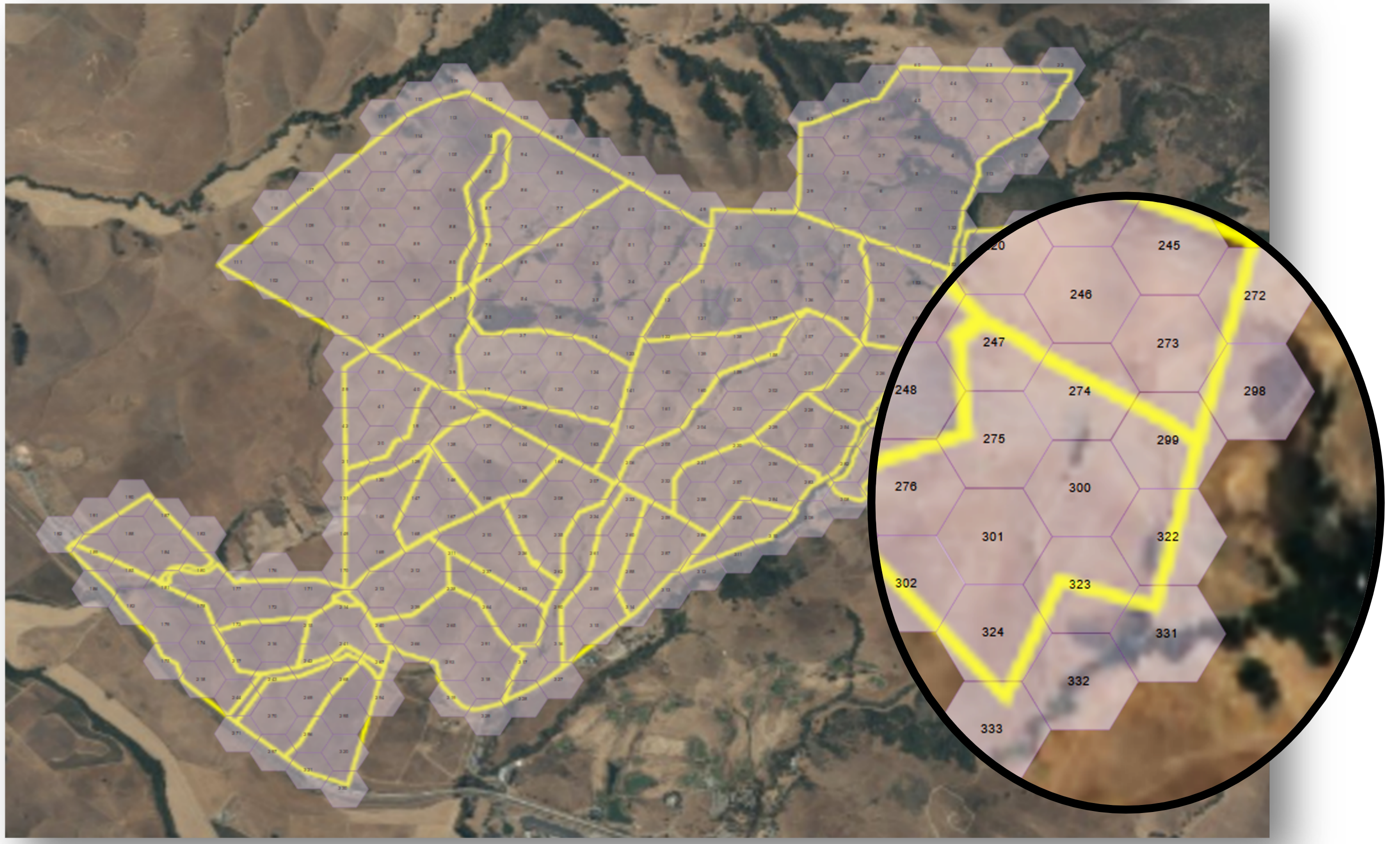


Tiling

- Hexagonal Lattice
- Heuristic approach to minimize nodes



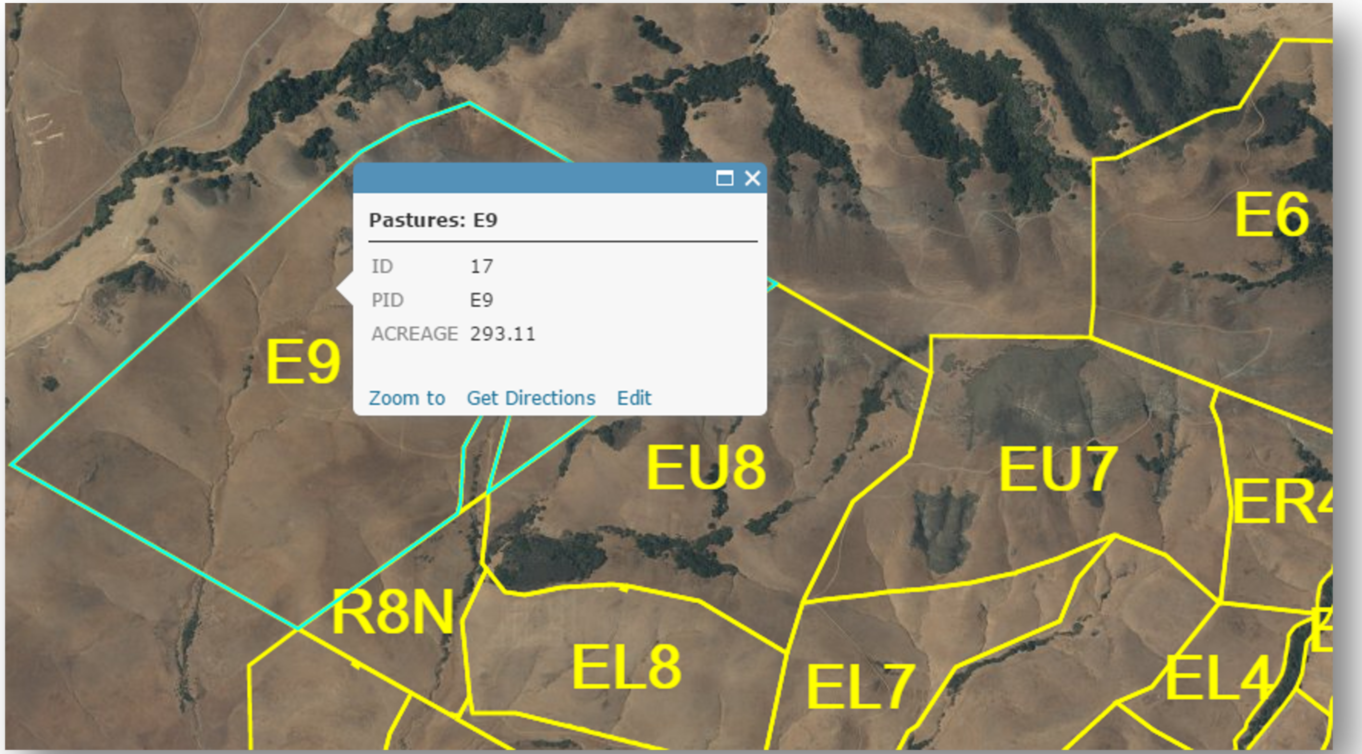




Pasture E9

Minimum Number of Nodes Visited

$$293.11 \text{ acres } \times \frac{43{,}560\text{ft}^{\ 2}}{1 \text{ acre}} \times \frac{\text{area scanned per node}}{384{,}845\,\text{ft}^2} \approx \boldsymbol{33\ nodes}$$



Traveling Salesman Problem

Objective Function

$Minimize \sum c_{ij}x_{ij}$

- $subject\ to$
  - $\sum_i x_{ij} = 1\ \forall_i$
  - $\sum_j x_{ji} = 1\ \forall_j$
  - $0 \leq x_{ij} \leq 1\ x_{ij}$ (integer)
  - $u_i - u_j + nx_{ij} \leq n - 1, \forall i, j \in N - \{1\}, i \neq j$

Variables

$$x_{ij} = \begin{cases} 1\ if\ arc\ ij\ is\ in\ the\ tour \\ 0\ otherwise \end{cases}$$

