IARIA
Tutorial 3
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The role of sensors in Agriculture 4.0

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Introduction

Sensors for agriculture

Drones for agriculture

The limitations or barriers to be overcome

Introduction - Why is it so important to include sensors in Agriculture?

Maximize the productivity of lands.

Increase the quality of harvested food.

Reduce the inputs of agriculture (water, fertilizers, pesticides,…).

Improve the working conditions of farmers.

Have smart and automatized machinery.

Introduction - What technologies can be included?

Sensors in Wireless Sensor Networks (WSN) → If possible physical sensors

Sensors in remote sensing (cameras, drones, and satellites)

Sensors in others (machinery and portable devices)

Introduction – In what crops can be included?

It can be included in all the existing crops.

Majorly included in extensive crops and greenhouses

Other examples can be found in woody crops (vineyards, citrus, and olives trees)

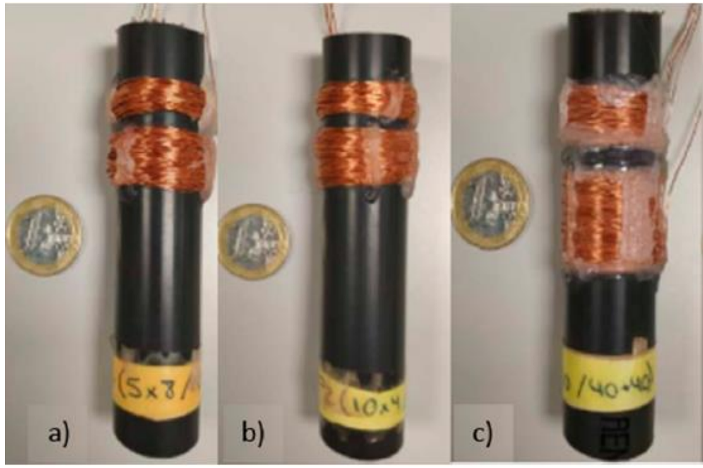
Sensors for Agriculture – Monitoring the water

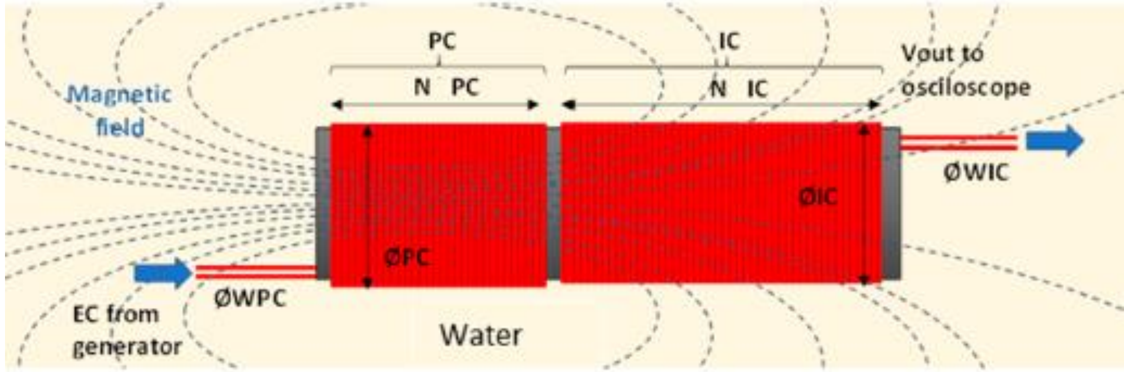
Motivation: Controlling the use of fertilizer in water

Task: Physical sensor (based on cooper coils) that measure the concentration of fertilizer

Objectives:

1. Evaluate if copper coils can be used to measure the concentration of fertilizer
2. Define the best prototype among the tested ones (multilayer ones)





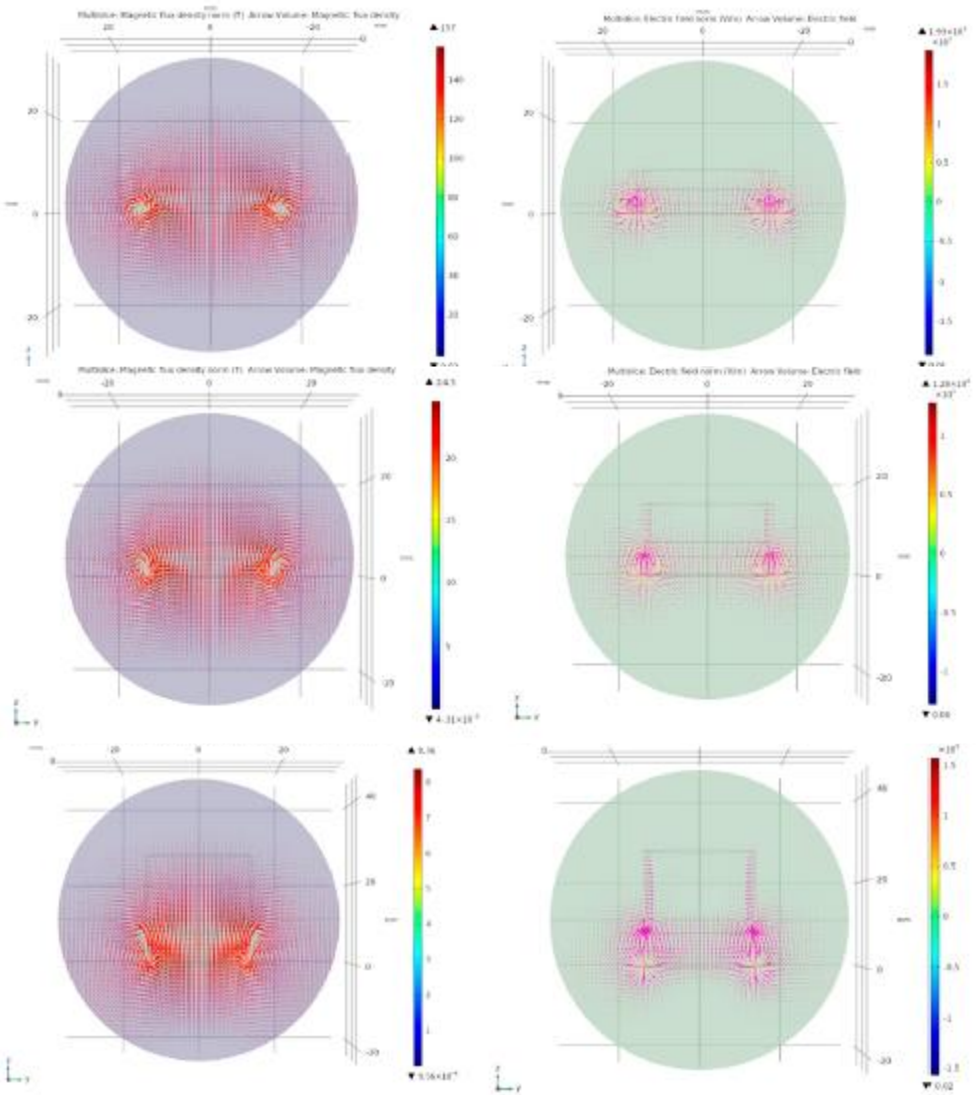
Sensors for Agriculture – Monitoring the water

