RFID JOURNAL LIVE!

20 YRS

2003 - 2022

MAY 17 - 19, 2022

MANDALAY BAY | LAS VEGAS, NV

REDUCING INVENTORY TIME WITH DRONES

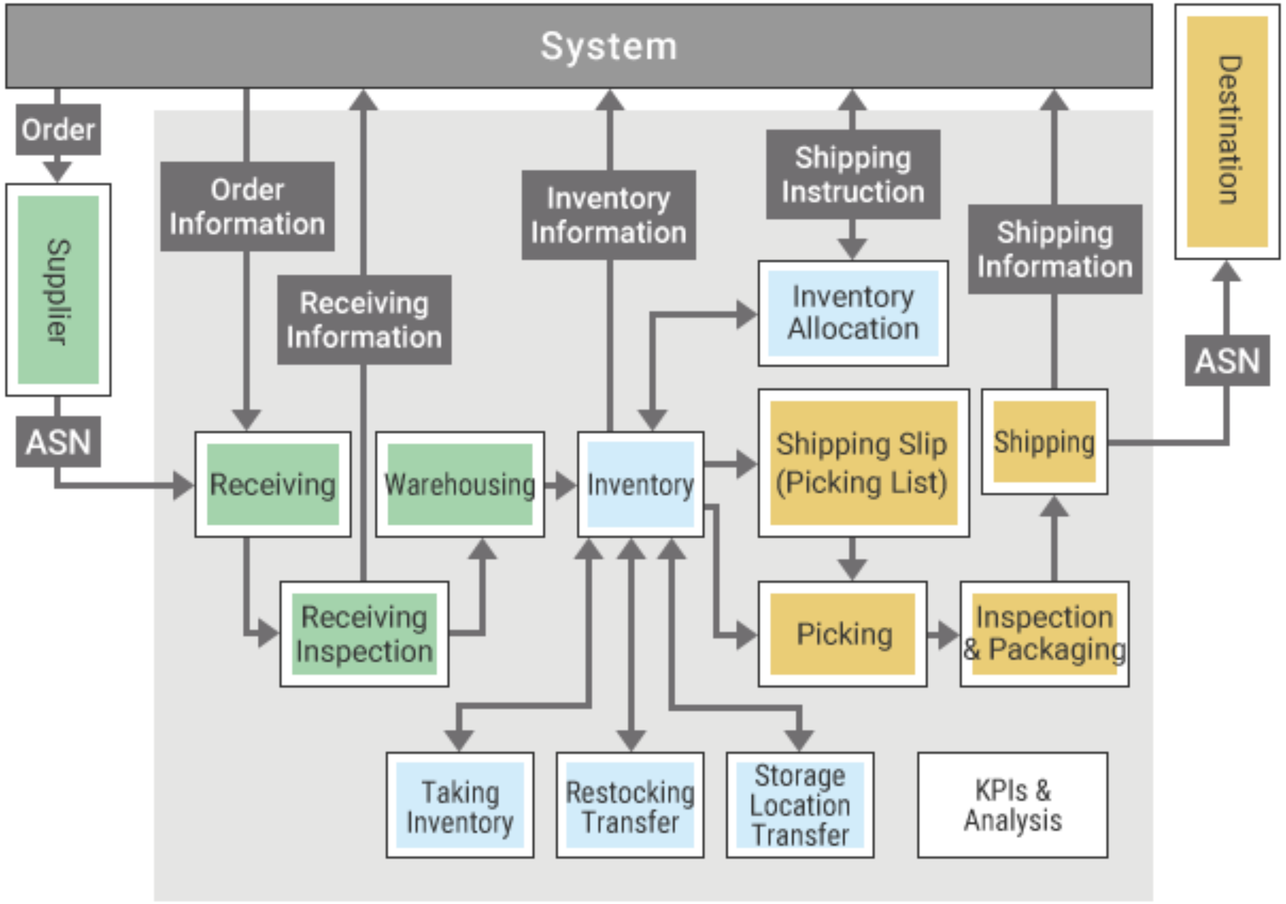
Professor Tali Freed, Ph.D., P.E.
Director, PolyGAIT R&D Center, Cal Poly State University
CEO, Process Expert, Process Improvement Consulting

Agenda

- Introduction
- Warehousing and Inventory
  - Indoor Inventory
  - Outdoor Inventory
    - Static Inventory
    - Livestock
- From Data Collection to Dashboard
- Using Machine Learning AI
- Precision Agriculture
- Conclusions
- References

Warehousing and Inventory

Complexity of Logistics Inventory



KPI: Key Performance Indicator

Importance of Inventory

Inventory-Related Business Decisions and Key Performance Indicators

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

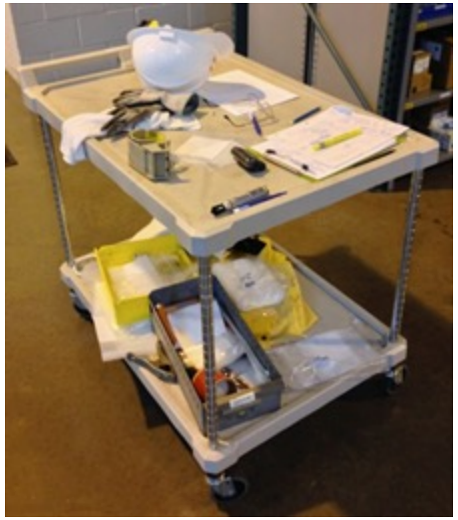
Manufacturing: Types of Inventory

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

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

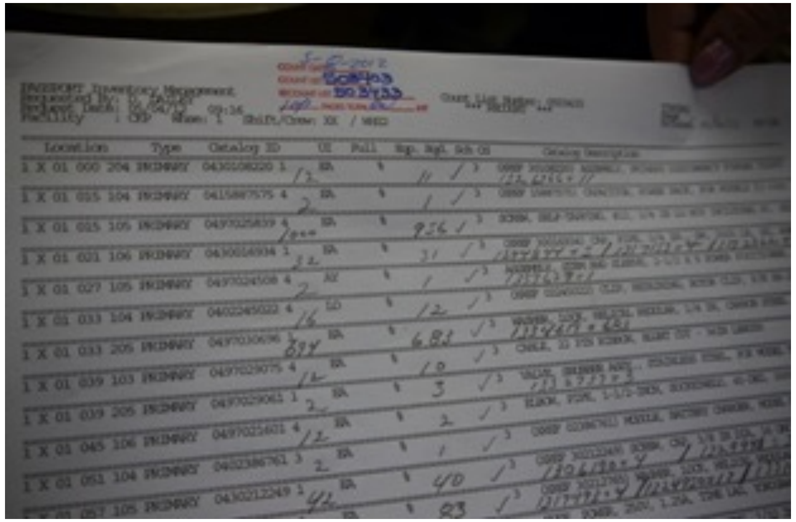
The cost to keep accurate inventory is VERY HIGH!