u: sequence in which node i is visited

n: number of nodes in tour

N: total number of nodes

c: arc length

Pasture E9

Path Length

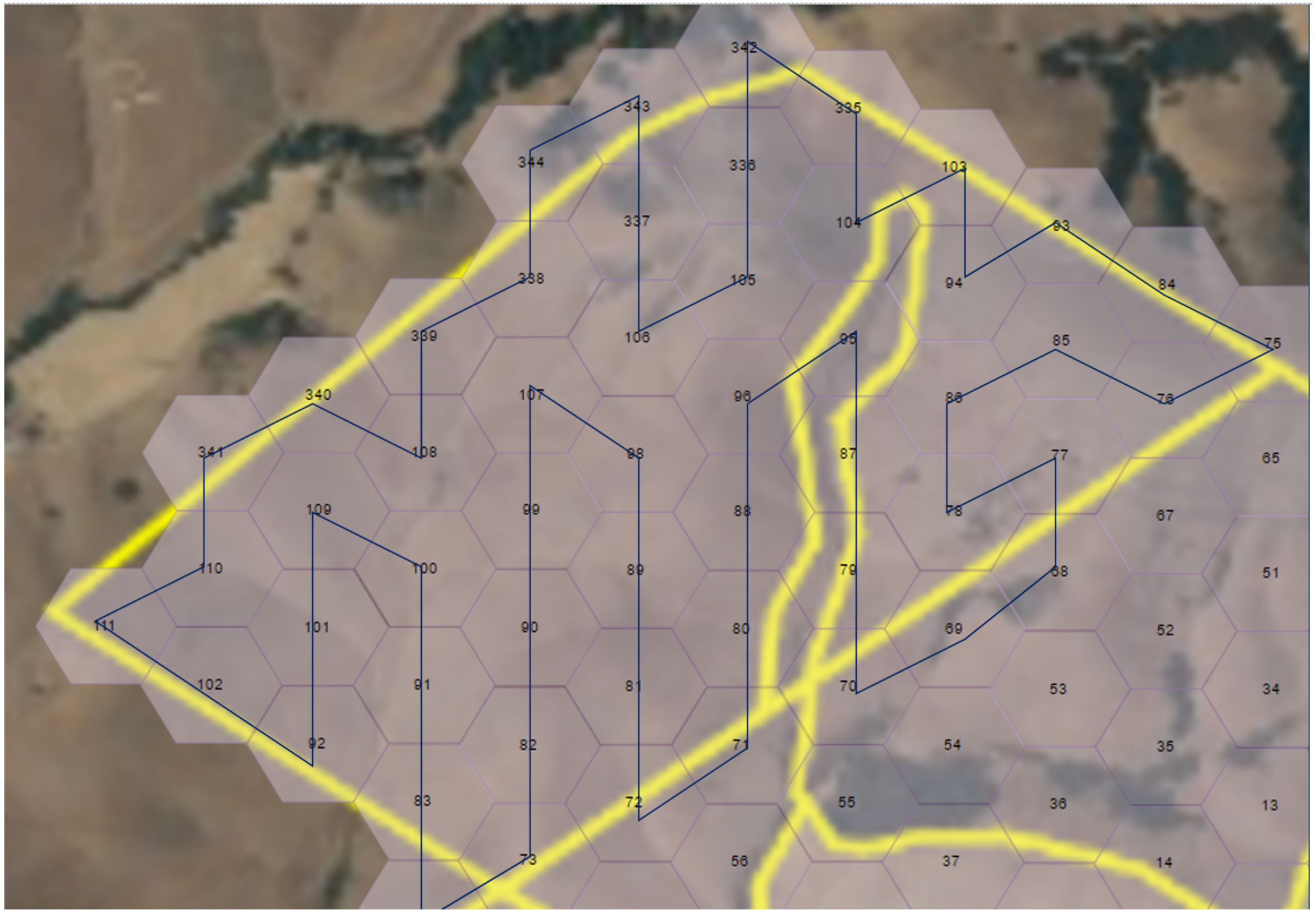
32,129.5ft

Flight Time

32,129.5ft x (52.5ft/s x 60s/min)