Motivation: Controlling the use of fertilizer in water

Task: Physical sensor (based on cooper coils) that measure the concentration of fertilizer

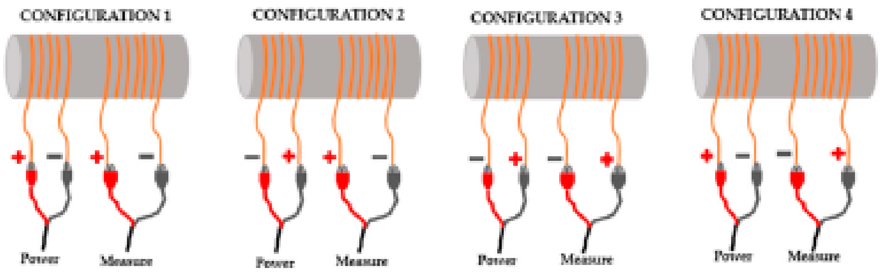
Objectives:

1. Evaluate if copper coils can be used to measure the concentration of fertilizer
    1. Simulation of magnetic flux density of powered coil
2. Define the best prototype among the tested ones (multilayer ones)



Basterrechea, D. A., Parra, L., Botella-Campos, M., Lloret, J., & Mauri, P. V. (2020). New Sensor Based on Magnetic Fields for Monitoring the Concentration of Organic Fertilisers in Fertigation Systems. *Applied Sciences*, *10*(20), 7222.

Sensors for Agriculture – Monitoring the water

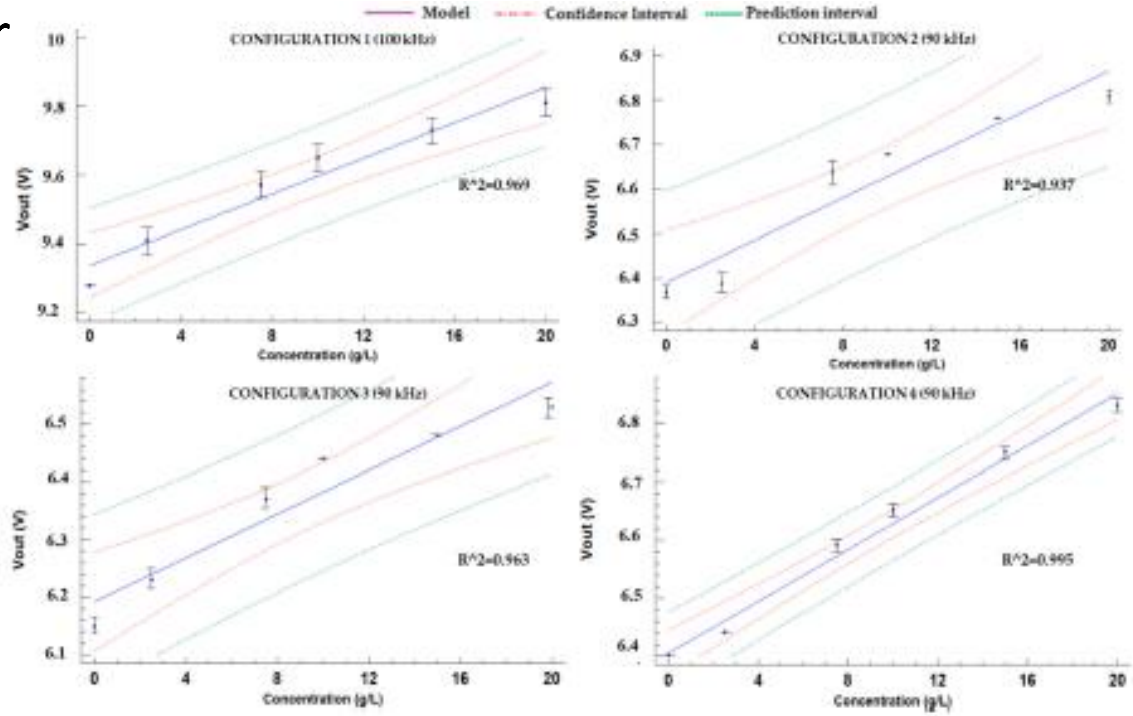


Motivation: Controlling the use of fertilizer in water

Task: Physical sensor (based on cooper coils) that measure the concentration of fertilizer

Objectives:

1. Evaluate if copper coils can be used to measure the concentration of fertilizer
    2. Calibration – 4 configurations per prototype
2. Define the best prototype among the tested ones (multilayer ones)



Example of calibration of Prototype 1 and its 4 configurations

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Sensors for Agriculture – Monitoring the water

Motivation: Controlling the use of fertilizer in water

Task: Physical sensor (based on cooper coils) that measure the concentration of fertilizer

Objectives:

1. Evaluate if copper coils can be used to measure the concentration of fertilizer
   3. Verifications
2. Define the best prototype among the tested ones (multilayer ones)

Concentration of OF (g/L)	Conf.	P1		P2		P3	
		AE (g/L)	RE (%)	AE (g/L)	RE (%)	AE (g/L)	RE (%)
5.00	1	1.04	20,81	0.66	13.26	0.02	0.43
12.50		2.37	18,94	0.85	6.81	0.41	3.3
17.50		0.31	1,77	2.04	11.64	0.02	0.12
5.00	2	0.78	15,57	2.11	42.25	1.71	34.1
12.50		0.97	7,77	0.52	4.19	1.05	8.43
17.50		2.49	14,22	3.04	17.37	1.06	6.03
5.00	3	1.41	28,14	2.66	53.14	0.52	10.43
12.50		1.70	13,59	1.03	8.21	0.84	6.71
17.50		1.35	7,73	2.42	13.85	2.46	14.05
5.00	4	1.14	22,82	3.15	62.91	0.85	16.97
12.50		1.53	12,26	0.03	0.28	0.55	4.44
17.50		0.37	2,12	3.61	20.63	1.28	7.33

Basterrechea, D. A., Parra, L., Botella-Campos, M., Lloret, J., & Mauri, P. V. (2020). New Sensor Based on Magnetic Fields for Monitoring the Concentration of Organic Fertilisers in Fertigation Systems. *Applied Sciences*, *10*(20), 7222.

Sensors for Agriculture – Monitoring the water

Motivation: Controlling the use of fertilizer in water

Task: Physical sensor (based on cooper coils) that measure the concentration of fertilizer

Objectives:

1. Evaluate if copper coils can be used to measure the concentration of fertilizer
2. Define the best prototype among the tested ones (multilayer ones)
    1. Comparison of prototypes (5 predefined requisites)

	Conf.	R1 $\Delta Vout$ [S1–S9] (V)	R2 Min. $Vout$ (V)	R3 N° Groups	R4 WF (kH)	R5		All
						AE [S3] (V)	$\overline{RE}$ (%)	
P1	1	0.53	9.28 *	7	100 *	0.02 *	0.19 *	
	2	0.44	6.37 *	7	90 *	0.03 *	0.52 *	
	3	0.39	6.15 *	9 *	90 *	0.22 *	3.5 *	
	4	0.43	6.40 *	8	90 *	0.07 *	1.05 *	
P2	1	1.41 *	8.64 *	8	110 *	0.65 *	7.05 *	
	2	1.41 *	7.95 *	6	110 *	0.75 *	8.45 *	
	3	1.41 *	8.40 *	6	110 *	0.7 *	7.41 *	
	4	1.84 *	7.41 *	6	110 *	0.83 *	9.53 *	
P3	1	1.29 *	7.65 *	9 *	140 *	0.62 *	8.86 *	*
	2	1.15 *	7.23 *	7	140 *	0.41 *	6.28 *	
	3	1.47 *	7.65 *	8	140 *	0.6 *	8.81 *	
	4	1.09 *	3.79 *	9 *	130 *	0.36 *	8.34 *	*

Prototype 3 with first configuration obtain the best results

Basterrechea, D. A., Parra, L., Botella-Campos, M., Lloret, J., & Mauri, P. V. (2020). New Sensor Based on Magnetic Fields for Monitoring the Concentration of Organic Fertilisers in Fertigation Systems. *Applied Sciences*, *10*(20), 7222.

Sensors for Agriculture – Monitoring the soil

Motivation: Controlling the soil moisture to irrigate

Task: Physical sensor (based on cooper coils) that measure the soil moisture

Objectives:

1. Evaluate if copper coils can be used to measure the soil moisture
2. Define if same calibration can be used for all soils (commercial devices need info. of soil type)
3. Define if temperature affects to its performance

Parra, M., Parra, L., Lloret, J., Mauri, P. V., & Llinares, J. V. (2019, October). Low-cost Soil Moisture Sensors Based on Inductive Coils Tested on Different Sorts of Soils. In 2019 Sixth International Conference on Internet of Things: Systems, Management and Security (IOTSMS) (pp. 616-622). IEEE.
Parra, M., Parra, L., Rocher, J., Lloret, J., Mauri, P. V., & Llinares, J. V. (2019, July). A Novel Low-Cost Conductivity Based Soil Moisture Sensor. In International Conference on Advanced Intelligent Systems for Sustainable Development (pp. 27-35). Springer, Cham.
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Sensors for Agriculture – Monitoring the soil

Name	Turns PC	Turns IC
P1	40	40
P2	40	80
P3	80	40
P4	40	100
P5	100	40

Pot	Water (mL)	Volumetric water content (%)
1	0	0,00%
2	175	5,83%
3	250	8,33%
4	500	16,66%