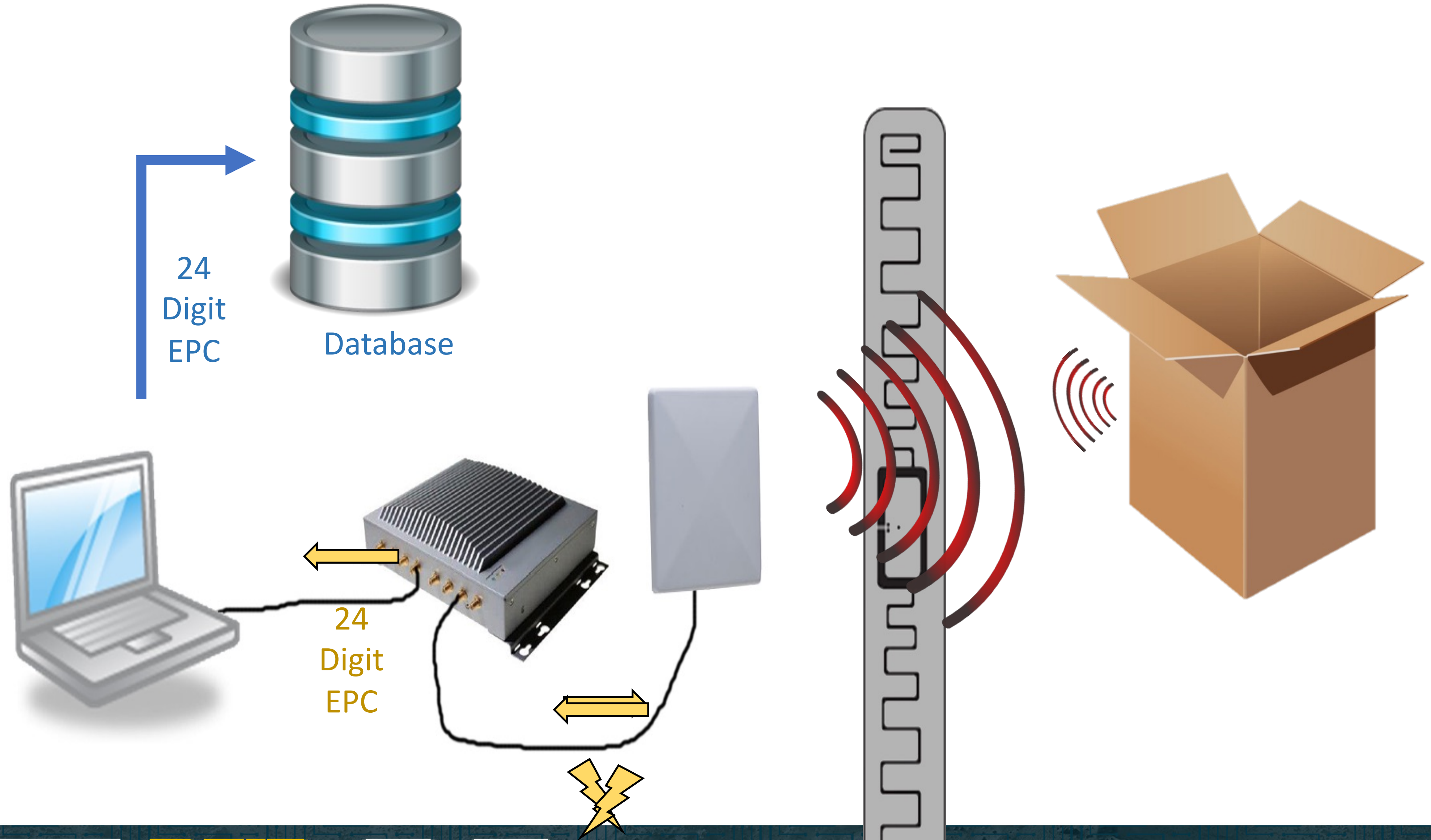
Manual Inventory Count



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

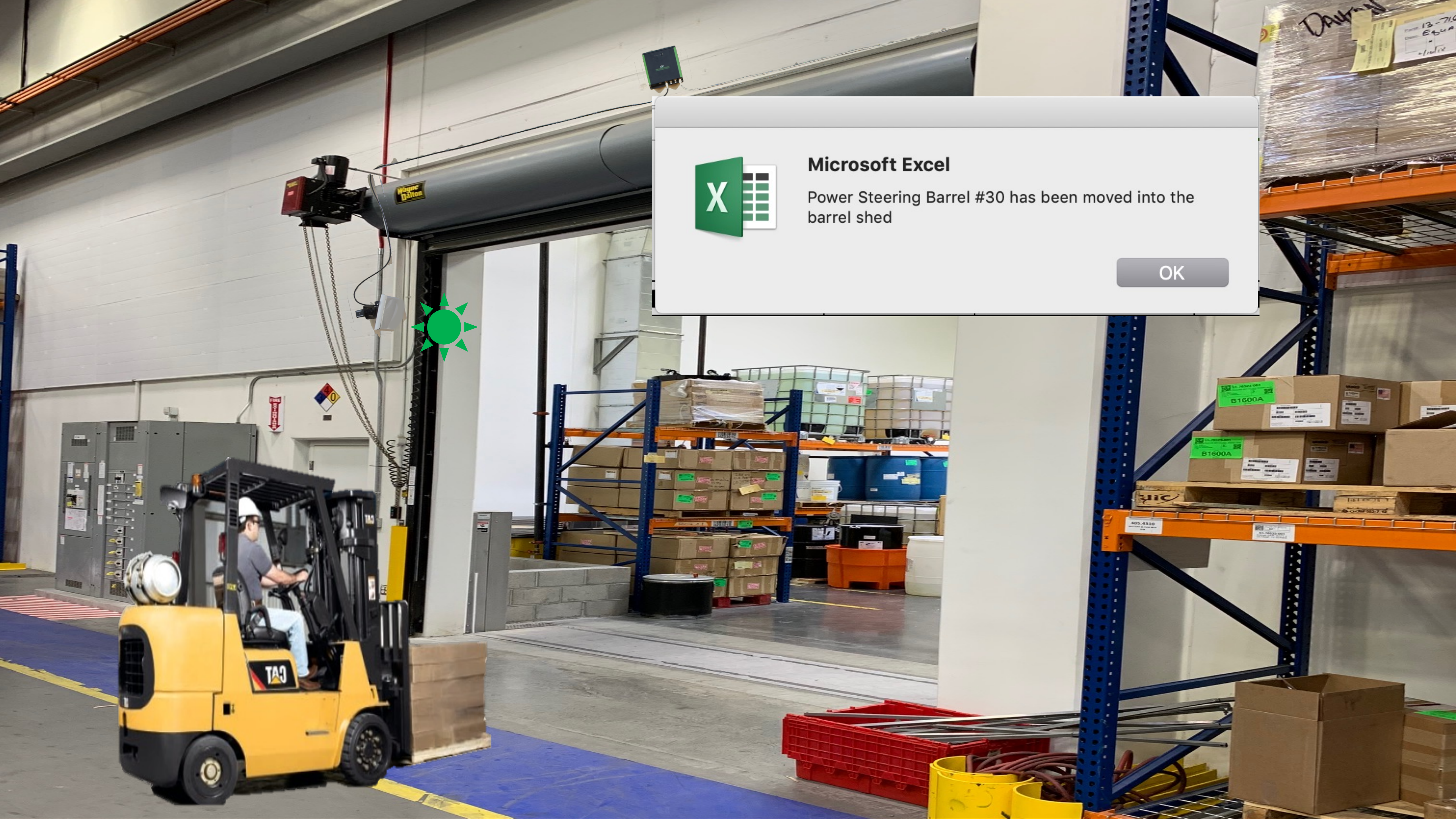
Set-Up:

- 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
IVE!
YRS
2003 - 2022
MAY 17 - 19, 2022


15-40
THIS ROW: MAXIMUM PERMISSIBLE LOADING
WARNING
FIRE
THIS ROW: MAXIMUM PERMISSIBLE LOADING
WARNING
FLAMMABLE
KEEP FIRE AWAY


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

Dock Door Scan & Display

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

Refresh Filter

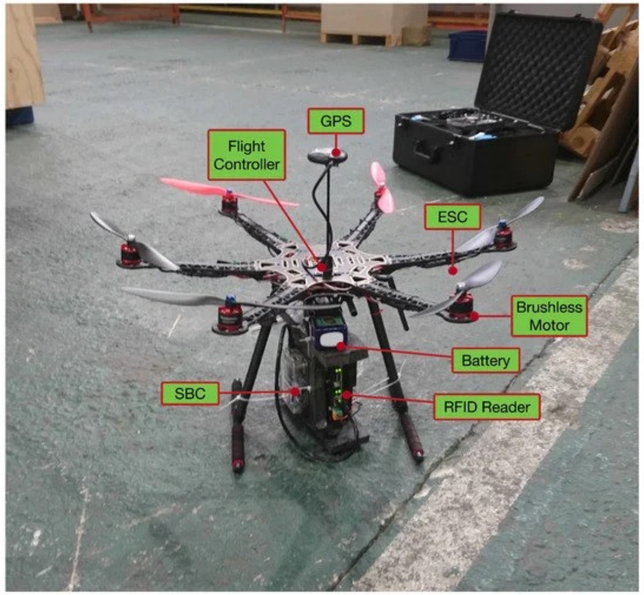
Tag Management > SGTIN's

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

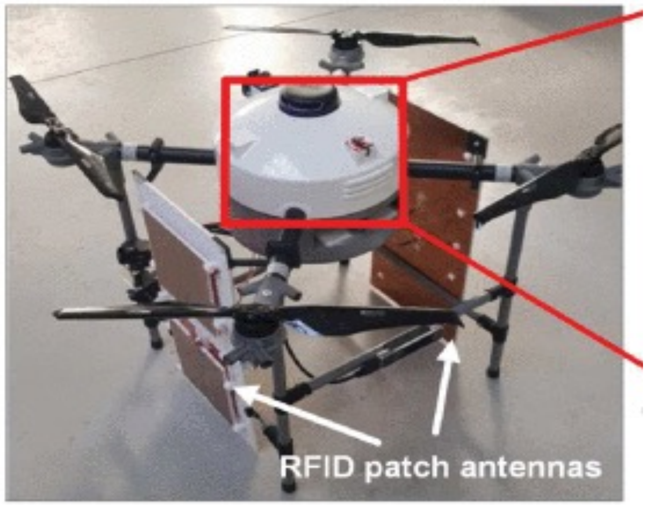


Common Set-Up:
- Packages tagged with RFID
- Drone equipped with RFID reader, antennas

Inventory tasks automated using RFID-UAV System

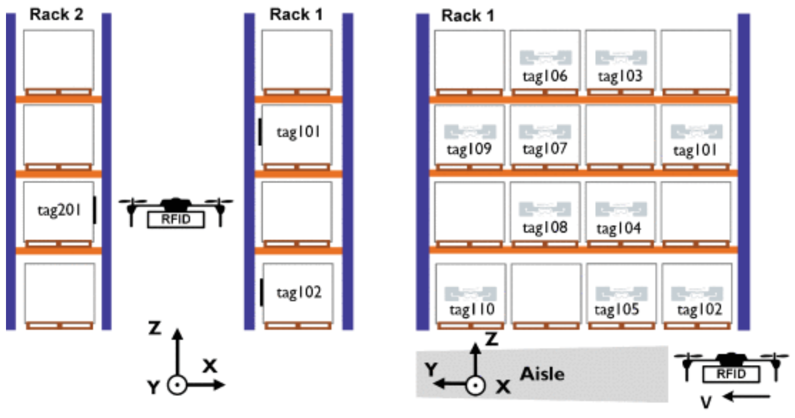
RFID tags placed on various packaging materials & shelves
- Tags read by RFID reader/antenna mounted on UAV
- Data transmitted to local computer or cloud
- Collects and processes inventory data in real time
- Autonomous flight path with people/vehicle coordination
- Automatic data verification and security
- Steep Learning Curve for drone operators and workers

Indoor Package Identification [1,14]



Received Signal Strength Identification (RSSI)

- Strength of RFID tag reading is used to locate its position
- Signal strength map overlay warehouse layout
- Identification of rack number, tag lateral location, rack-level
- Interference from environment is common
- Reading Inaccuracy can be corrected using machine-learning visual matching
- Drone hover-scan time can be reduced quickly
- Drone limitations: battery, safety
- Significant technology ROI once established



(a) (b)

Conceptual Possibilities (Simulated)

Tracking of perishable items [7]

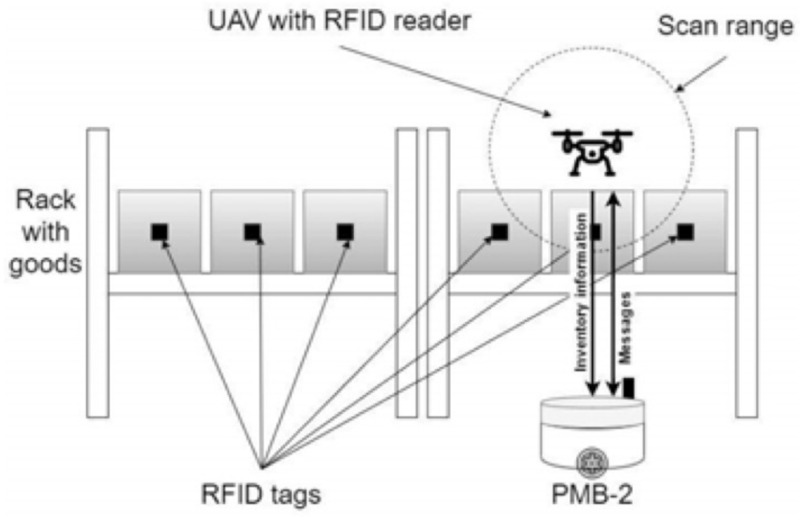
- Utilizing RFID and dielectric tags in tandem to check freshness of bottled items when conducting inventory