+ Ascent /Descent Time

= **10.21 minutes**



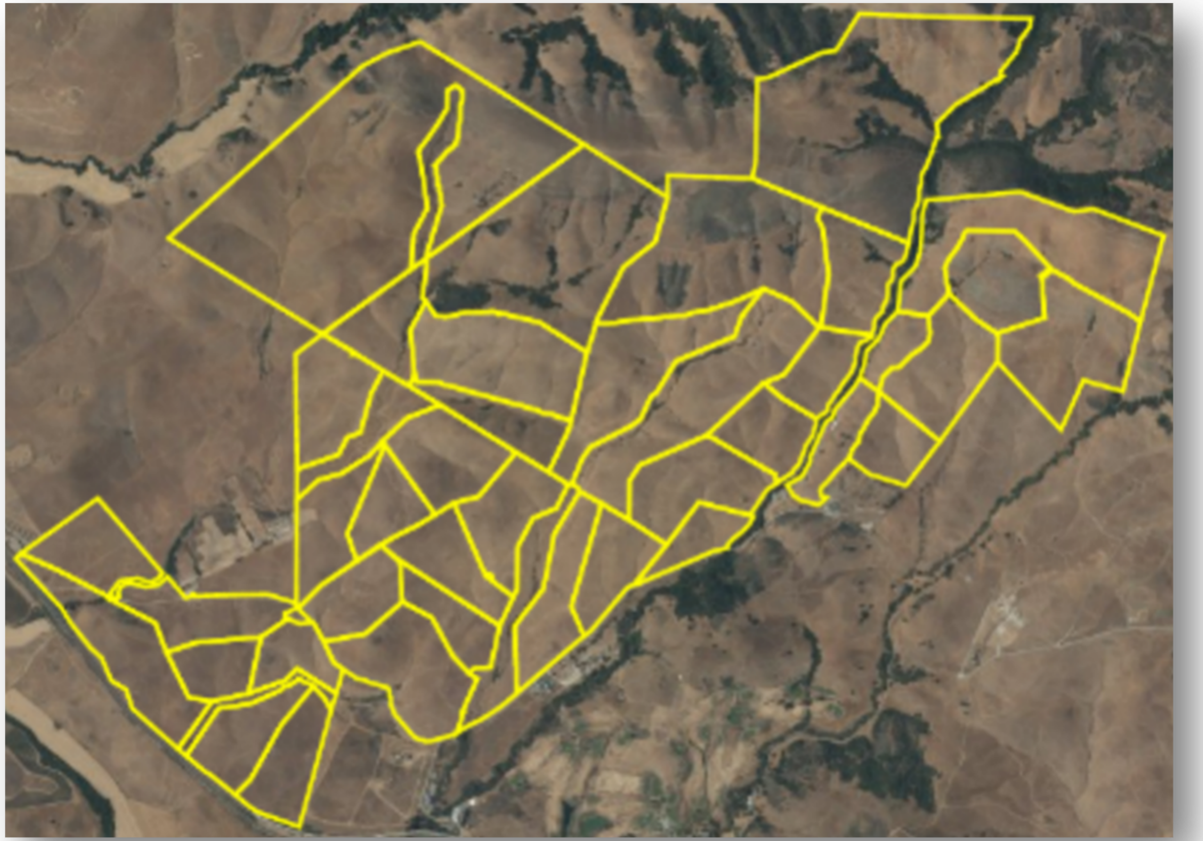
Walters & Escuela Ranches

Minimum Number of Nodes Visited

$$2562\text{ acres} \times \frac{43{,}560\text{ft}^{2}}{1\text{ acre}} \times \frac{\text{area scanned per node}}{384{,}845\text{ft}^2} \approx \boldsymbol{290\ nodes}$$

Time to Travel to all Nodes

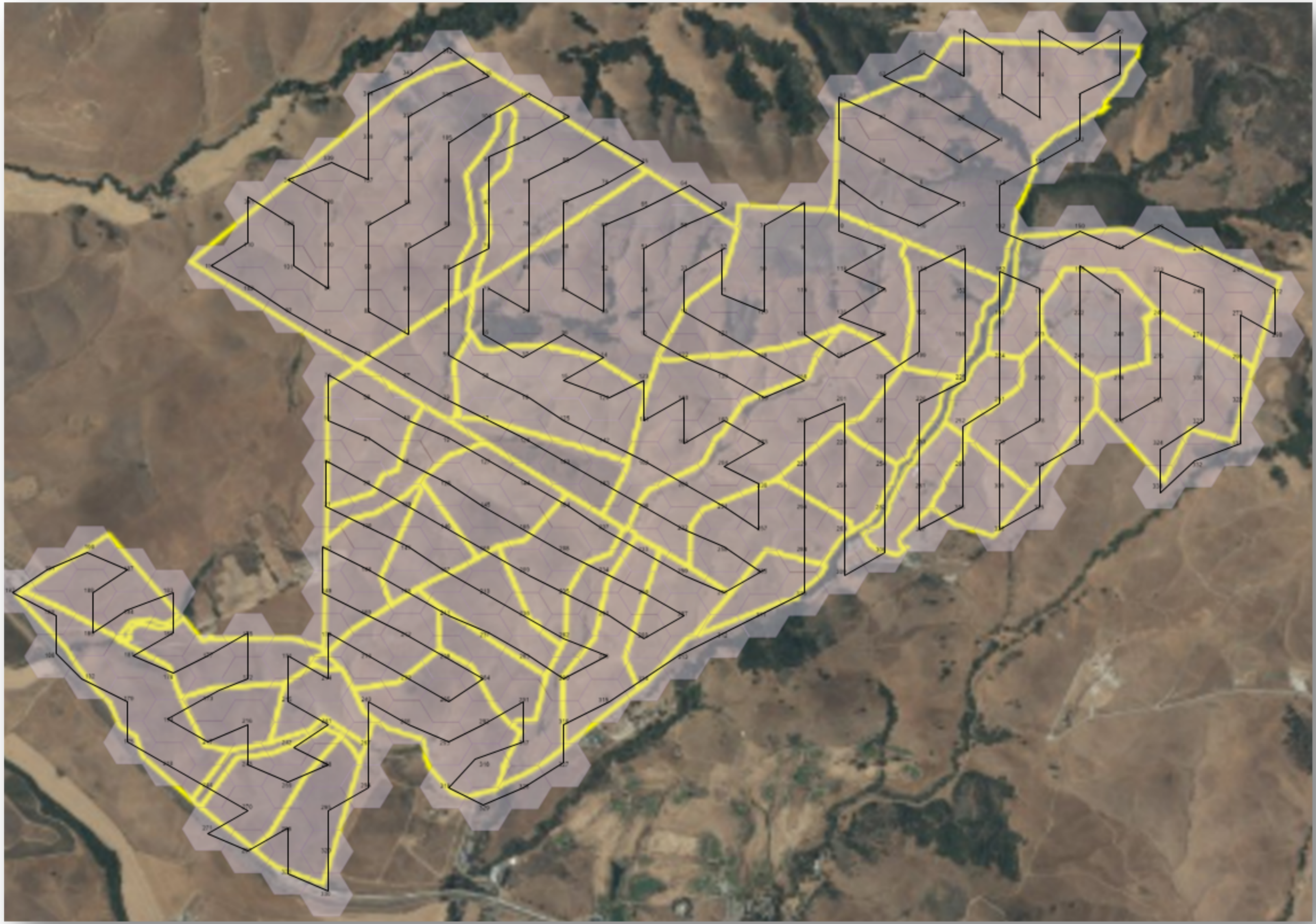
$$290\text{ nodes } \times 700\text{ft between nodes} \div \frac{52.5\text{ft}}{s} = \boldsymbol{64.47\ min}$$