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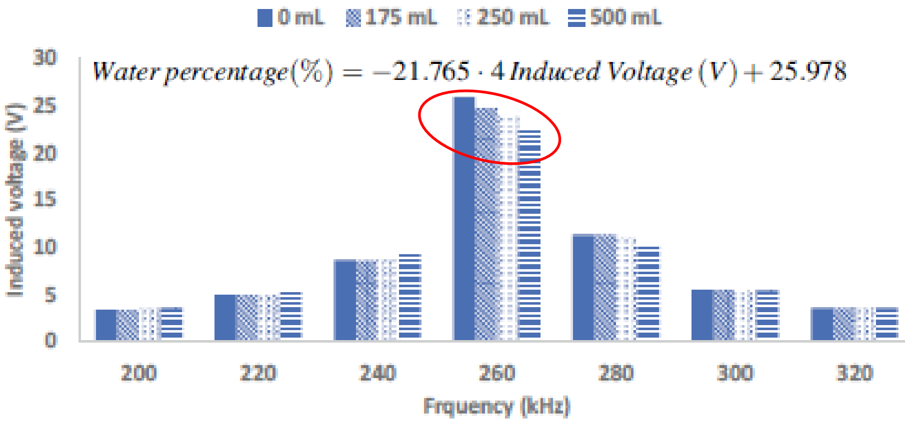

Best working frequencies of P3 and model

Objectives:

1. Evaluate if copper coils can be used to measure the soil moisture – *1 soil multiple prototypes*
2. Define if same calibration can be used for all soils (commercial devices need info. of soil type)
3. Define if temperature affects to its performance

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Sensors for Agriculture – Monitoring the soil

	P1	P2	P3
Diameter of Inner PVC tube (mm)	25	25	25
Layers	8	1	1
Casing	Yes	No	No
Separation between coils (mm)	10	5	5
Diameter of Casing PVC tube (mm)	43		
Number of Windings of PC	80	5	10
Number of Windings of IC	40	10	5

Motivation: Controlling the soil moisture to irrigate

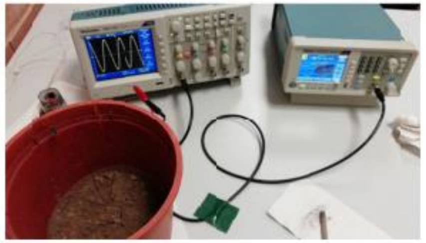
Task: Physical sensor (based on cooper coils) that measure the soil moisture

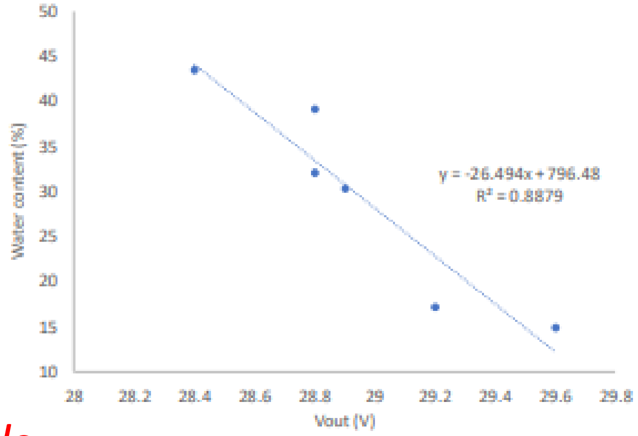
Total weight (g)	Water weight (g)	Water volume (cm3)	Water percentage %
2363	1689	1689	75.21
2277	1603	1603	71.38
2181	1507	1507	67.10
2086	1412	1412	62.87
1982	1308	1308	58.24
1833	1159	1159	51.61

Soil 1

Total weight (g)	Water weight (g)	Water volume (cm3)	Water percentage %
2363	1689	1689	75.21
2277	1603	1603	71.38
2181	1507	1507	67.10
2086	1412	1412	62.87
1982	1308	1308	58.24
1833	1159	1159	51.61

Soil 2





Calibration of P1 with Soil 2

Objectives:

1. Evaluate if copper coils can be used to measure the soil moisture
2. Define if same calibration can be used for all soils – *multiple soils and multiple coils* → *Same model is not valid for both soils*
3. Define if temperature affects to its performance

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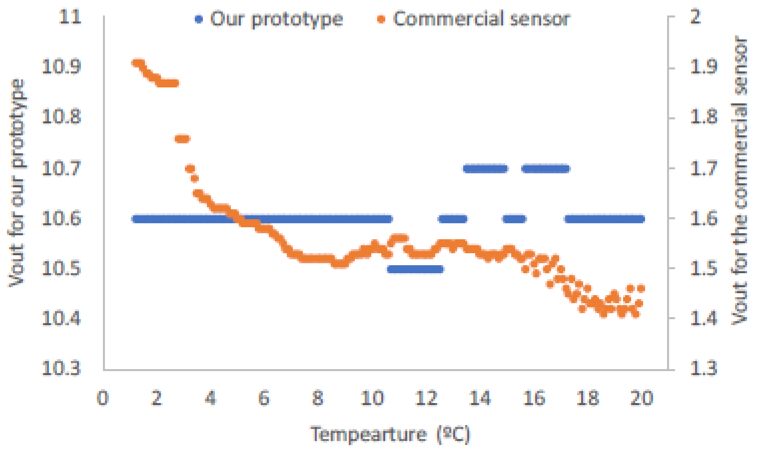
Sensors for Agriculture – Monitoring the soil

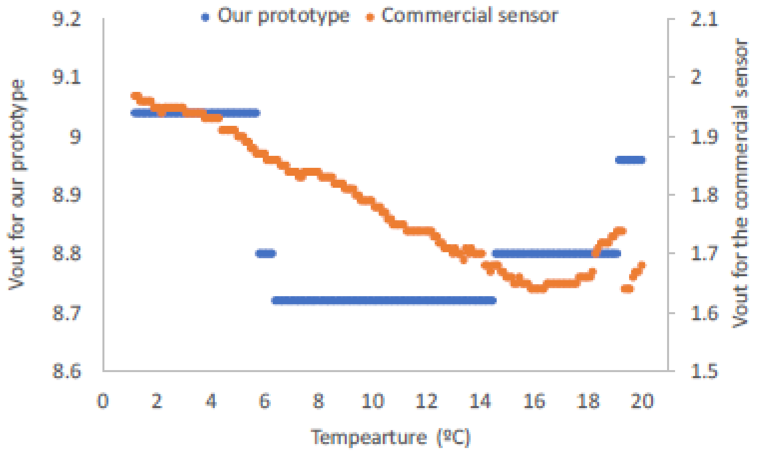
Motivation: Controlling the soil moisture to irrigate