Autonomous path planning and decision making [11]

- UAV path planning utilizing RFID tag-based localization algorithms

Cooperative robotic missions [12,1]

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



Outdoor Inventory Management

Open storage areas

- Stockyards and construction sites
- Ports
- Inventory location may be unpredictable
- Wide open areas cause inaccurate positioning systems; rough GPS data used
- Environmental Hazards e.g., vehicles, cranes
- Drones and electronic equipment subject to rough weather conditions

Current Technologies

Squadrone System: Apach Drone with RFID Load [6]

Andromeda Systems Incorporated: ADVISOR Drone [1]

Examples of Current Technologies

Exponent Technology (https://exponent-ts.com)
DJI Drones carrying RFID reader
Example video of taking inventory of new vehicles at a parking lot

Seeker
Indoor drone with autonomous path carrying camera
https://www.modalai.com/pages/seeker-autonomous-indoor-drone

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

Cal Poly PolyGAIT R&D Center

Outdoor Equipment Inventory
Using
UHF RFID
Artificial Intelligence & Machine Learning

Problem Statement

- Outdoor inventory tracking is expensive, inefficient, and unreliable for many companies
- Inventory shrinkage is high (e.g., US military shrinkage estimated at $5.8B)
- Emerging UAV/RFID technology enables solutions for inventory tracking

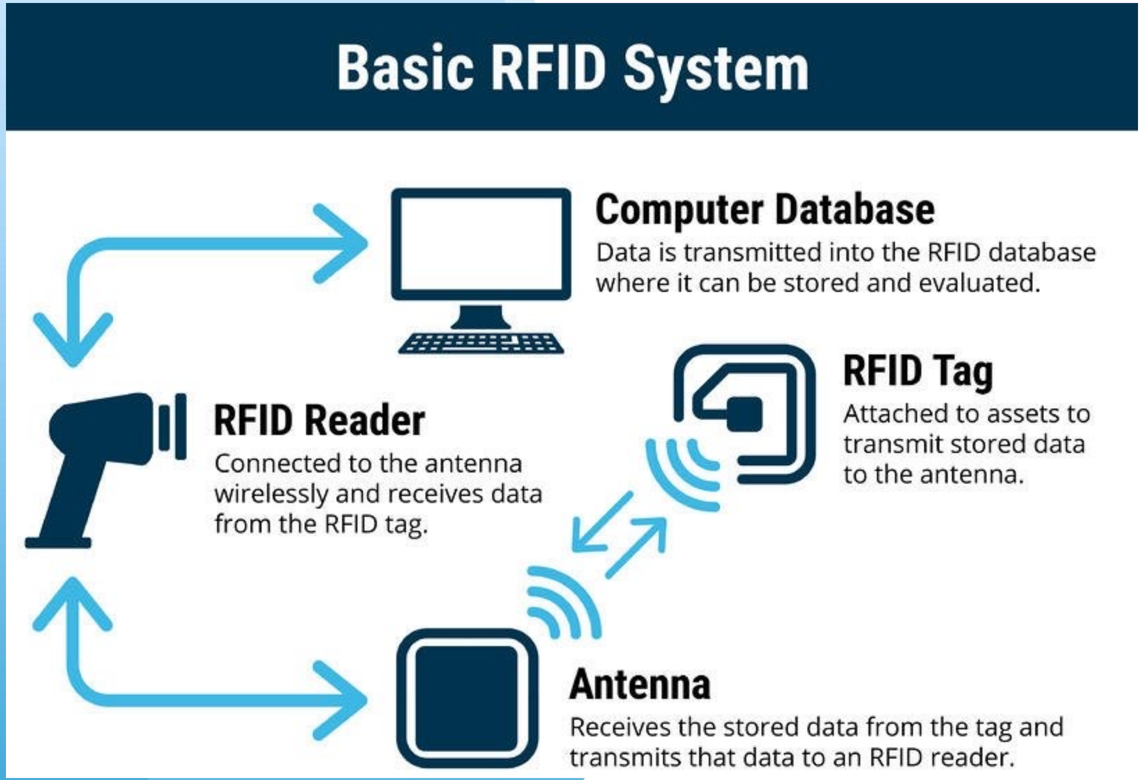
Background

Billions of dollars worth of inventory and equipment is stored in outdoor spaces in many industries

It is often costly and inefficient to manage and count the inventory on a regular basis

Outdoor environments pose a unique challenge because of the vast areas that need to be managed

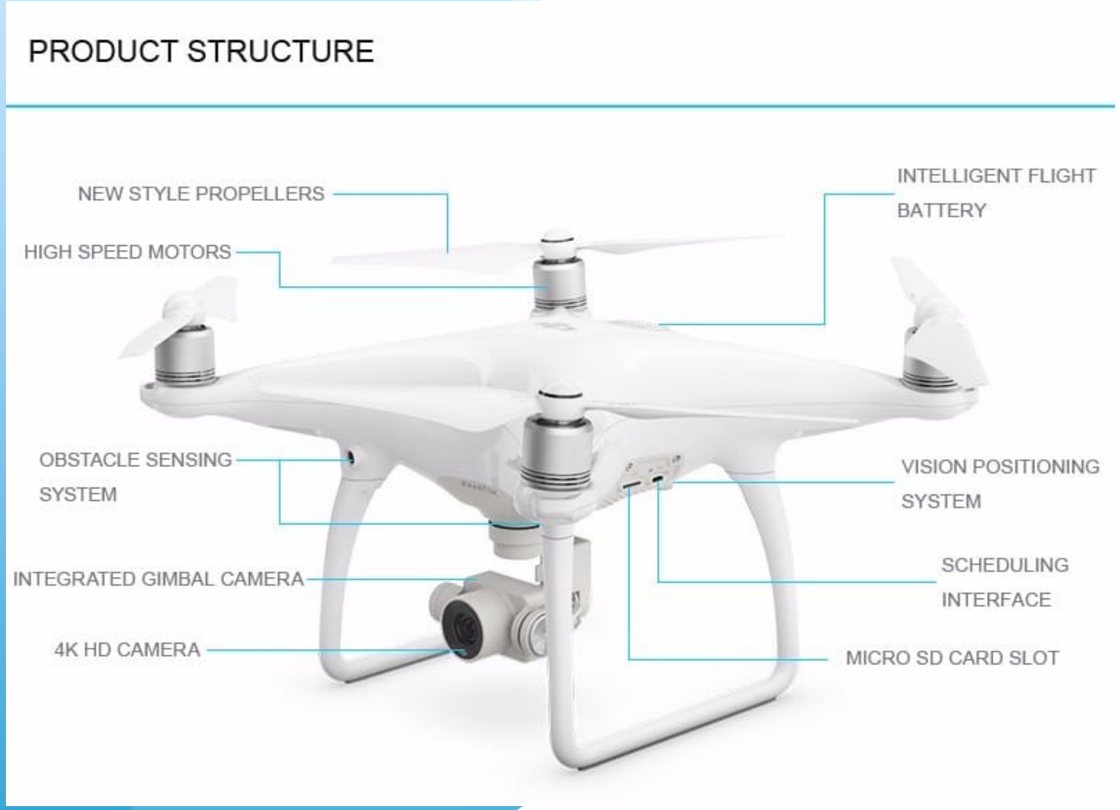
Literature Review



RFID – Radio Frequency Identification

- Enables wireless information/data transfers of tagged objects
- Basic system components
  - Tags
  - Antennas
  - Readers
  - Databases
  - Data Transfer Infrastructure
- Sensors and IOT Extensions

Literature Review



UAV – Unmanned Aerial Vehicle

- Military roots
- Basic System
  - Flight computer
  - Stabilizer
  - Camera (w/Gimbal)
  - Mission control
  - Com. System w/Ground Control
- Paved the way to automated flight activities
- Potential for application in inventory management

Literature Review

Machine Vision

- Subset of Artificial Intelligence and Machine Learning
- Algorithms are trained on vast libraries of images
- Could be used to program flight automation entirely
- System could chart its own flight paths based on object classifications probabilities

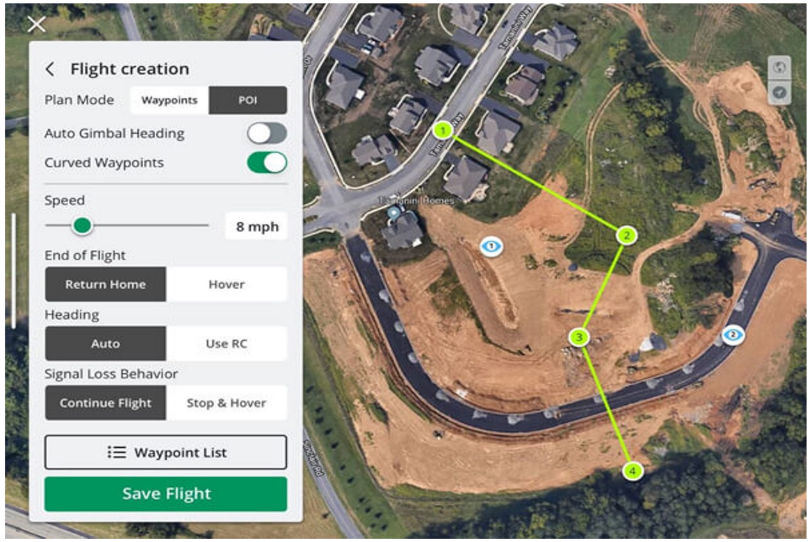
Possible Solution Directions

Possible Solution Directions

RFID and Drone Integration with Pilot: Fully Manual Solution

- UAV
- RFID Scanner mounted on drone
- Pilot defined flight path

RFID and Drone Integration with Pre-Planned Flight Path: Semi Automated Solution



- UAV
- RFID Scanner mounted on drone
- Predetermined flightpath using software

Fully Automated drone/RFID Integration with Machine Vision: Fully Automated Solution

