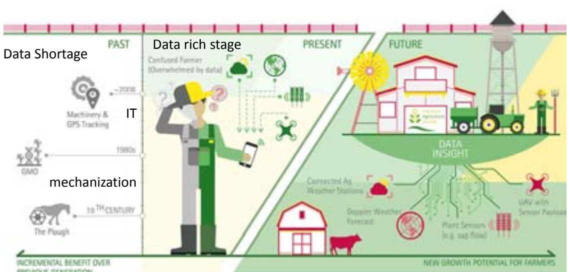
Sensing Technologies for Precision Agriculture

Ning Wang

Dept. of Biosystems and Agricultural Engineering
Oklahoma State University

Evolution of Agriculture



https://www.accenture.com/us-en/insight-accenture-digital-agriculture-solutions

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Precision Agriculture (PA)

Data acquisition:

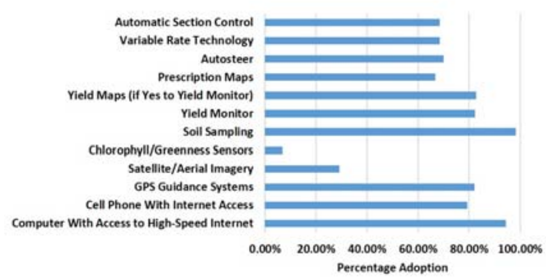
By generating detailed insights of machine operations, crop growth, soil conditions, and weather conditions, the sensing technologies for precision agriculture can assist farmers in making data-based management decisions to optimize yield and boost revenue while minimizing expenses, the chances of crop failure, and environment impact.

Productivity | Efficiency | Profitability | Sustainability

Sensing technology for PA

- Machine
  - Auto-steering (GPS-assisted)
  - Guidance (Lightbars, DGPS, RTK GPS)
  - Section and row control (planters, seeders,…)
  - Precision spraying (Boom height, section and nozzle control, flow control, droplet size…)
  - Variable rate technology (seed, fertilizer, chemical…)
- Crop
  - Color, height, density, uniformity, stalk diameter, NDVI, LAI, Leaf temperature, yield, ……
  - Imaging, spectral, ultrasonic, radio, microwave, physical principle, LiDAR….
- Soil
  - Moisture, EC, pH, N, P, K, texture …
  - Optical (VIS, IR, microwave, radar…), TDR, capacitive, resistive, GPR, Electrode,…
- Weather

Sensing technology for PA



(Precision Agriculture Usage and Big Agriculture Data, Cornhusker Economics May 27, 2015)

Sensing technology for PA

Carriers for sensing systems:

- Satellite-based
  - Remote sensing
  - Spectral imaging
- Aerial-based
  - Far-ground: manned flight
  - Close-ground: UAV
- Ground-based
  - Manual
  - Autonomous

Sensing technology for PA

Applications

- In-field crop production
  - Speed, Portability, Robustness
  - Cost
- Off-line for crop production
  - Accuracy, time
- Breeding (small plot, high accuracy, high throughput)
  - Phenotyping system
    - Speed, high accuracy, repeatability, tolerance of interference…
    - Multi-sensor fusion, data integration, data interpretation…

Precision Agriculture Application
- By-Plant Measurements

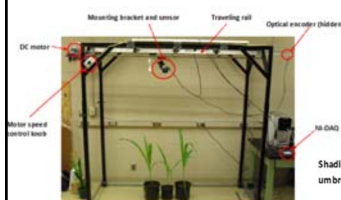
- Ultrasonic Sensor:
  - NORAC Inc., Saskatchewan, Canada
  - Transducer: SensComp 600 Series, 50kHz
  - 15° beam angle
  - Effective sensing range: 0.4m ~ 1.3m
  - Communication: CAN bus to USB
  - 12 VDC power supply

- Laser Range Finder:
  - LMS291, SICK Inc., Germany
  - Near-infrared at 905 nm
  - Effective sensing range: < 8m (1mm resolution)
  - 100° maximum scanning angle, 0.25° angle resolution
  - Communication: RS422 with 500k bps
  - 24 VDC power supply
- Range Camera:
  - SR4000 and SR3000, MESA Imaging AG Inc., Switzerland
  - Light source: NIR at 850 nm
  - Image sensor with 144 × 176 active pixels
  - Field of view is 34.6° (v) × 43.6° (h)
  - Communication: USB
  - 12 VDC power supply