Task: Physical sensor (based on cooper coils) that measure the soil moisture

Objectives:

1. Evaluate if copper coils can be used to measure the soil moisture
2. Define if same calibration can be used for all soils
3. Define if temperature affects to its performance
   - Comparison of our model with other low cost ones





Variation of out model of 0,2V and 0,35V (±0,1 of 10,6V and ±0,175 of 8,9V)
Variation of commercial ones 0,5V and 0,4V (±0,25 of 1,8V and ±0,2 of 1,8V)

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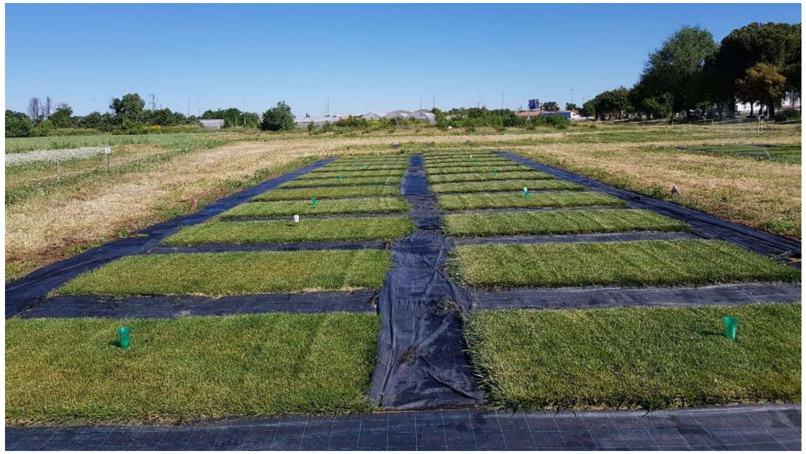
Sensors for Agriculture – Measuring plant status with portable devices



Motivation: Differentiate species (based on variables)

Task: Use portable devices to monitor the species using physical sensors in turf grass

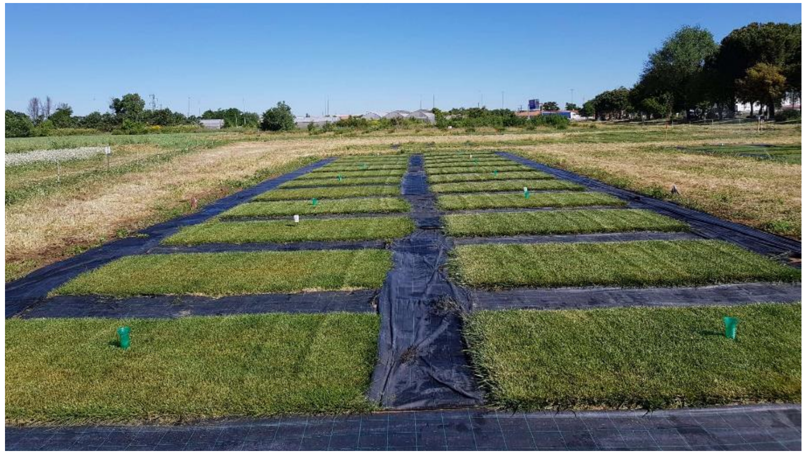
Objectives:

1. Evaluate if portable devices can differentiate plant species
   1. Soil moisture (SM), canopy temperature (CT), NDVI
   2. +Images (GA and GGA indixes)
   3. 4 Different combination of species (Control, PC, PZ, and PB)

2. Is it possible to estimate one variable from another?

Mauri, P.V, Parra, L. Lloret, J., Yousfi, S., Marín J.F. (2020, October). Testing and Validation of Monitoring Technologies to Assess the Performance and Genotyping of Poa pratensis (C3) Mixed with Other Grass Species (C4). The Twelfth International Conference on Advances in System Testing and Validation Lifecycle (VALID 2020) (pp. 1-6)

Sensors for Agriculture – Measuring plant status with portable devices



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GA is the best indicator of grass species

	SM	CT	NDVI	GA	GGA
Control	35.2583 [a]	14.6125 [a]	0.76 [a]	0.67875 [b]	0.35 [a]
PC	35.5 [a]	14.8417 [a]	0.745 [a]	0.61805 [a]	0.295 [a]
PB	34.3944 [a]	14.6056 [a]	0.79 [b]	0.77944 [c]	0.48 [b]
PZ	36.3722 [a]	14.4694 [a]	0.77 [b]	0.76472 [c]	0.425 [b]
Level of significance	0.8727 [ns]	0.9579 [ns]	0.0005***	0.0000***	0.0000***

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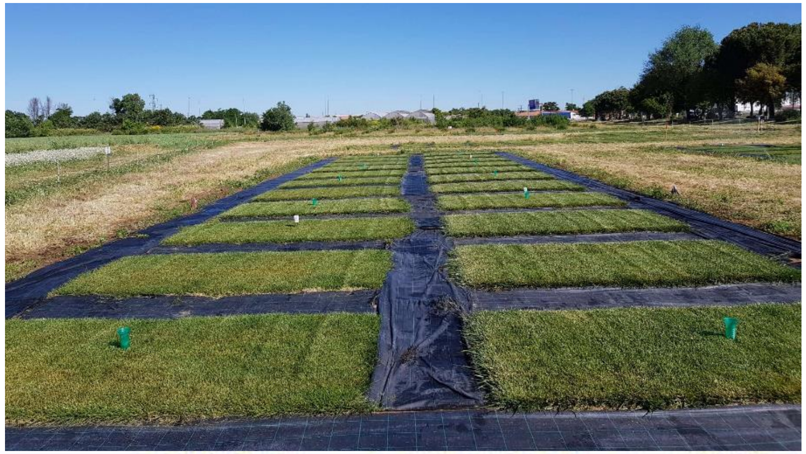
Sensors for Agriculture – Measuring plant status with portable devices