Selected Solution

Fully Automated drone/RFID Integration with Machine Vision

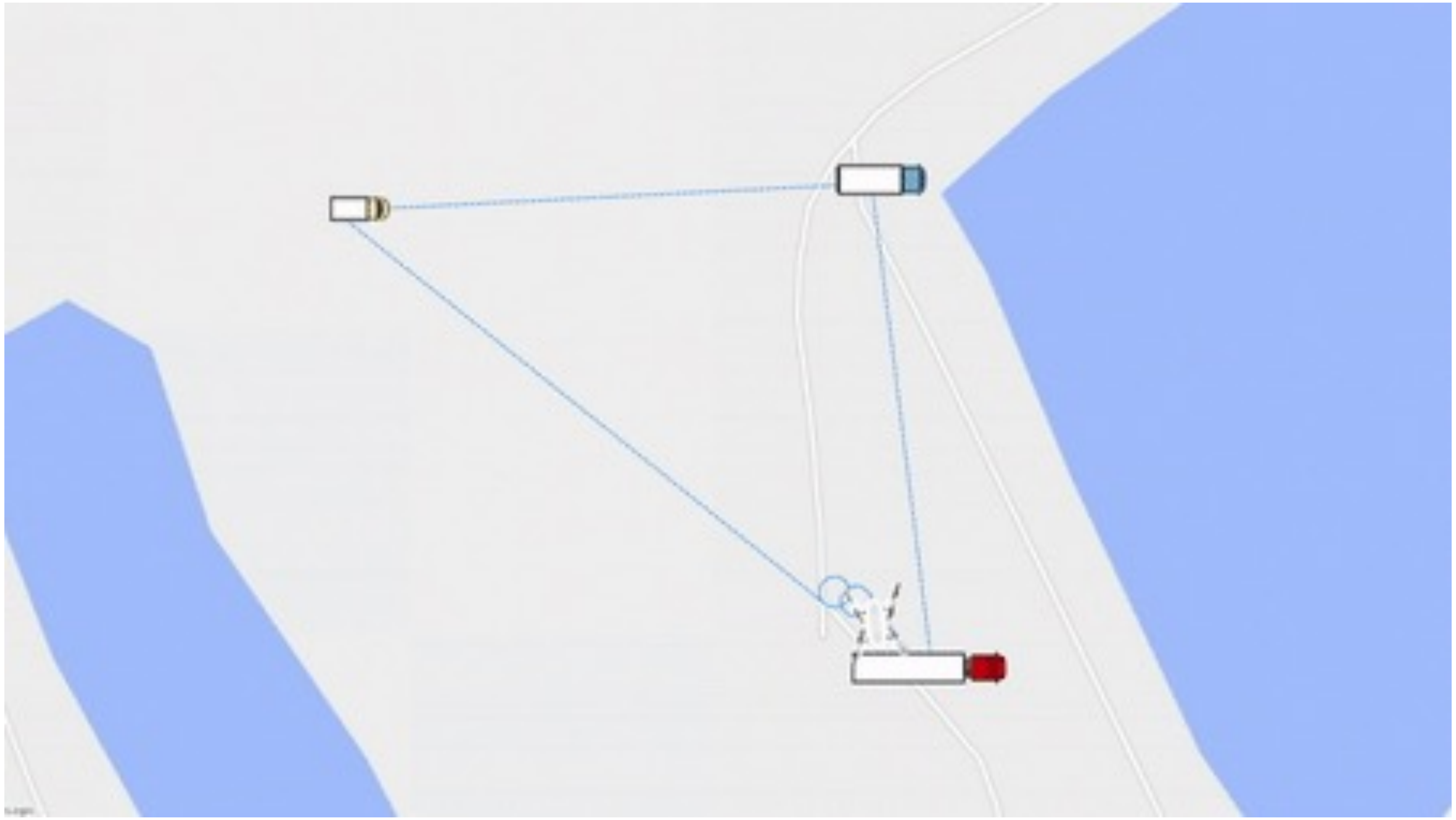
Chosen via AHP analysis yielding the highest score.

- System
  - UAV
  - Light RFID scanner mounted on drone
  - Automation via image recognition technology
- Benefits
  - Automation
  - Scalability
  - Sustainability
  - Practical Implementation
  - Promising ROI

Experimental Design

- Factors
  - Manual drone
  - Fully manual
- Response
  - Time (sec)
- Experimental Process
  - Takeoff drone
  - Scan each inventory item (vehicle) with RFID & computer vision
- Experimental analysis
  - One-way ANOVA

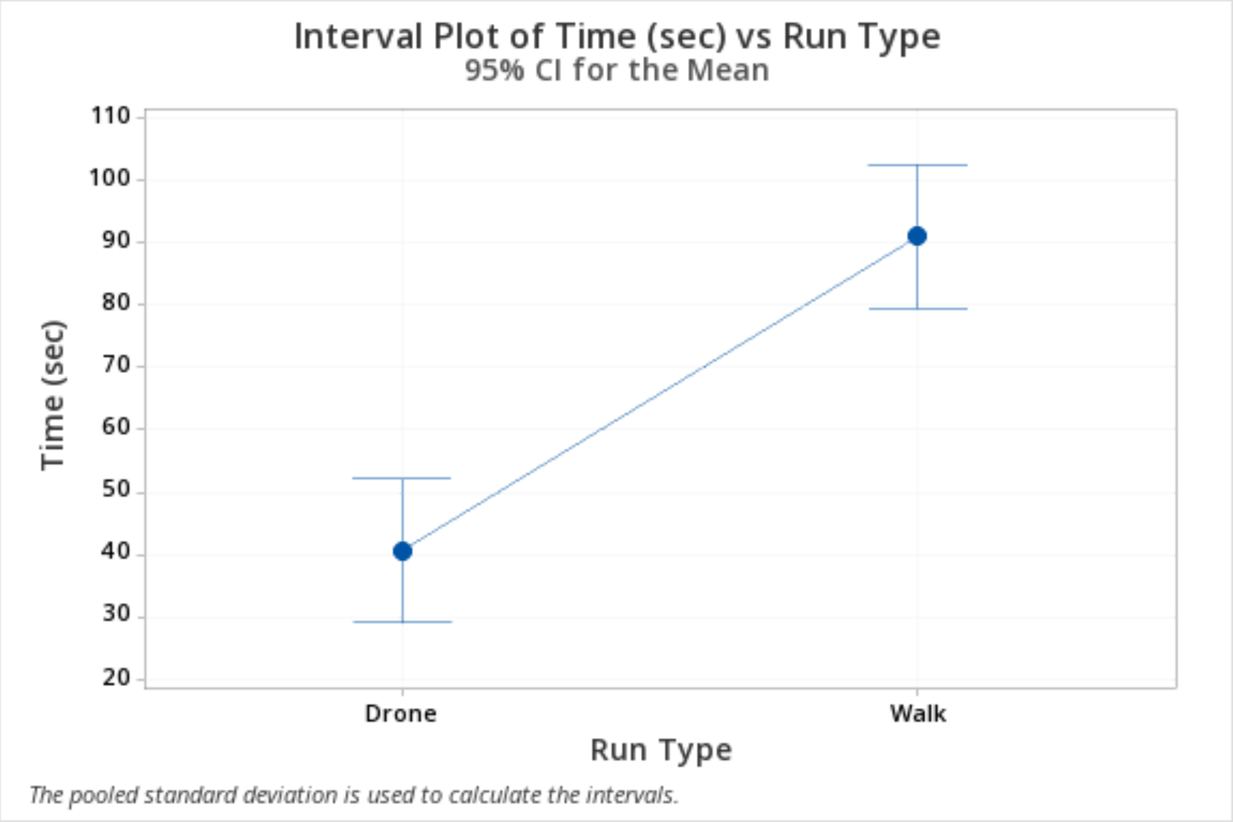
Experimental Simulation



- Simulation using accurate data
  - Coordinates
  - Distances
- Data collection at each vehicle/asset
  - RFID scan
  - Probability associated to object recognition
  - Image of asset
- Time data
  - 6 second RFID scan within 20 feet of asset
  - Normal distribution of time data based on experiment

Experimental Analysis

- The difference between the drone and walking was statistically significant at a **95% confidence level**
- Mean of the drone time was approximately **40.793 sec** and the walking time was **90.946 sec**
- The drone times were on average **55% faster** compared to the walking times

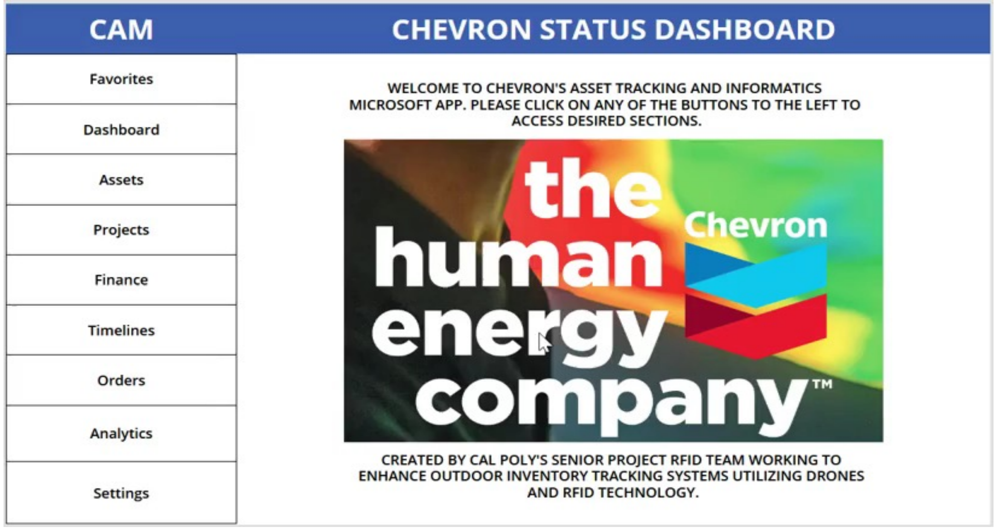


Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Run Type	1	50414	50414	38.02	0.000
Error	78	103431	1326		
Total	79	153845			