Traditional Grazing

205,508ft

65 min total flight time



Precision Agriculture

The Need for Precision Agriculture

- National freshwater shortages are concerning the agriculture industry

- Improving irrigation efficiency would product similar yields for less water

The Importance of Soil Moisture

A crops yield, quality, and lifecycle can be directly affected by its soil moisture

Soil moisture determines: [10]

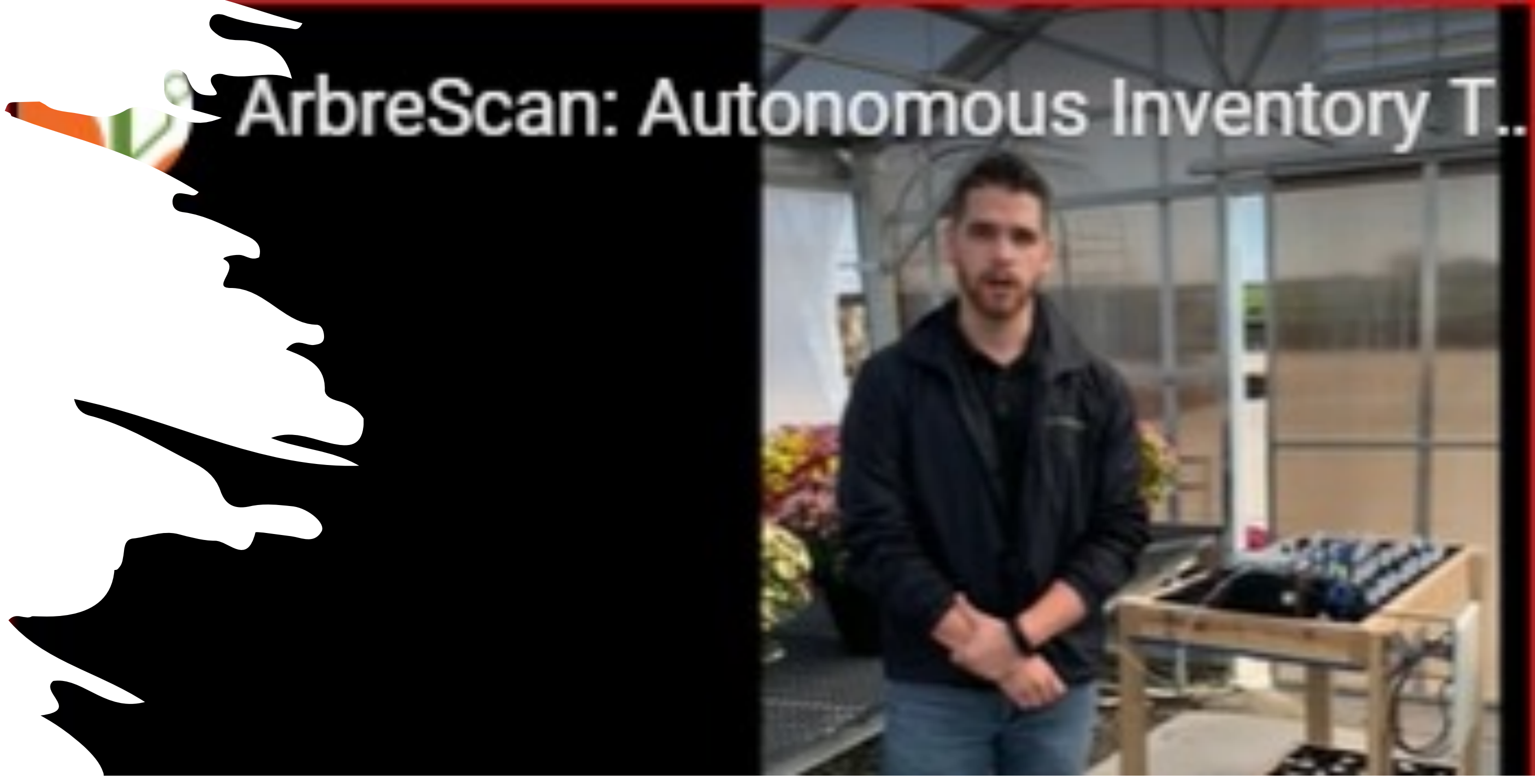
- When to sow crops
- How machinery affects the crops
- When a potential drought is incoming

Active Research in RFID Precision Agriculture

New innovations in RFID technology allow an effective low-cost alternative to traditional sensors [18]

- **Smart Active Labels (SALs)** RFID tags can communicate with microcontrollers and sensors [5]
    - Effective: 0.99 correlation between calculated and actual values
    - Cost: Each unit approximately costs $10.