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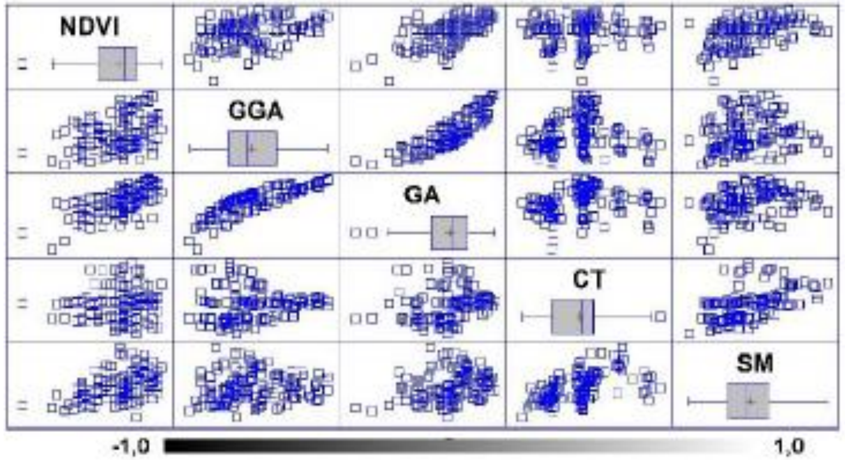

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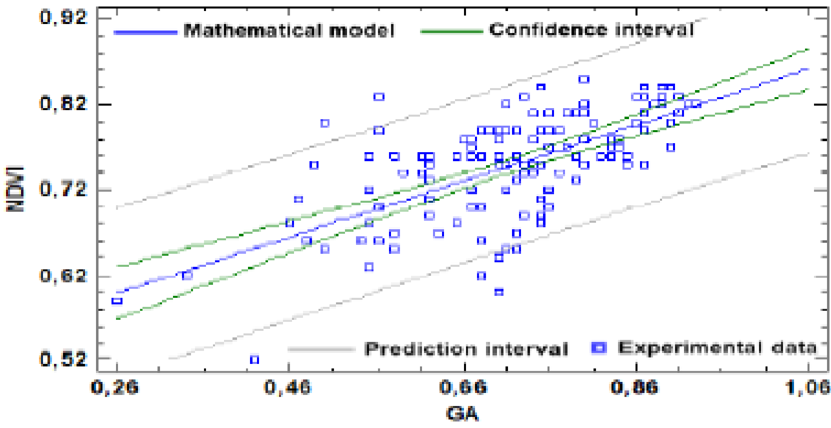
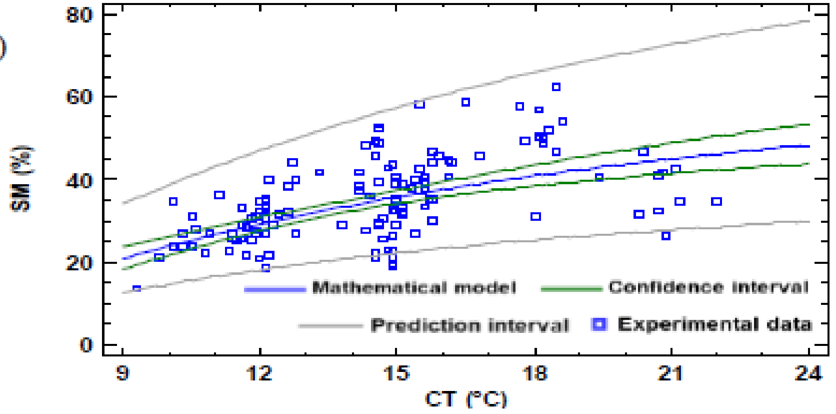


$$NDVI = 0.513359 + 0.329084 \cdot GA$$
$$SM (\%) = \exp(4.38257 - 12.0825/CT\ (^{\circ}C))$$



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Drones for Agriculture – Using a mobile node to gather the information

Motivation: Recognizing the status of grass

Task: Autonomous WSN for Lawns Monitoring

Objectives:

1. Estimate the possibility of analyzing the image offline

   - Algorithm

   - Operations with matrixes (RGB image)

Marín, J., Rocher, J., Parra, L., Sendra, S., Lloret, J., & Mauri, P. V. (2017, October). Autonomous WSN for lawns monitoring in smart cities. In *2017 IEEE/ACS 14th International Conference on Computer Systems and Applications (AICCSA)* (pp. 501-508). IEEE.

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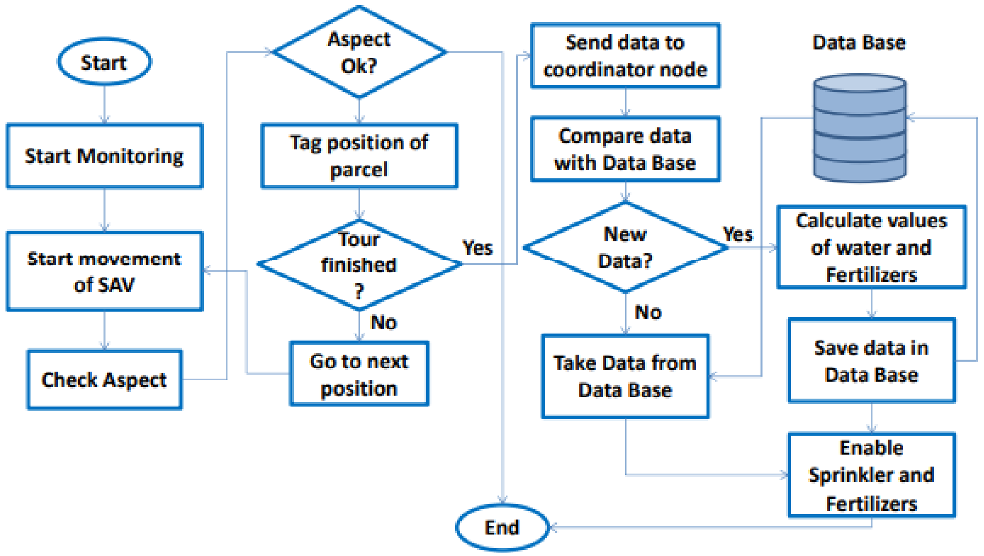