Research Projects

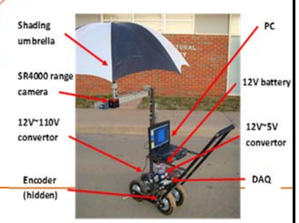
- Precision Agriculture Application
  - By-plant sensing and control (Ground sensing)
  - UAV (preliminary)
  - Crop characteristics
- Wireless sensor network (WSN) applications
  - Precision agriculture
  - Environmental monitoring
  - Precision livestock
  - Study on critical issues on WSN applications
- Food Security
  - Animal Behavior monitoring (Precision Livestock)
  - Sensor and control systems for phenotyping applications
- Food Safety
  - Hand Hygiene Compliance

Precision Agriculture Application
- By-Plant Measurements



Lab Experiment

Field Data Acquisition



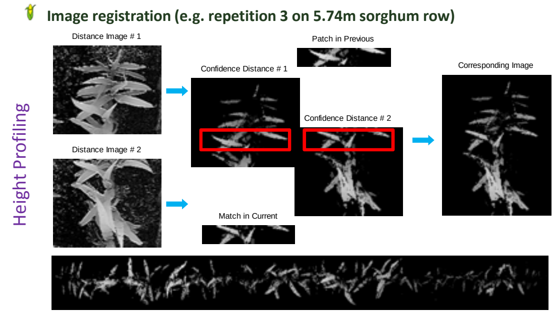
Precision Agriculture Application
- By-Plant Measurements

- **Traditional single-rate N application causes 33% of nitrogen use efficiency (NUE) in world cereal production**
- **A 1% increase of NUE worldwide could save $234,658,462**
- **Research shows that yield of crop is varied by plant.**
- **NDVI and plant height is a good predictor of in-season corn forage biomass and forage yield**
- **Stock diameter is another useful indicator of plant growth and health situation.**

http://nue.okstate.edu/Index_Resolution.htm

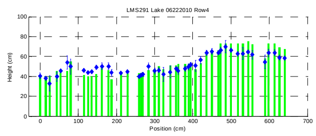
Precision Agriculture Application
- By-Plant Measurements

- Image registration (e.g. repetition 3 on 5.74m sorghum row)



Precision Agriculture Application
- By-Plant Measurements

2009



2010, V4

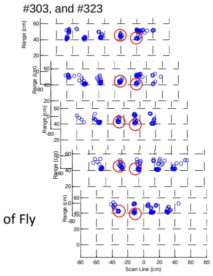
	Pros	Cons
Ultrasonic Sensor	•Low cost •Robust performance in field application	•Sensitive to the orientation and area of the sensing surface, so that it may not be the best in height measurement for corn-like crop
Laser Range Finder	•High accuracy •Robust and stable performance in field application	•Relatively high cost •Bigger volume
Range Camera	•Has the potential of realizing height measurement and plant shape recognition at the same time	•Too sensitive to the outdoor sunlight •Easy to induce in error during the image registration •High cost

Precision Agriculture Application
- By-Plant Measurements

Advantage of Using 2D Line Scan (LiDAR) Approach

TOF – Time of Fly

Scan #243, #263, #283, #303, and #323



Cart moving direction

Precision Agriculture Application
- By-Plant Measurements

Corn Spacing Measurement

Objective:

- To develop a sensing system using LiDAR technique to automatically measure corn plant within-row spacing
- To develop a technique to determine by-plant locations

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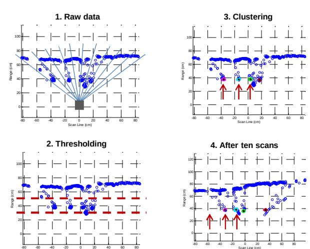
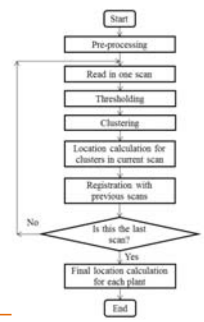
Precision Agriculture Application
- By-Plant Measurements