System Overview

Computer Vision



RFID

Dashboard

Conclusion

- UAV/RFID system integration with Machine Vision is a solution to inventory tracking needs in outdoor areas
- Direct solution to inventory shrinkage for companies holding inventory outdoors
- Promising platform for automation & Scalability

Paper No. SPE-190014-MS

Use of Drones for Oilfield Equipment Inventory

Tali Freed, Professor, Industrial and Manufacturing Engineering Department

Mason Medizade, Professor, Mechanical Engineering Department

Allen Duong, M.Sc. Mechanical Engineering Candidate

California Polytechnic State University, San Luis Obispo

Inventory of Oilfield Tubulars

Hundreds or thousands tubulars

Across large fields

Labor Intensive Inventory

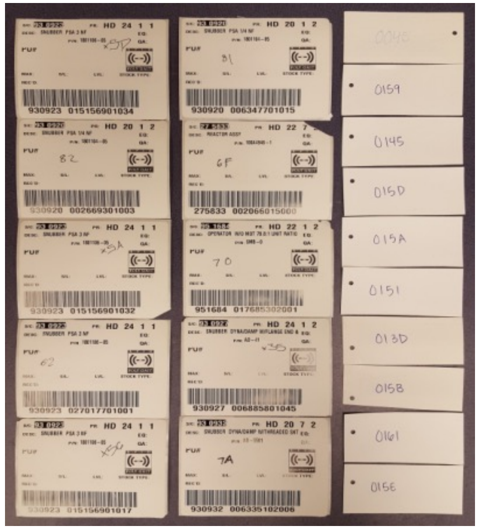
RFID to the Rescue

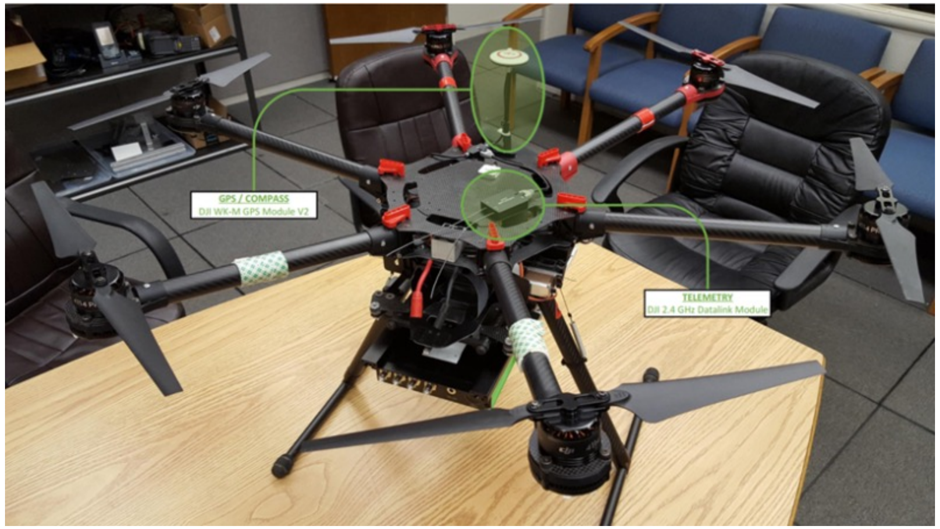
Passive UHF RFID

Tag cost = $0.15

Adhered to pipe cap
or to foam insulator

RFID reader on UAV





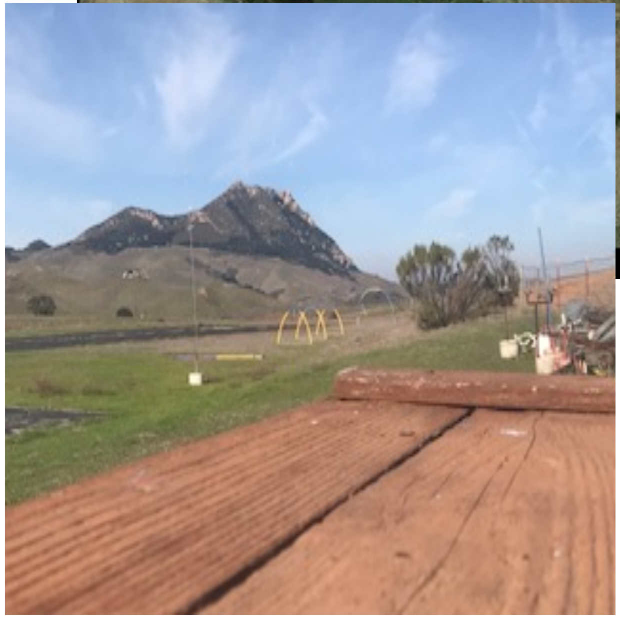
Experiment #1 – Establish Base Read Range