Operation algorithm to analyze data

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Drones for Agriculture – Using a mobile node to gather the information

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Objectives:

1. Estimate the possibility of analyzing the image offline
   - Algorithm
   - Operations with matrixes (RGB image)

$$A = \begin{bmatrix} a1,1 & a1,2 & \cdots & a1,150 \\ a2,1 & a2,2 & \ddots & a2,150 \\ \vdots & \vdots & & \vdots \\ a100,1 & a100,2 & \cdots & a100,150 \end{bmatrix} \quad (1)$$

$$B = \begin{bmatrix} 39.5 & 39.5 & \cdots & 39.5 \\ 39.5 & 39.5 & \ddots & 39.5 \\ \vdots & \vdots & & \vdots \\ 39.5 & 39.5 & \cdots & 39.5 \end{bmatrix} \quad (2)$$

$$C = A - B \quad (3)$$

$$D = \begin{bmatrix} \frac{\frac{c1,1}{|c1,1|}+1}{2} & \cdots & \frac{\frac{c1,150}{|c1,150|}+1}{2} \\ \vdots & \ddots & \vdots \\ \frac{\frac{c1,100}{|c1,100|}+1}{2} & \cdots & \frac{\frac{c100,150}{|c100,150|}+1}{2} \end{bmatrix} \quad (4)$$

$$E = \begin{bmatrix} 60.5 & 60.5 & \cdots & 60.5 \\ 60.5 & 60.5 & \ddots & 60.5 \\ \vdots & \vdots & & \vdots \\ 60.5 & 60.5 & \cdots & 60.5 \end{bmatrix} \quad (5)$$

$$F = A - E \quad (6)$$

$$G = \begin{bmatrix} \frac{\frac{f1,1}{-|f1,1|}+1}{2} & \cdots & \frac{\frac{f1,150}{-|f1,150|}+1}{2} \\ \vdots & \ddots & \vdots \\ \frac{\frac{f1,100}{-|f1,100|}+1}{2} & \cdots & \frac{\frac{f100,150}{-|f100,150|}+1}{2} \end{bmatrix} \quad (7)$$

$$H = D \times G \quad (8)$$

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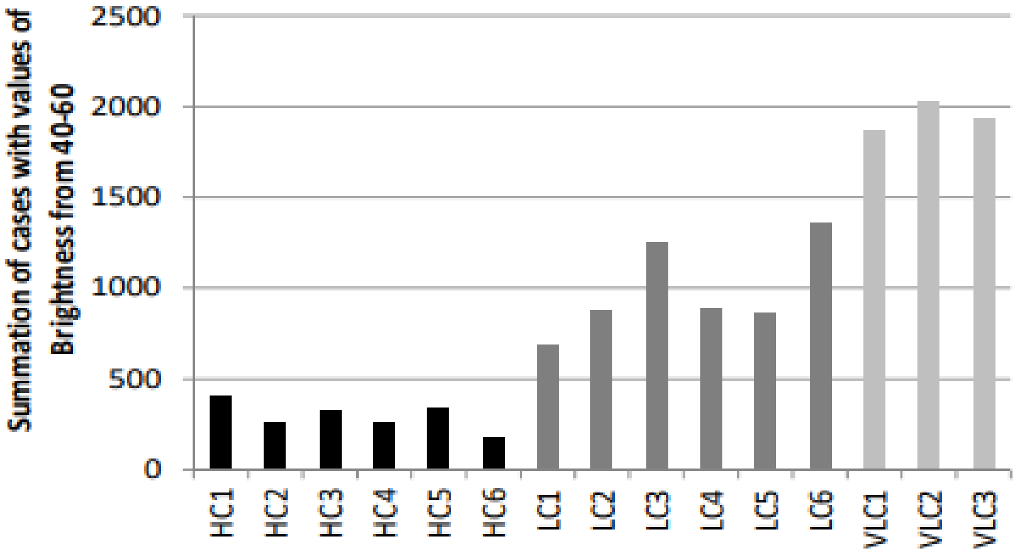
Drones for Agriculture – Using a mobile node to gather the information



Motivation: Recognizing the status of grass

Task: Autonomous WSN for Lawns Monitoring

Objectives:

1. Estimate the possibility of analyzing the image offline

-Tested with plots with:
High Grass Coverage (HC) a);
Low Grass Coverage (LC) b);
Very Low Grass Coverage (VLC) c).

a) b) c)