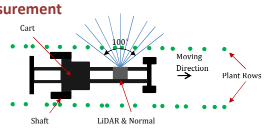
Flowchart of Data Processing Algorithm



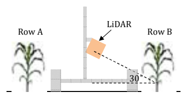


Precision Agriculture Application
- By-Plant Measurements

Corn Spacing Measurement



Plot	Population (plants/acre)	Nitrogen rate (lbs/acre)
1	20,000	0
2	20,000	80
3	20,000	160
4	26,000	80
5	20,000	0
6	20,000	80
7	20,000	160
8	26,000	80



- May to June in 2011 and 2012
- LabVIEW program to control and log sensor data with time stamps and encoder readings
- Ground truth data being manually measured

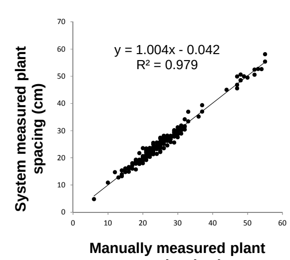
Previous platform – a steel cart

Precision Agriculture Application
- By-Plant Measurements

RMSE of Spacing estimate: 0.23 cm

RMSE of location estimate: 0.38cm

RMSE of plant counts: 3.51

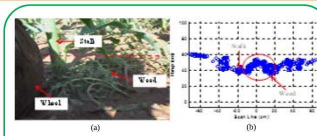


Precision Agriculture Application
- By-Plant Measurements

Biosystems & Agricultural Engineering, Oklahoma State University

Where Errors Come From?

Sheath interference with stalk locations



(a) (b)

Weed interference

Typical laid-over leaf interference

- Algorithms
- Encoder readings were different with actual movement distances

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Precision Agriculture Application
- By-Plant Measurements
Corn Stalk Diameter Measurement

Biosystems & Agricultural Engineering, Oklahoma State University

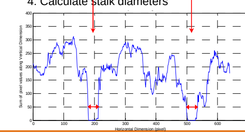
LiDAR + Webcam

1: Original RGB image at V12 growth stage

2: Extracted green image

3: Binary image after thresholding

4: Calculate stalk diameters

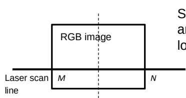


Precision Agriculture Application
- By-Plant Measurements
Corn Stalk Diameter Measurement

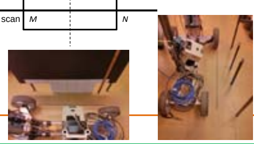
Biosystems & Agricultural Engineering, Oklahoma State University

LiDAR + Webcam

- o LiDAR: SICK LMS291
- o Webcam: Microsoft LifeCam
- o LiDAR to locate stalks
- o RGB image to measure stalk diameters



Sensor matching and size estimate look-up tables



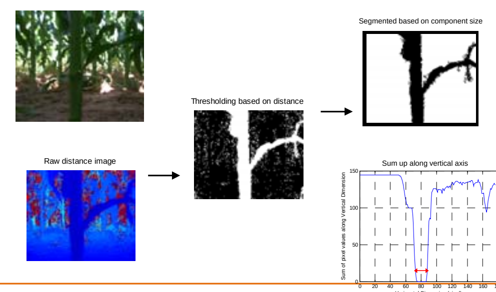
3D Range Camera

- o SwissRanger SR4000
- o Combination of location and shape measurements
- o Drawbacks:
  - o low signal to noise ratio outdoor
  - o small field of view (44°×35°)

Precision Agriculture Application
- By-Plant Measurements
Corn Stalk Diameter Measurement

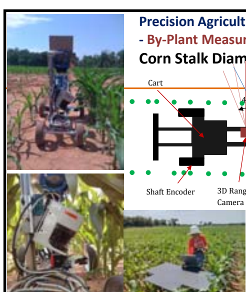
Biosystems & Agricultural Engineering, Oklahoma State University

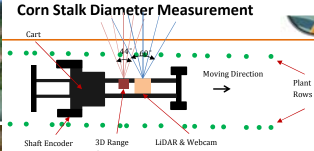
3D Range Camera



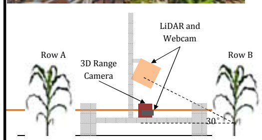
Precision Agriculture Application
- By-Plant Measurements
Corn Stalk Diameter Measurement

Plot	Population (Plants/ac)	N-rate lbs/ac
1	20,000	0
2	20,000	80
3	20,000	160
4	26,000	80





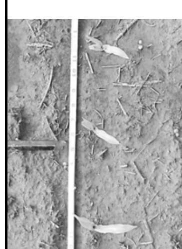
- Ground truth data:
  - o perimeter,
  - o diameter along the row direction
  - o stalk orientation