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

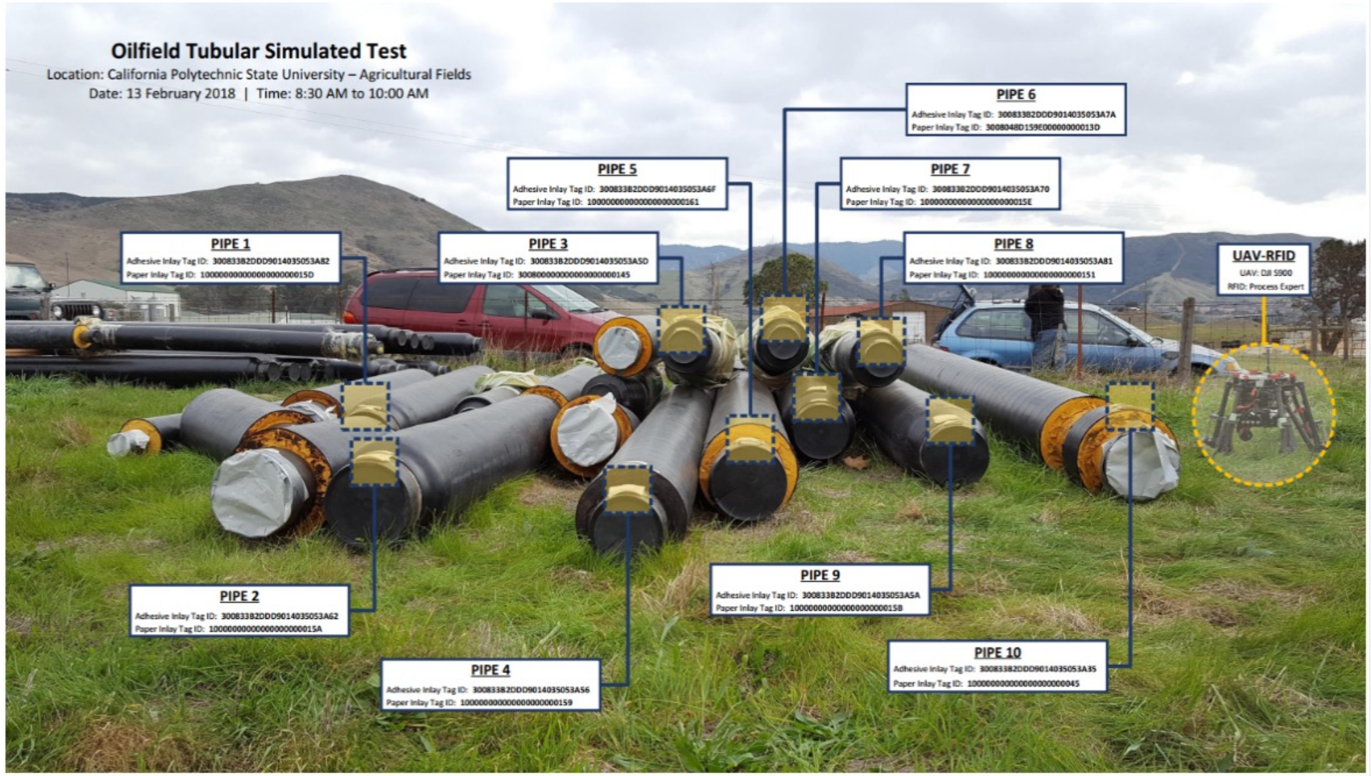
Experiment #3 – Reading 2 Tag Types

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



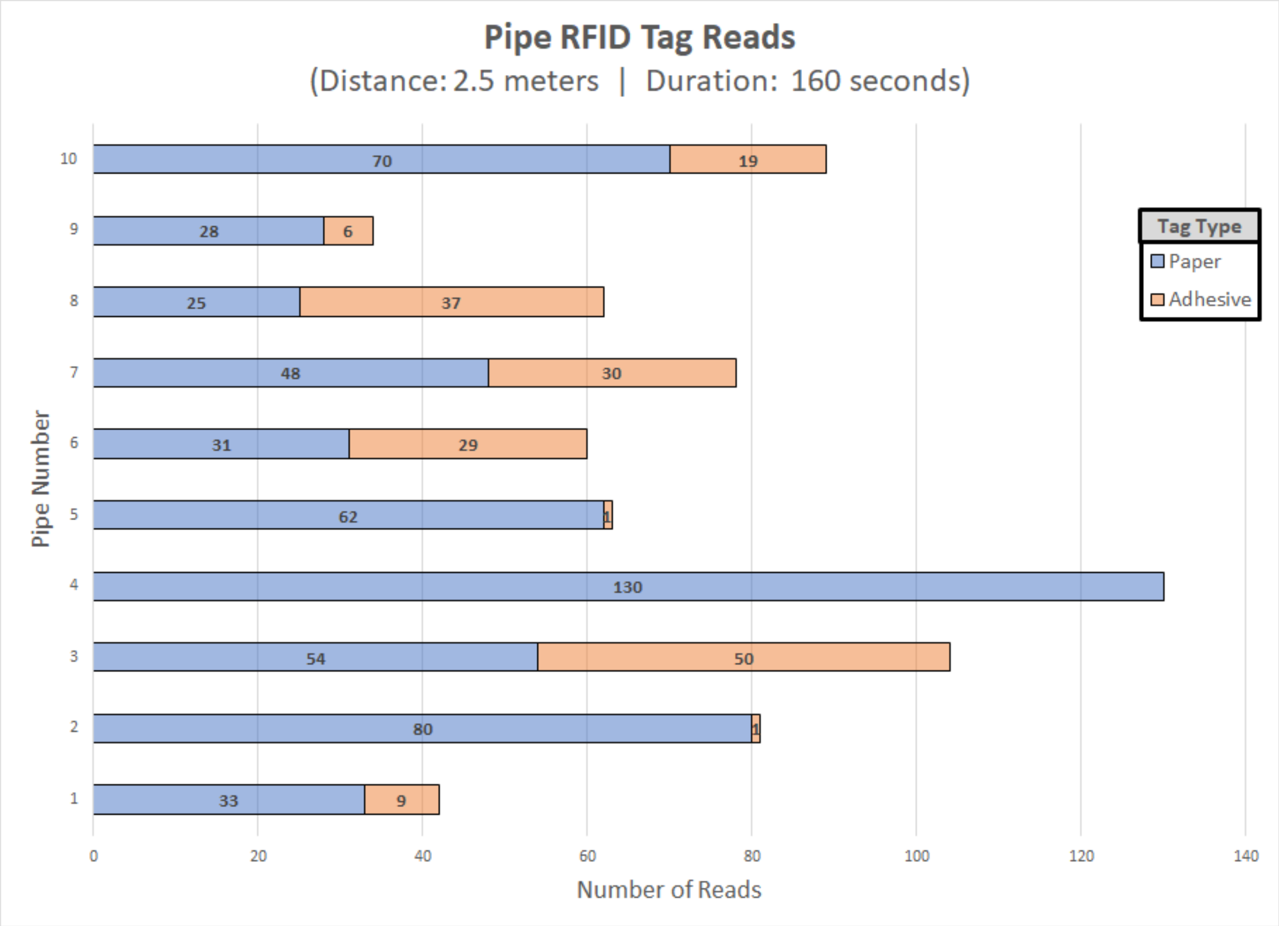
Number of Tag Reads – Reading Reliability

Variability is common

Experiment with tag types

Experiment with insulation

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



Optimized Route (TSP)

Similar to Autonomous Robot

Collision Avoidance

Low Battery Crash Prevention

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.

PolyGAIT RFID-UAV Studies

Investigated RFID-UAV time limitation [4]

- *10 min to scan a 293-acre pasture*
  - *Area divided into hexagons*
  - *Hover time of 1 second for RFID capture*
  - *GPS data matched to RFID*
  - *Cattle location identified*
  - *Replaces searching for lost cattle on foot or ATV*

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

RFID & Livestock Management

- Ear tags amongst the most common cattle RFID tags methods
  - *Ear tags are typically low-frequency with short reading distance (few inches)*
    - *Some ear tag options are UHF*
  - *Two types of RFID readers: mounted static readers, mobile (handheld or wand) readers*

Above: Example of a Static RFID Reader Unit

Left: Ear-tagged cow read with RFID reader wand

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]

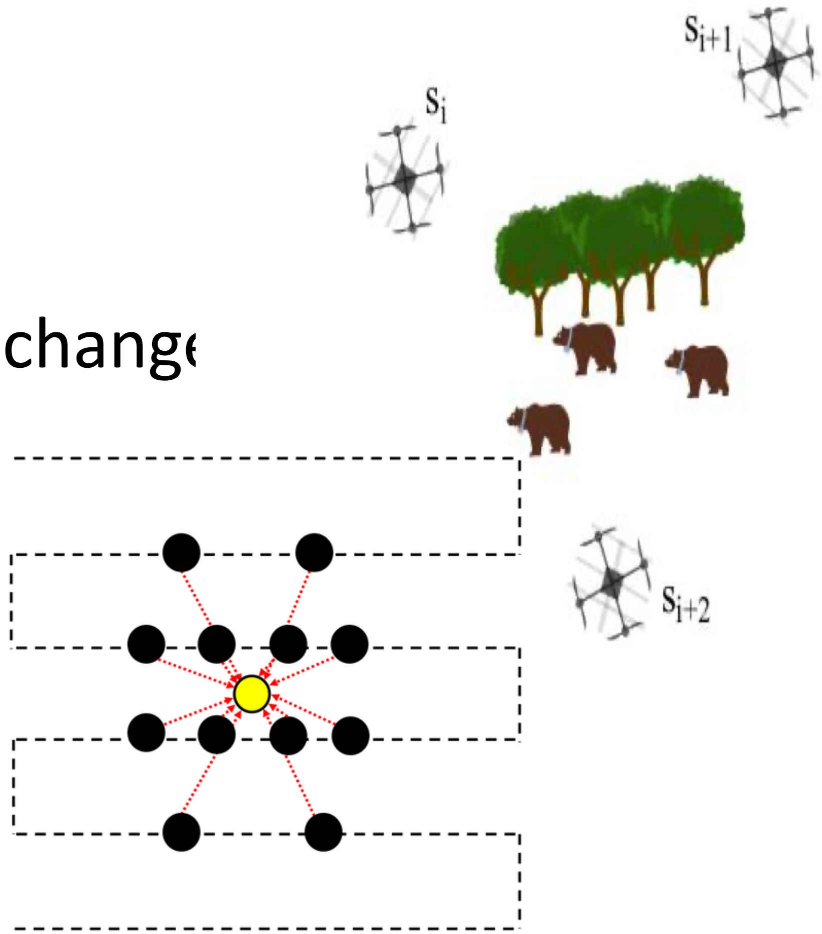
- Removes the risk associated with manual herding via all-terrain vehicles
- Allow for remote operation and herding activities

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]*

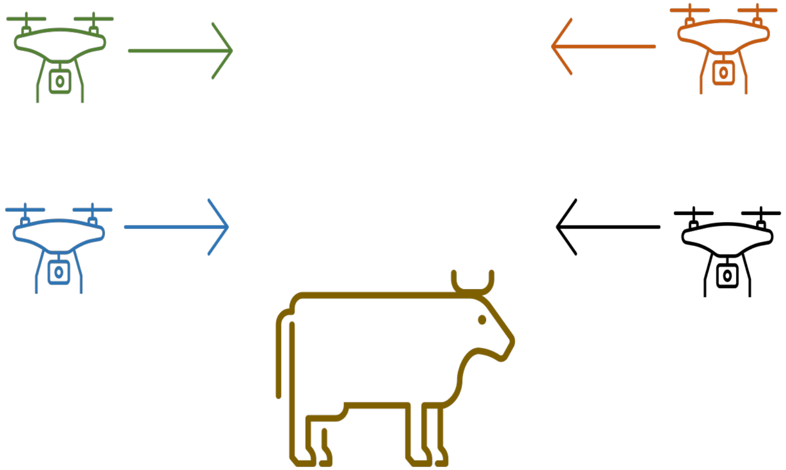
- Legal Flight Regulations
- Animal Welfare
- System Cost
- Limited battery life
  - Particularly problematic for multi-rotor UAVs
  - Payloads further decrease battery life
- Environmental factors
  - Both natural and manmade obstacles
- Operational logistics
  - Paperwork, pilot training and equipment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

PolyGAIT UAV Cattle Behavioral Study: Setup

- UAV used: DJI Phantom 4 Pro V2.0
    - *Smaller than RFID-equipped UAV*
    - *Average flight time: 30 min*
    - *Visual data collected from on-board camera*

- Two factors tested in a randomized block design
    - *Direction of approach (front, back)*
    - *Height above ground (3m & 6m)*
    - *Data blocked by individual cow*

Above: DJI Phantom 4 Pro v2.0 UAV used in testing



Left: Visual diagram of initial experiment design, each color denoting a unique run

PolyGAIT CATTLE 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

UAVs & Animal Behavior

- UAVs known to disturb wildlife, specifically when flying in target-oriented flight patterns [9]
    - *Similar distress responses observed in large guanaco herds*

- No significant behavioral effect on 2-year-old cattle when flying 9 meters AGL with a single UAV
    - *Repeated flights over multiple days resulted in acclimation to UAV presence*

PolyGAIT RFID-UAV Cattle Study: Setup

- RFID tags: Avery-Dennison Dogbone
  - *UHF passive tag (950-960 MHz)*
  - *Max range: 12m, 8 sec to read*
- RFID system: MiniStock
  - *Developed by Process Expert*
  - *Long-range UHF RFID reader*
  - *Wifi equipped for instant data transfer*
- UAV used: DJI S900
  (discontinued, comparable to DJI Matrice)
  - *Hexacopter design*
  - *Unburdened flight time: 20 min*

PolyGAIT RFID-UAV Cattle Study: Setup

- Passive UHF RFID tags placed on cattle collars
    - *2 tags placed on each collar*
    - *Collars provided insulation from cow body*
    - *Tags placed in different orientations to maximize likelihood of read*

Left: RFID tags placed on leather cattle collar

Right: Demonstration of cattle collar on heifer

PolyGAIT RFID-UAV Cattle Study: Setup

- UAV fitted to carry RFID system
    - *Secondary power-bank attached to power RFID system onboard UAV*
    - *Cell phone hotspot provided wifi connection for live/in-field RFID data transfer without landing*

PolyGAIT RFID-UAV Cattle Study: Testing

- Small four-cattle herd used for testing
  - *Docile cows, all frequently handled*
  - *Two 9-month to 1-year old heifers collared with tags*
  - *Additional two heifers not tagged*

- Quiet, small pasture location

- Two UAVs flown simultaneously at unique altitudes
  - *DJI S900 for RFID data collection*
  - *DJI Phantom for visual reconnaissance*

PolyGAIT RFID-UAV Cattle Study - Results

- Cattle initially wary of UAV presence
    - *Exhibited nervous behavior (increased vigilance, movement away from the UAV)*
    - *No extreme stress behavior (no vocalization, hoof stamping, etc.)*

PolyGAIT RFID-UAV Cattle Study - Results

- RFID data successfully collected from both tagged cattle
  - *Cattle quickly acclimated to UAV presence (~2 minutes)*
  - *Successful RFID reads 6m AGL*

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!