RFID for Plant Nurseries



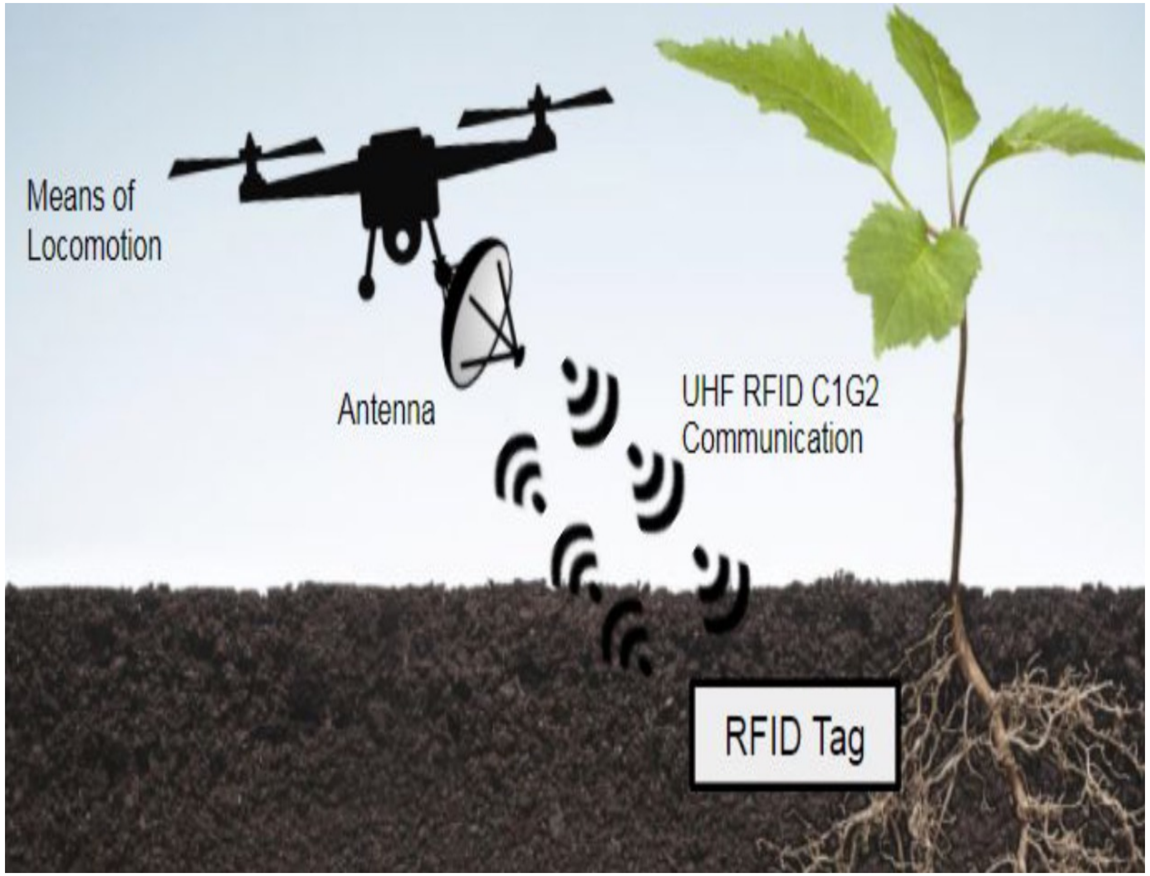
- **Arbre Technologies**
- **RFID Tags**
- **measure plant growth**
- Arbretech.com

RFID POLY GAIT

Conceptual: The UAV Connection

UAVs would be used in conjunction with RFID SALs, to create a network of remote sensors [13]

- The drone transports the receiver and its gathered data
- The UAV can collect readings without disrupting the budding crop



Industry Application: Senitron RFID Solutions

- Senitron uses RFID tags to track inventory and growth in plant nurseries [19]

- End-to-end solutions including:
  - RFID equipment
  - Unmanned Aerial System
  - Data Collection/Inventory Software

Wildlife and Domestic Animal Tracking

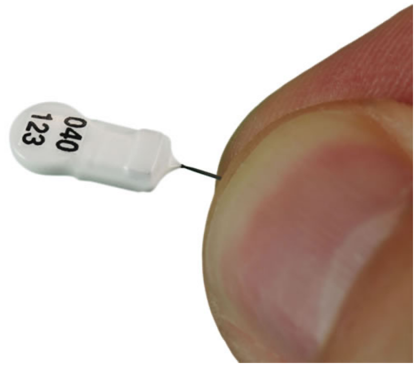
RFID for Wildlife Tracking

Traditional wildlife tracking methods involve tagging captured animals, which are then read upon recapture