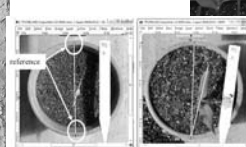


- Conducted this June
- Modified golf cart
- Two approaches
- Shaft encoder
- Shade for 3D range camera
- One LabVIEW program to control and log three sensors' data with time stamps and encoder readings

Precision Agriculture Application - By-Plant Measurements

Methods to evaluate the plant orientations

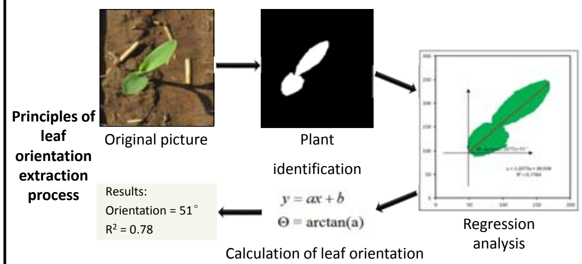




- **Manual measurements**
- **Very tedious and slow**
- **Subjective**

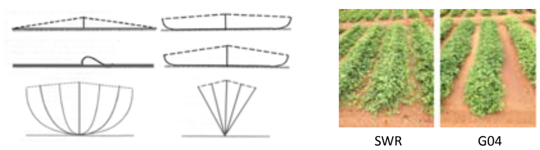
Precision Agriculture Application
- By-Plant Measurements

Evaluation leaf orientation



Peanut Plant Canopy Characterization

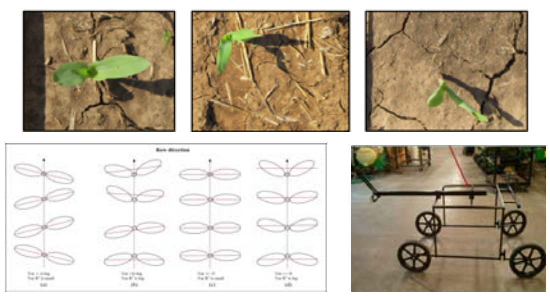
Peanut Growth habits



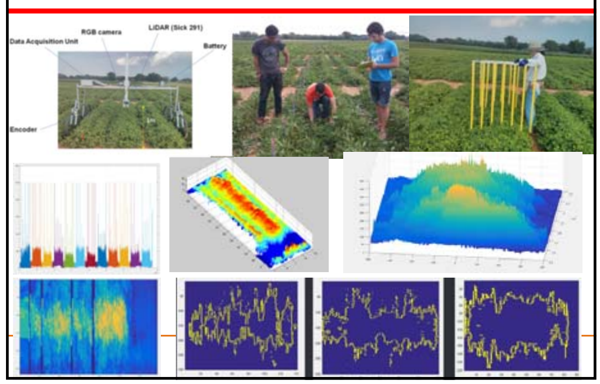
Canopy traits such as density and upright growth habit contribute to host resistance by creating environments less conducive to disease or by reducing opportunities for contact with infested soil.

Precision Agriculture Application
- By-Plant Measurements

Evaluation leaf orientations



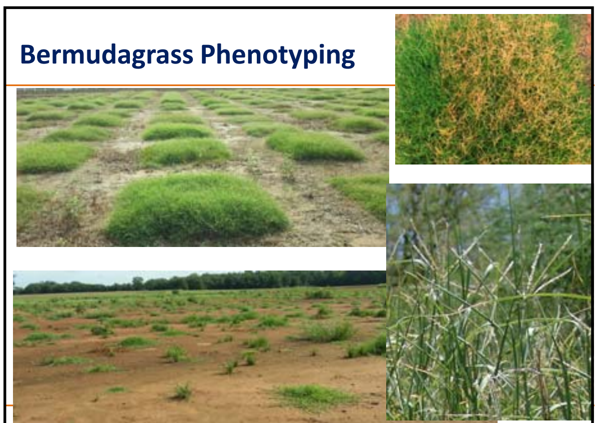
Peanut Plant Canopy Characterization



Peanut Plant Canopy Characterization

- Breeding process needs high-throughput field sensing to assess plant traits for growth, tolerance, resistance, yield
  - canopy profile, plant coverage, compactness, stem diameter, height, width;
  - color, leaf area index, leaf angle;
  - chlorophyll content, temperature, humidity
- Automatic **sensing** greatly accelerates breeding evaluation process