20 YRS

2003 - 2022

References

1. *Advisor Drone Services: Revolutionizing Inventory and Asset Tracking*. Andromeda Systems Incorporated. (n.d.). Retrieved September 22, 2021, from https://androsysinc.com/advisor-inventory-and-asset-tracking/.

2. Barbedo, J. G., & Koenigkan, L. V. (2018). Perspectives on the use of unmanned aerial systems to monitor cattle. *Outlook on Agriculture*, *47*(3), 214–222. https://doi.org/10.1177/0030727018781876

3. Bayram, H., Stefas, N., Engin, K. S., & Isler, V. (2017). Tracking wildlife with multiple uavs: System design, safety and field experiments. *2017 International Symposium on Multi-Robot and Multi-Agent Systems (MRS)*. https://doi.org/10.1109/mrs.2017.8250937

4. Buffi, A., Nepa, P., & Cioni, R. (2017). SARFID on drone: Drone-based UHF-RFID tag localization. *2017 IEEE International Conference On RFID Technology & Application (RFID-TA)*. https://doi.org/10.1109/rfid-ta.2017.8098872

5. da Fonseca, N. S., Freire, R. C., Batista, A., Fontgalland, G., & Tedjini, S. (2017). A passive capacitive soil moisture and environment temperature UHF RFID based sensor for low cost agricultural applications. *2017 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC)*. https://doi.org/10.1109/imoc.2017.8121099

6. *Drone RFID reader and inventory services - Squadrone system*. Squadrone. (2020, October 1). Retrieved September 22, 2021, from https://squadrone-system.com/en/solutions/drone-rfid/.

7. F. A. Almalki, "Utilizing Drone for Food Quality and Safety Detection using Wireless Sensors," 2020 IEEE 3rd International Conference on Information Communication and Signal Processing (ICICSP), 2020, pp. 405-412, doi: 10.1109/ICICSP50920.2020.9232046.

8. Fernández-Caramés, T. M., Blanco-Novoa, O., Froiz-Míguez, I., & Fraga-Lamas, P. (2019, May 25). *Towards an AUTONOMOUS Industry 4.0 Warehouse: A UAV and blockchain-based system for inventory and Traceability applications in big data-driven supply chain management*. MDPI. Retrieved September 13, 2021, from https://www.mdpi.com/1424-8220/19/10/2394.

9. Gillan, J. K., Ponce-Campos, G. E., Swetnam, T. L., Gorlier, A., Heilman, P., & McClaran, M. P. (2021). Innovations to expand drone data collection and analysis for rangeland monitoring. *Ecosphere*, *12*(7). https://doi.org/10.1002/ecs2.3649

10. Hardie, M. (2020). Review of novel and emerging proximal soil moisture sensors for use in agriculture. *Sensors*, *20*(23), 6934. https://doi.org/10.3390/s20236934

11. J. Zhang et al., "Robust RFID Based 6-DoF Localization for Unmanned Aerial Vehicles," in IEEE Access, vol. 7, pp. 77348-77361, 2019, doi: 10.1109/ACCESS.2019.2922211.

12. Khazetdinov, Artur & Aleksandrov, Andrey & Zakiev, Aufar & Magid, Evgeni & Hsia, Kuo-Hsien. (2020). RFID-Based Warehouse Management System Prototyping Using A Heterogeneous Team Of Robots. 10.13180/clawar.2020.24-26.08.32.

Additional References

13. Korošak, Ž., Suhadolnik, N., & Pleteršek, A. (2019). The implementation of a low power environmental monitoring and soil moisture measurement system based on UHF RFID. *Sensors*, *19*(24), 5527. https://doi.org/10.3390/s19245527
14. Li, C., Tanghe, E., Suanet, P., Plets, D., Hoebeke, J., De Poorter, E., & Joseph, W. (2021). ReLoc 2.0: UHF-RFID Relative Localization for Drone-Based Inventory Management. IEEE
15. Transactions on Instrumentation and Measurement, 70, 1–13. https://doi.org/10.1109/TIM.2021.3069377
16. Luvisi, A. (2016). Electronic Identification Technology for agriculture, plant, and food. A Review. *Agronomy for Sustainable Development*, *36*(1). https://doi.org/10.1007/s13593-016-0352-3
17. *Motus Wildlife Tracking System*. (n.d.). Motus Wildlife Tracking System. Retrieved September 13, 2021, from https://motus.org
18. Quino, J., Maja, J. M., Robbins, J., Fernandez, R. T., Owen, J. S., & Chappell, M. (2021). RFID and DRONES: The next generation of Plant Inventory. *AgriEngineering*, *3*(2), 168–181. https://doi.org/10.3390/agriengineering3020011
19. *RFID solutions: Inventory management & asset tracking system*. Senitron.net. (2021, September 2). Retrieved September 22, 2021, from https://senitron.net/.
20. Roberts, B., Neal, M., Snooke, N., Labrosse, F., Curteis, T., & Fraser, M. (2020). A bespoke low-cost system for radio tracking animals using multi-rotor and fixed-wing unmanned aerial vehicles. *Methods in Ecology and Evolution*, *11*(11), 1427–1433. https://doi.org/10.1111/2041-210x.13464
21. SunshineCoastDaily. (2015, May 20). *Need to round up some cattle? Send in the drones*. The Courier Mail. Retrieved September 22, 2021, from https://www.couriermail.com.au/news/queensland/central-and-north-burnett/need-to-round-up-some-cattle-send-in-the-drones/news-story/a04ff45238788f7cc9902501de23864a.
22. Swain, C., McNees, K., & Ferraro, K. (2019). The Use of Drones to Support "Cattle Tracking" Activities to Monitor Livestock Movements and Wildlife Numbers. *Proceedings of Student Research and Creative Inquiry Day*, *3*.
23. Won, D., Chi, S., & Park, M. (2020). UAV-RFID Integration for Construction Resource Localization. *KSCE Journal Of Civil Engineering*, *24*(6), 1683-1695. https://doi.org/10.1007/s12205-020-2074-y
24. Won, D., Park, M., & Chi, S. (2018). Construction Resource Localization Based on UAV-RFID Platform Using Machine Learning Algorithm. *2018 IEEE International Conference On Industrial Engineering And Engineering Management (IEEM)*. https://doi.org/10.1109/ieem.2018.8607668
25. Wildlife Drones. (2021, September 8). *Radio-tracking wildlife - learn how drone-based wildlife telemetry works*. Wildlife Drones. Retrieved September 22, 2021, from https://wildlifedrones.net/radio-tracking/.

References

1. Abdulai, G., Sama, M.P., & Jackson, J. (2021). A preliminary study of the physiological and behavioral response of beef cattle to unmanned aerial vehicles (UAVs). *Applied Animal Behaviour Science, 241*, 105355.
2. Animal Disease Traceability, (2020) 9 C.F.R § 86.4.
3. Canadian Cattle Identification Agency, (April 2013). RFID Reader Standards, Procedures, and Testing Document: Radio Frequency Identification (RFID), Version 8. http://canadaid.ca/wp-content/documents/CCIA_Reader_Standards_Version_8-April-2013_Final.pdf
4. Freed, T., Carson, V., & Doerr, K., (Dec 2020). *Optimizing a RFID-UAV cattle search tour*. Retrieved March 5, 2022, from https://www.researchgate.net/publication/347866343_Optimizing_a_RFID-UAV_cattle_search_tour
5. Goolsby J., Jung J., Landivar J., McCutcheon W., Lacewell R., Duhaime R., Schwartz A., (2016). Evaluation of Unmanned Aerial Vehicles (UAVs) for detection of Cattle in the Cattle Fever Tick Permanent Quarantine Zone. *Subtrop. Agric. Environ.* **67**:24–27.
6. Grandin, T., & Shivley, C. (2015). How Farm Animals React and Perceive Stressful Situations Such As Handling, Restraint, and Transport. *Animals : an open access journal from MDPI*, *5*(4), 1233–1251. https://doi.org/10.3390/ani5040409
7. Jung S., & Ariyur K.B., (Jun 2017). Strategic cattle roundup using multiple quadrotor UAVs, *Int. J. Aeronaut. Space Sci.*, vol. 18, no. 2, pp. 315-326.
8. Li X., Xing L. (Dec 2019) Reactive Deployment of Autonomous Drones for Livestock Monitoring based on Density-based Clustering; Proceedings of the 2019 IEEE International Conference on Robotics and Biomimetics (ROBIO); Dali, China.pp. 2421–2426.
9. Mulero-Pázmány, M., Jenni-Eiermann, S., Strebel, N., Sattler, T., Negro, J. J., & Tablado, Z. (2017). Unmanned Aircraft Systems as a new source of disturbance for wildlife: A systematic review. *PLOS ONE*, *12*(6). https://doi.org/10.1371/journal.pone.0178448
10. Pierce C.F., Speidel S.E, Coleman S.J., Enns R.M., Bailey D.W., Medrano J.F., Cánovas A., Meiman P.J., Howery L.D., Mandeville W.F., & Thomas M.G., (Feb 2020). Genome-wide association studies of beef cow terrain-use traits using Bayesian multiple-SNP regression, Livestock Science, Volume 232,2020,103900, ISSN 1871-1413, https://doi.org/10.1016/j.livsci.2019.103900.
11. Schroeder N.M., Panebianco A, Gonzalez M.R., & Carmanchahi P., (2020). An experimental approach to evaluate the potential of drones in terrestrial mammal research: a gregarious ungulate as a study model. *R. Soc. open sci.***7** 191482191482 http://doi.org/10.1098/rsos.191482
12. Siror, J.K., Sheng, H., Wang, D., & Wu, J. (2009). Use of RFID Technologies to Combat Cattle Rustling in the East Africa. *2009 Fifth International Joint Conference on INC, IMS and IDC*, 1556-1562.
13. Sun Y.,Yi S., Hou F., Luo D., Hu J., Zhou Z., (3 Sept 2020). Quantifying the Dynamics of Livestock Distribution by Unmanned Aerial Vehicles (UAVs): A Case Study of Yak Grazing at the Household Scale. Rangeland Ecology and Management, 73(5), 642-648
14. Trevarthen, A., & Michael, K. (2008). The RFID-enabled Dairy Farm: Towards Total Farm Management. *2008 7th International Conference on Mobile Business*. https://doi.org/10.1109/icmb.2008.39
15. Williams, L. R., Fox, D. R., Bishop-Hurley, G. J., & Swain, D. L. (2019). Use of radio frequency identification (RFID) technology to record grazing beef cattle water point use. *Computers and Electronics in Agriculture*, *156*, 193–202. https://doi.org/10.1016/j.compag.2018.11.025