- External tags: bands, collars
- Internal tags: passive integrated transponder (PIT) microchip

Integrating GPS and/or RFID technology into tags allows for animal movement to be more thoroughly tracked

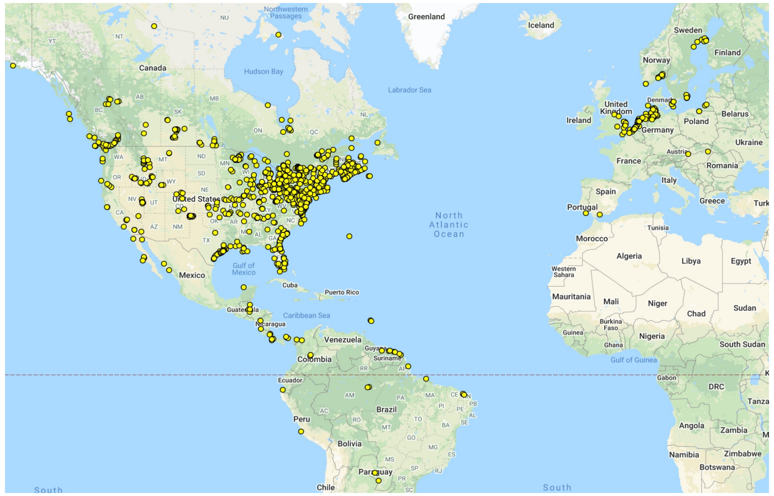
- Behavior patterns can be more continuously monitored
- Physical recapture is no longer necessary to track wildlife movement



RFID Wildlife Tracking Systems

Motus: Canadian-based wildlife tracking organization that uses automated radio-telemetry technology to monitor wildlife movement and behavior [17]

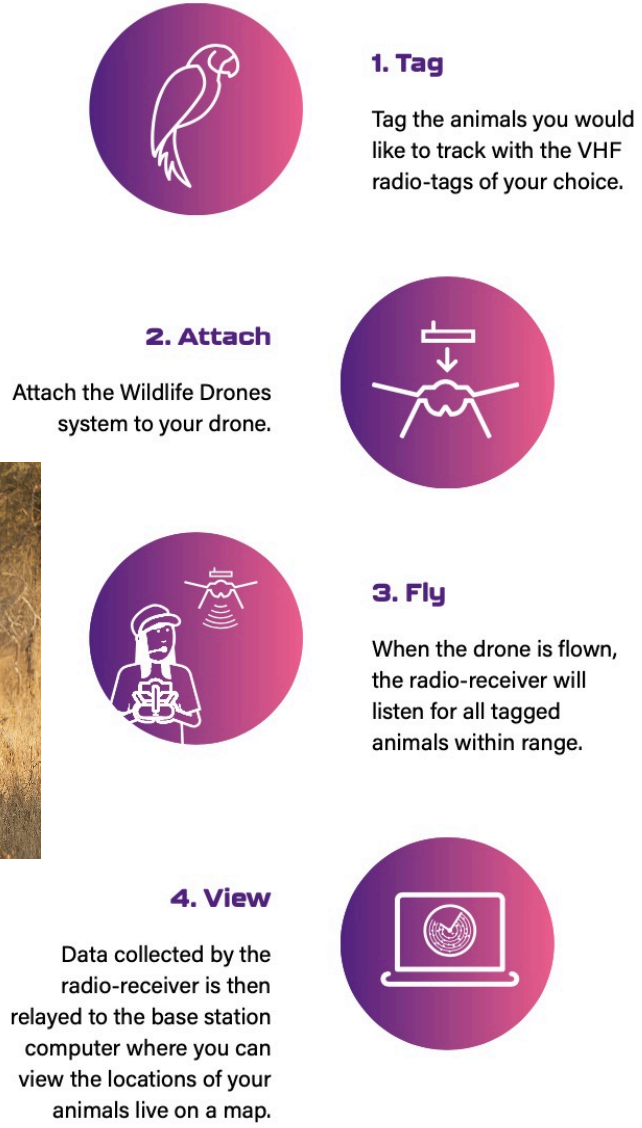
- Nano-tagged animals are tracked through a network of towers



Industry RFID UAV Wildlife Tracking Systems

Wildlife Drones: Australian-based company developing tracking systems for commercial UAVs [25]

- VHF radio transmitter tags
- Real-time tag reading
- Capable of reading 40 animals at once
- System attached to existing commercial drones
- Conservation-oriented
- Expanding into agricultural animal tracking