Bermudagrass Phenotyping



Guide to NTEP Turfgrass Ratings

Trait	Criteria (rating from 1 – 9 in visual inspection by trained evaluator)	3D Imaging ?	Measured value
Genetic Color	1- light green; 9- dark green	Y	Color
Winter Color	1 - straw brown or no color retention; 9 - dark green	Y	Color
Spring Greenup	1- straw brown; 9-completely green.	Y	Color
Leaf Texture	1 – coarse; 9 – fine	Possible	Color
Density and vertical growth	1 – min density; 9 -max density	Y	Color, Height
Living Ground Cover and vertical growth	surface area covered by the originally planted species	Y	Color, Height
Seedling Vigor/Establishment and vertical growth	1 – min vigor; 9 – max vigor	Y	Color, Height, Cover
Disease or Insect Damage	1 - no resistance or 100% injury; 9 - complete resistance or no injury	Possible	Color
Drought Tolerance	1- complete wilting, 100% leaf firing, complete dormancy or no plant recovery; 9 - no wilting, no leaf firing, 100% greenno dormancy, or 100% recovery.	Possible	Color
Frost Tolerance	1 - 100% leaf injury; 9 - no injury.	Possible	Color
Traffic Tolerance	1 - no tolerance or 100% injury; 9 - complete tolerance or no injury	Possible	Color
Thatch Accumulation	Measured values	Possible	Color
Seedhead	1- max seedhead; 9- no seedheads.	Possible	Color
Mowing Quality	1 - poorest mowing quality/most steminess and 9 - cleanest cut /no steaminess	Possible	Color

Bermudagrass Phenotyping

Forward	#1	#2	#3	#4	#5
Image					
Av. Red	66.65	58.57	67.33	65	74.04
Av. Green	89.96	99.62	112.28	106.24	107.106
Av. Blue	67.09	59.4	69.4	63.89	70.7055
Min. Green	7	7	7	7	7
Max. Green	199	212	215	218	198
Min. "Greenness"	0	0	0	0	0
Max. "Greenness"	131	151	150	154	133
Av. "Greenness"	23.08	40.64	43.87	41.7971	34.733
Min. DGCI	0.5268	0.4715	0.4907	0.48	0.4484
Max. DGCI	1.015	1.0217	1.0253	1.0281	1.0277
Av. DGCI	0.7826	0.7114	0.7145	0.6976	0.7027
Depth (mm)	73.4406	98.0015	99.4525	89.4695	80.9584

Plant Color

Plant height

Bermudagrass Phenotyping

Sensor
- Microsoft Kinect for Windows V2
  - RGB images
  - Infrared images
  - Depth images (distance)

Kinect v2 ($150)

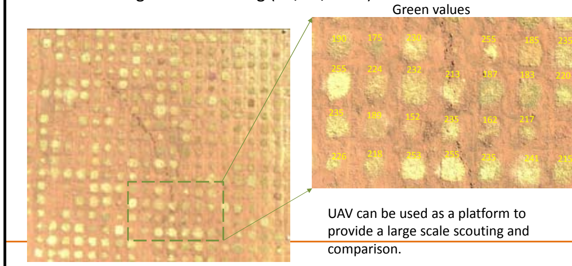
Software
- A Visual Studio program to capture RGB, infrared and depth images.
- A set of MATLAB scripts to extract useful information related to plant characteristics from the collected images.

- **Moving platform**
  - Movable carts for taking images in the field

Bermudagrass Phenotyping

- UAV for a large scale scouting (12/03/2015)

Green values



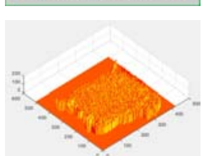
UAV can be used as a platform to provide a large scale scouting and comparison.