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]

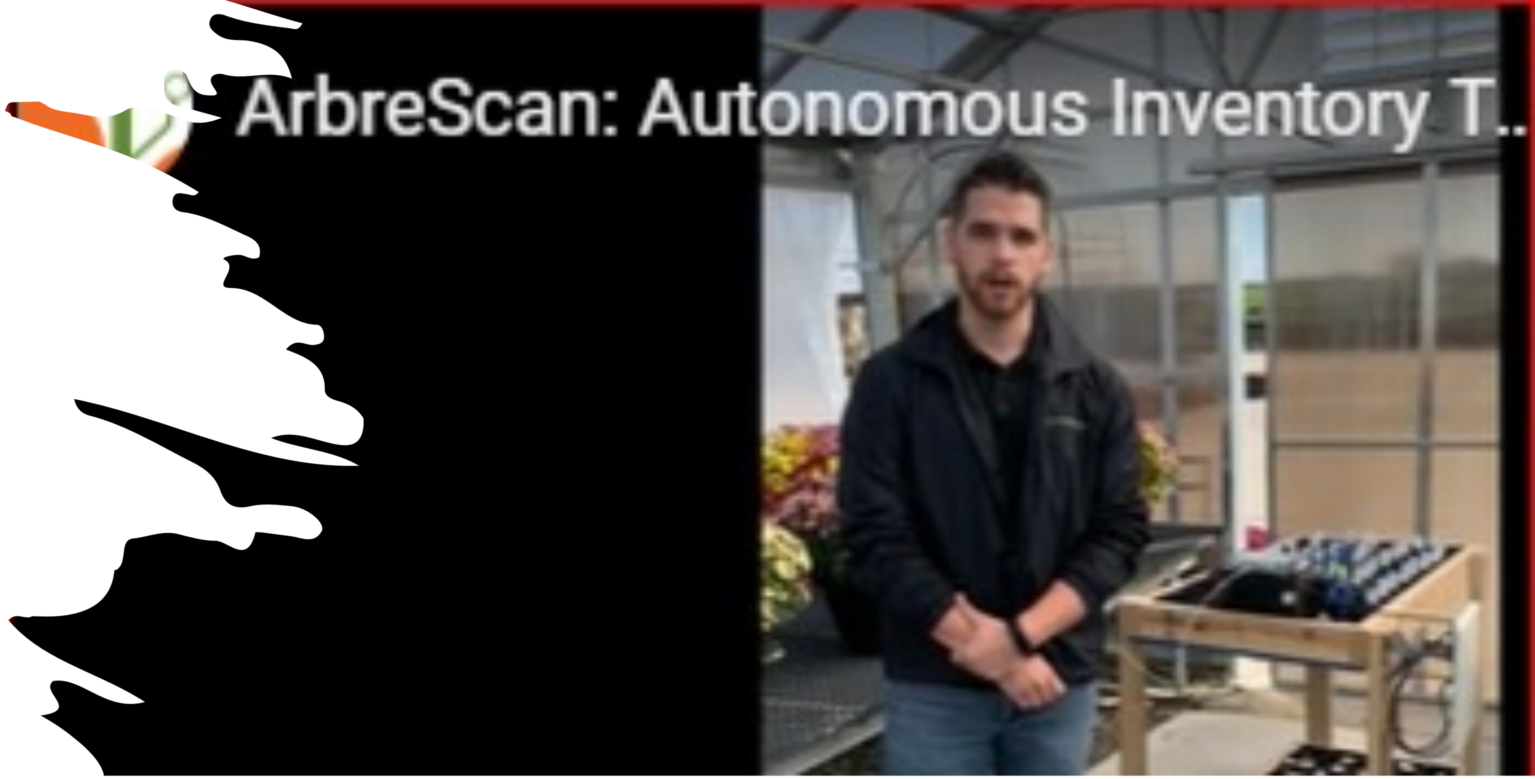
- When to sow crops
- How machinery affects the crops
- When a potential drought is incoming

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

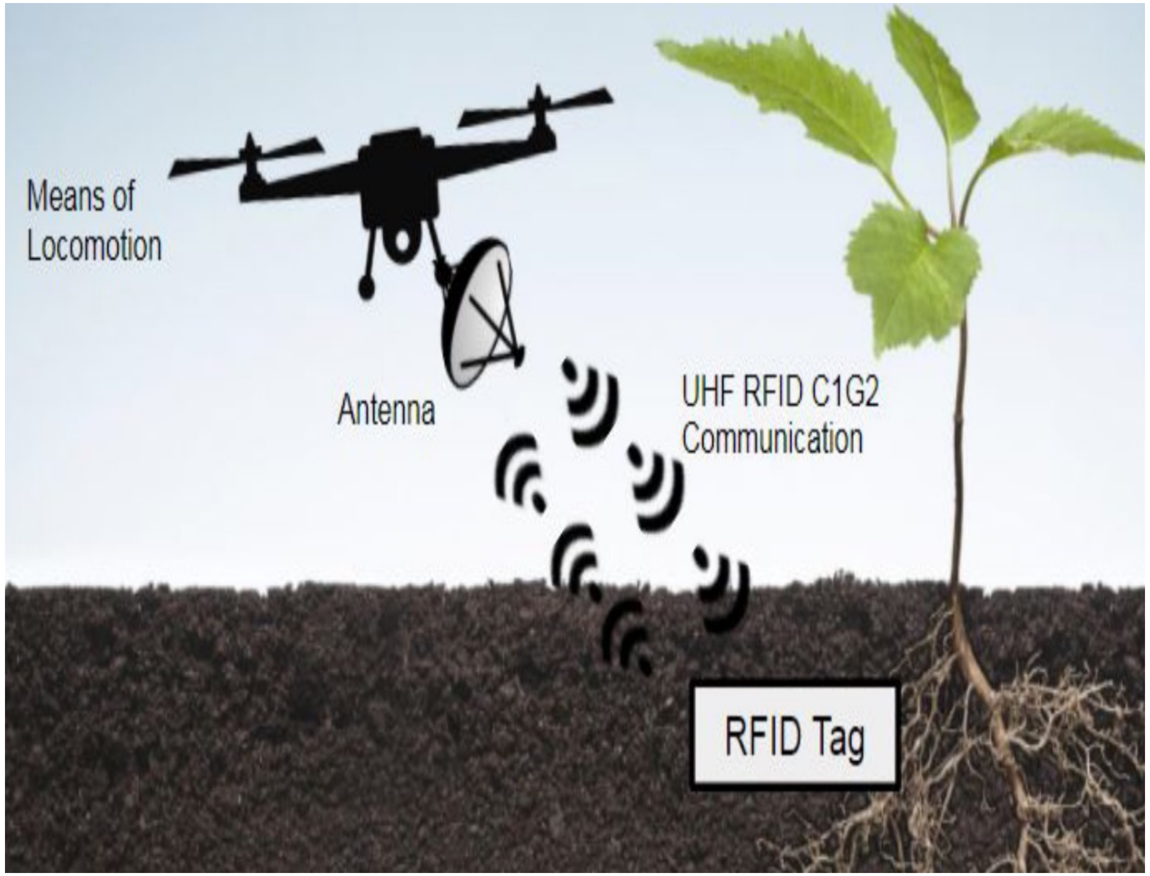


- **Arbre Technologies**
- **RFID Tags**
- **measure plant growth**
- Arbretech.com

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



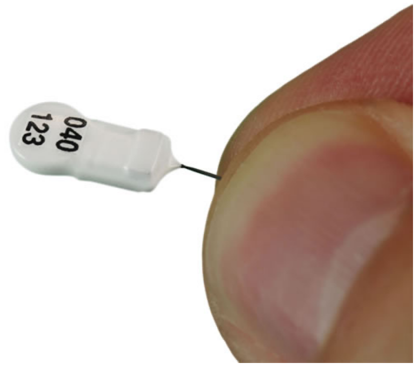
Industry Application: Senitron RFID Solutions

- 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

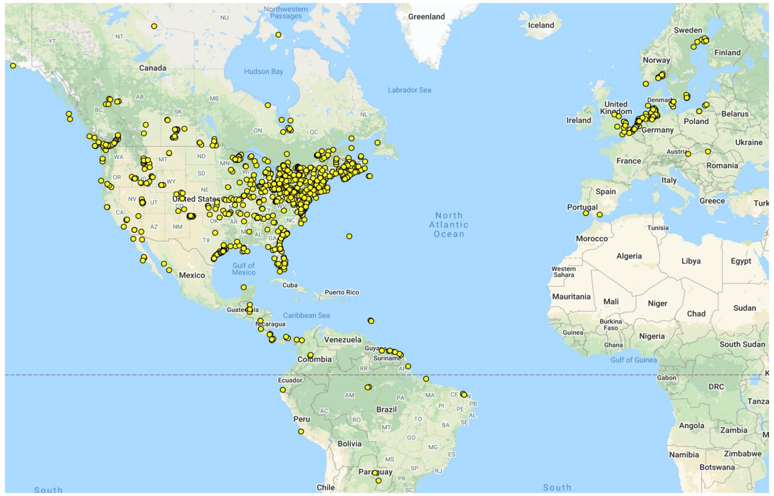
Integrating GPS and/or RFID technology into tags allows for animal movement to be more thoroughly tracked

- 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

1. Tag

Tag the animals you would like to track with the VHF radio-tags of your choice.

2. Attach

Attach the Wildlife Drones system to your drone.

3. Fly

When the drone is flown, the radio-receiver will listen for all tagged animals within range.

4. View

Data collected by the radio-receiver is then relayed to the base station computer where you can view the locations of your animals live on a map.