RFID for Domestic Animal Tracking

RFID tagging is common in the agricultural and farming sectors

Existing RFID tag reading methods:

- Hand-scanning low-frequency tags
- Strategically placed readers

Current RFID tagging system limitations:

- Limited data points can be gathered
- Large rangeland environments
- Close distance necessary to scan tags
- RFID tags for bulls often fall off due to aggressive behavior

Industry RFID UAV Livestock Tracking Systems

UAVs have become popular tools within the livestock industry

Farmers in Australia/New Zealand are using UAVs to herd cattle [21]

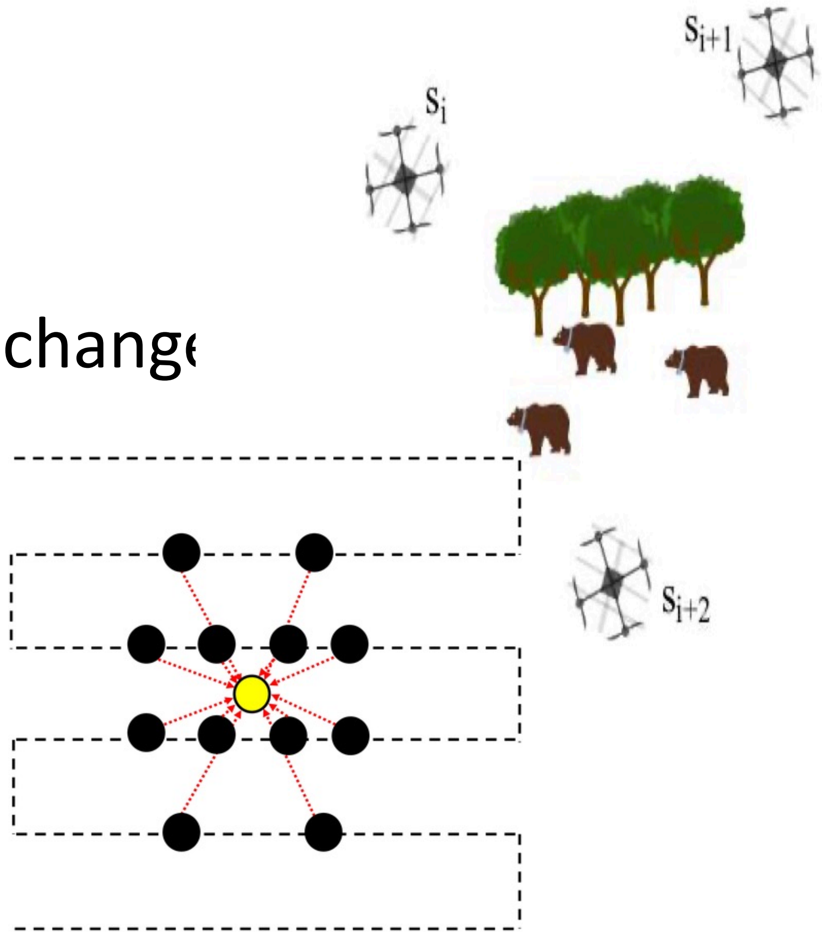
- Removes the risk associated with manual herding via all-terrain vehicles
- Allow for remote operation and herding activities

Lab Tested RFID UAV Livestock Tracking Systems

Technical challenges depend on UAV type

- Multi-rotor:
  - Pros: high maneuverability and altitude change
  - Cons: battery life limits area covered
- Fixed wing:
  - Pros: efficiently cover wide areas
  - Cons: require high altitudes for flight

Animal localization is a primary challenge *[3]*



Challenges of Animal Tracking RFID UAS [2]

- Legal Flight Regulations
- Animal Welfare
- System Cost
- Limited battery life
  - Particularly problematic for multi-rotor UAVs
  - Payloads further decrease battery life
- Environmental factors
  - Both natural and manmade obstacles
- Operational logistics
  - Paperwork, pilot training and equipment maintenance

Upcoming PolyGAIT RFID UAS Study

Development of a UAS for cattle monitoring using visual images, UHF RFID, and GPS data

- Decrease in manual labor time and faster data collection
- Development of a machine learning system for cattle counting
- Development of GPS data streaming platform

Preliminary study into cattle fear response to multi-rotor UAVs of different sizes at various flight altitudes

Conclusions & Future Directions

- ***Drones are very useful for image-based capture of inventory***
- ***Machine learning techniques enables cost-effective inventory count***

- ***RFID Drones are very useful for static and dynamic inventory at large open spaces***
  - ***Examples of outdoor inventory include equipment, materials, vehicles, animals, plants***
- ***Indoor RFID drones may be hazardous and have low ROI***
- ***Challenges: Data capture, autonomous routing, and collision avoidance, & collaborative operation software development***
- ***Additional challenges: Risk and Cost***

- ***Nevertheless - bright and exciting future ahead***

THANK YOU

RFID JOURNAL LIVE!

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