Bermudagrass Phenotyping

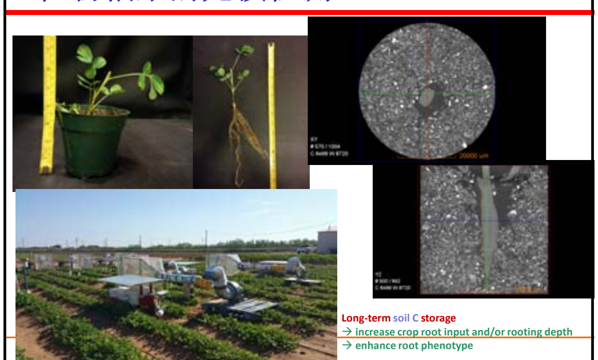
Parameter to be extracted from collected:

RGB images: 2448 x 3264
- **Size (green area in an image)**
- **Color (levels of greenness)**

Depth images: 512 x 424
- **Height**
- **Uniformity (smoothness)**



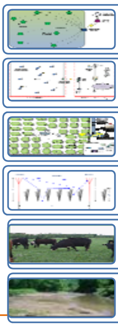
植物根系的无损检测



Long-term soil C storage
→ increase crop root input and/or rooting depth
→ enhance root phenotype

USDA ARS – Lubbock, TX

Research on WSN



First generation of WSN (2007-2008)
- Soil Moisture monitoring
- Tmote system

Second generation of WSN (2008-2010)
- Soil property monitoring (Soil MC, EC, Temp)
- Crossbow system

Wireless camera sensor network (2008-2013)
- Pecan weevil population monitoring
- Janic system

Radio propagation model for WSN used in crop field (2009-2013)
- Second generation WSN
- Wheat field

Cattle monitoring (2005-2013)
- Grazing activity

Sediment monitoring (2008-2013)
- Collaboration with KSU
- Webserver and database

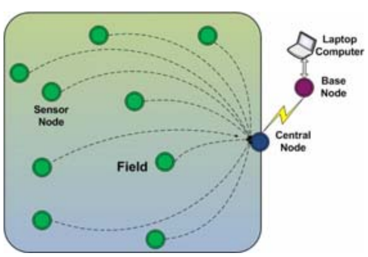
INSECT MONITORING

Autonomous monitoring has potential to cut significant time and expense for growers.

OSU OSU Fact Sheet EPP-7190

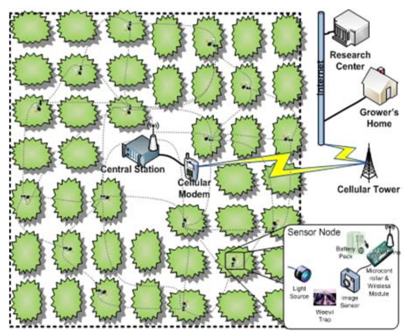
First Generation

Soil Moisture Monitoring System



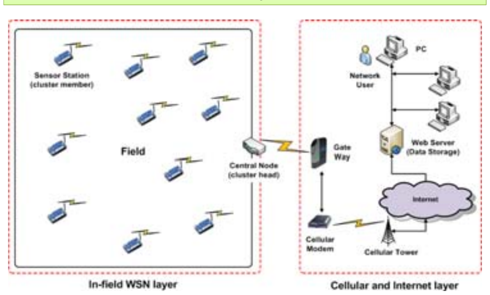
Structure:
Star-topology with 10 Sensor Nodes, one Central Node and one Base Node

INSECT MONITORING



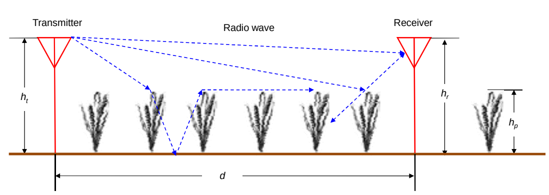
Second Generation

The WSN Conceptual Model



Radio Signal Path Loss Model

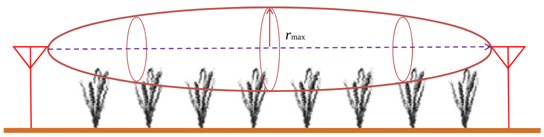
In the field, wheat canopy is the major reflection surface and obstacle along the transmission path, attenuation introduces by plant height



Sketch map of plant influences on radio wave propagation inside wheat field, h_t and h_r are transmitter and receiver height, h_p is plant height and d is the separation distance

Radio Signal Path Loss Model

Fresnel Zone Clearance



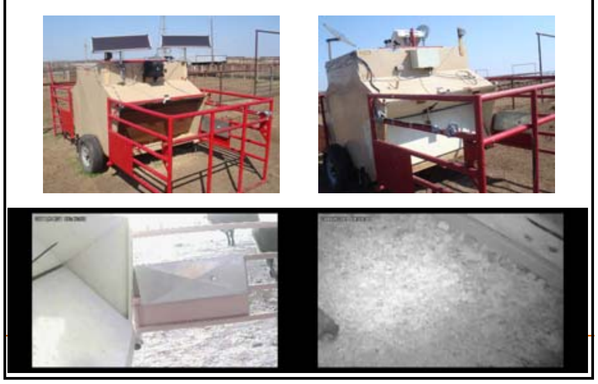
When both sensor and base station are at a 3*m* height. The Fresnel zone of 2470MHz is clear for all separation distances, but for 915MHz there's some obstruction when the distance is 130*m*. A 20% clearance tolerance was introduced and the allowed plant height at the largest r_{max} was re-calculated as

$$H_2 = 3 - (3.26 - 3.26 \times 20\%) = 0.4m$$

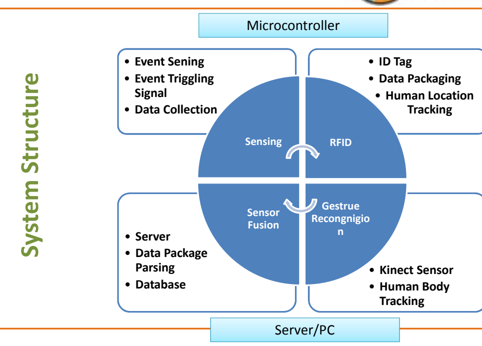
Food Safety
Hand Hygiene Compliance Monitoring

- Improper food handler practices contributed to approximately 97% of foodborne illnesses in food-service establishments and homes in USA (Howes, et al., 1996).
- 93% of the foodborne illnesses outbreaks were caused by the pathogens carried by food workers before or during the food processing.
- The annual cost to deal with foodborne illness outbreaks was estimated in between 6.5 to 35 billion USD in the U.S. each year. (Guzewich and Ross, 1999, Buzby & Roberts, 1997)

AUTOMATIC CATTLE FEEDER CONTROL



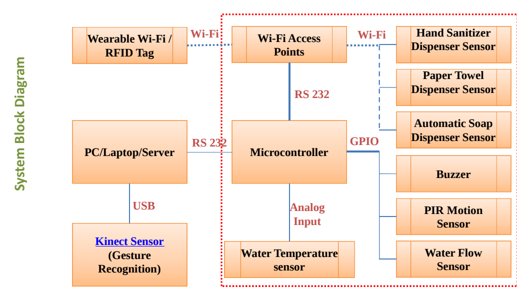
Food Safety
Hand Hygiene Compliance Monitoring



AUTOMATIC CATTLE FEEDER CONTROL

- RFID – Radio Frequency Identification
  - Not mandatory in most of the states in USA, but getting more and more attention
    - Better cattle production management
    - Fighting for cattle rustling
  - Types of RFID
    - Ear tags
    - Bolus
    - Microchip Implant
    - Tattoo

Food Safety
Hand Hygiene Compliance Monitoring



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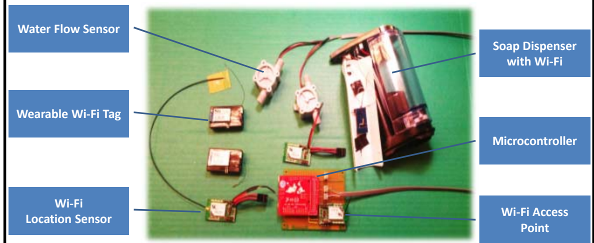
Prototype System



Prototype System for Hand Hygiene Monitoring: Microcontroller system

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Thanks for your attention!

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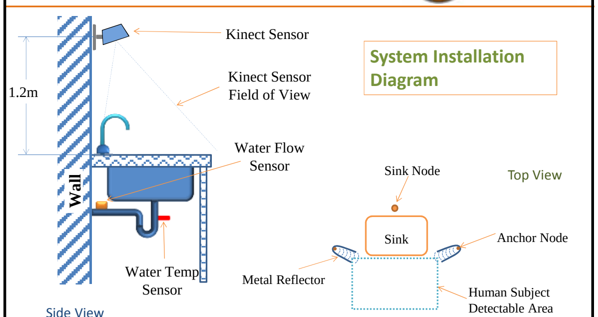
System Installation Diagram



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Prototype System Demo