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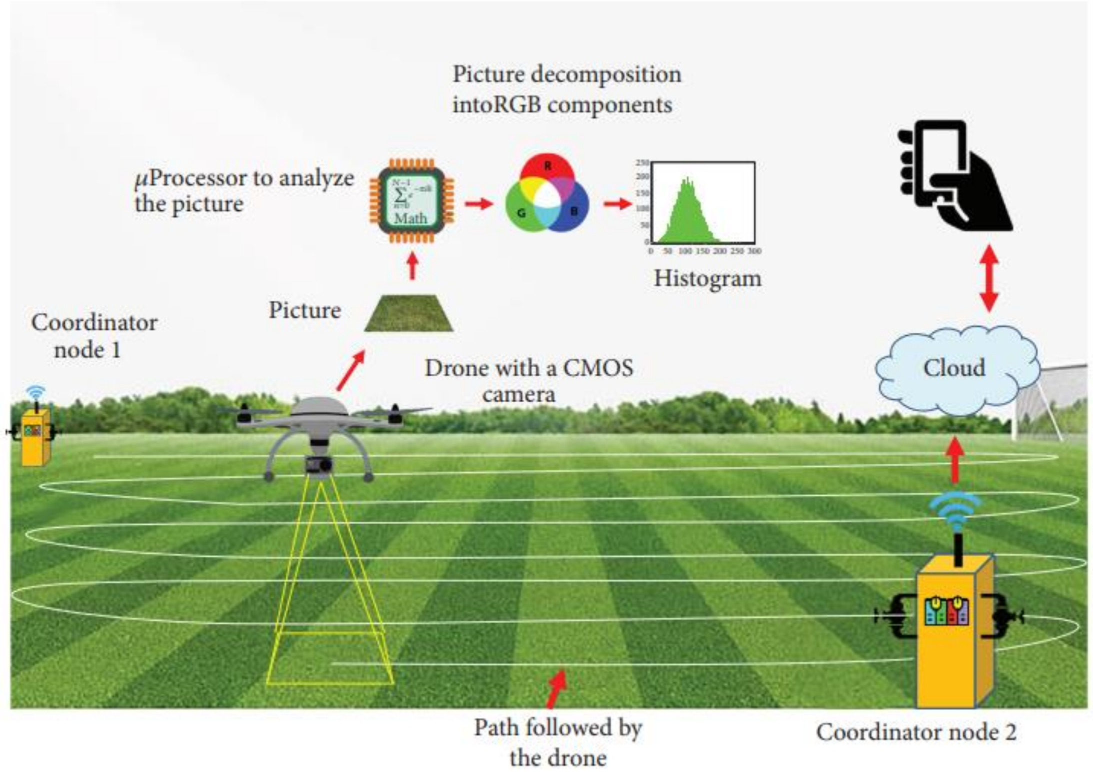
Drones for Agriculture – Using a mobile node to gather the information

Motivation: Recognizing the status of grass

Task: Autonomous WSN for Lawns Monitoring

Objectives:

1. Compare the performance of a drone with a terrestrial vehicle



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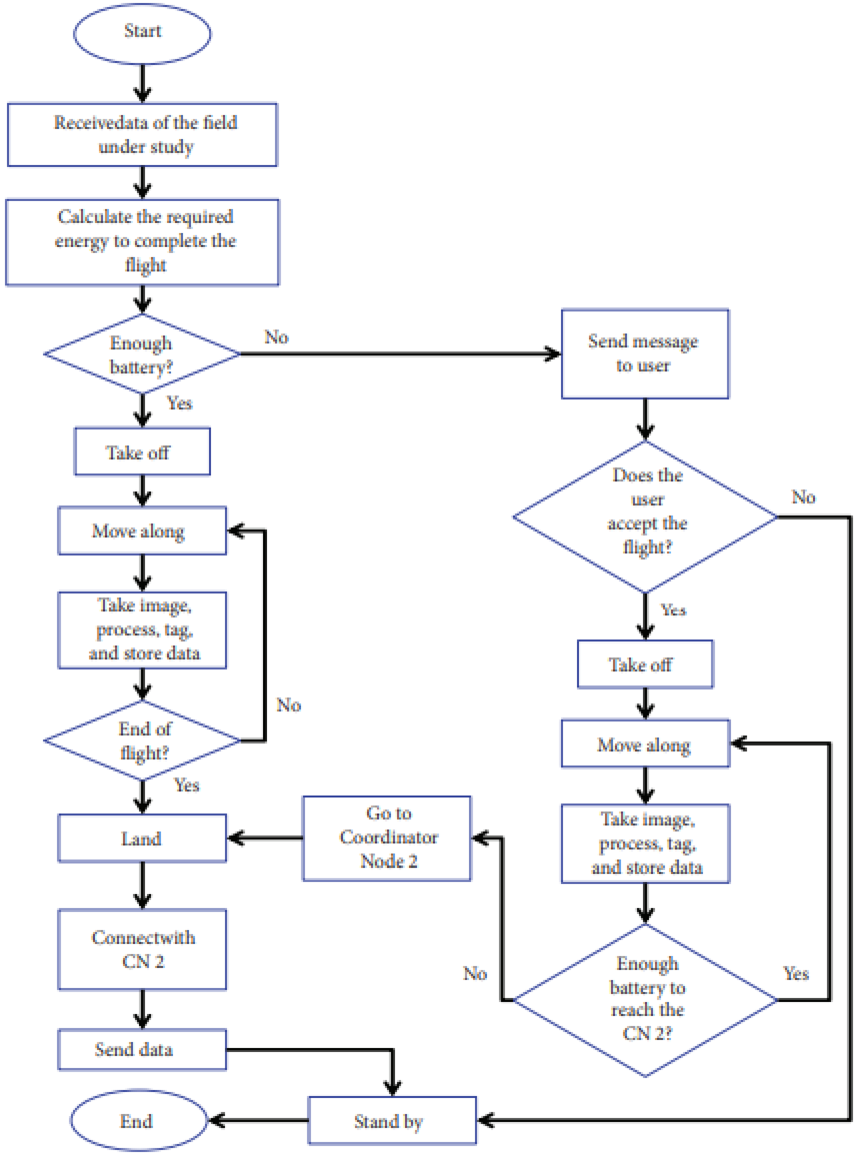

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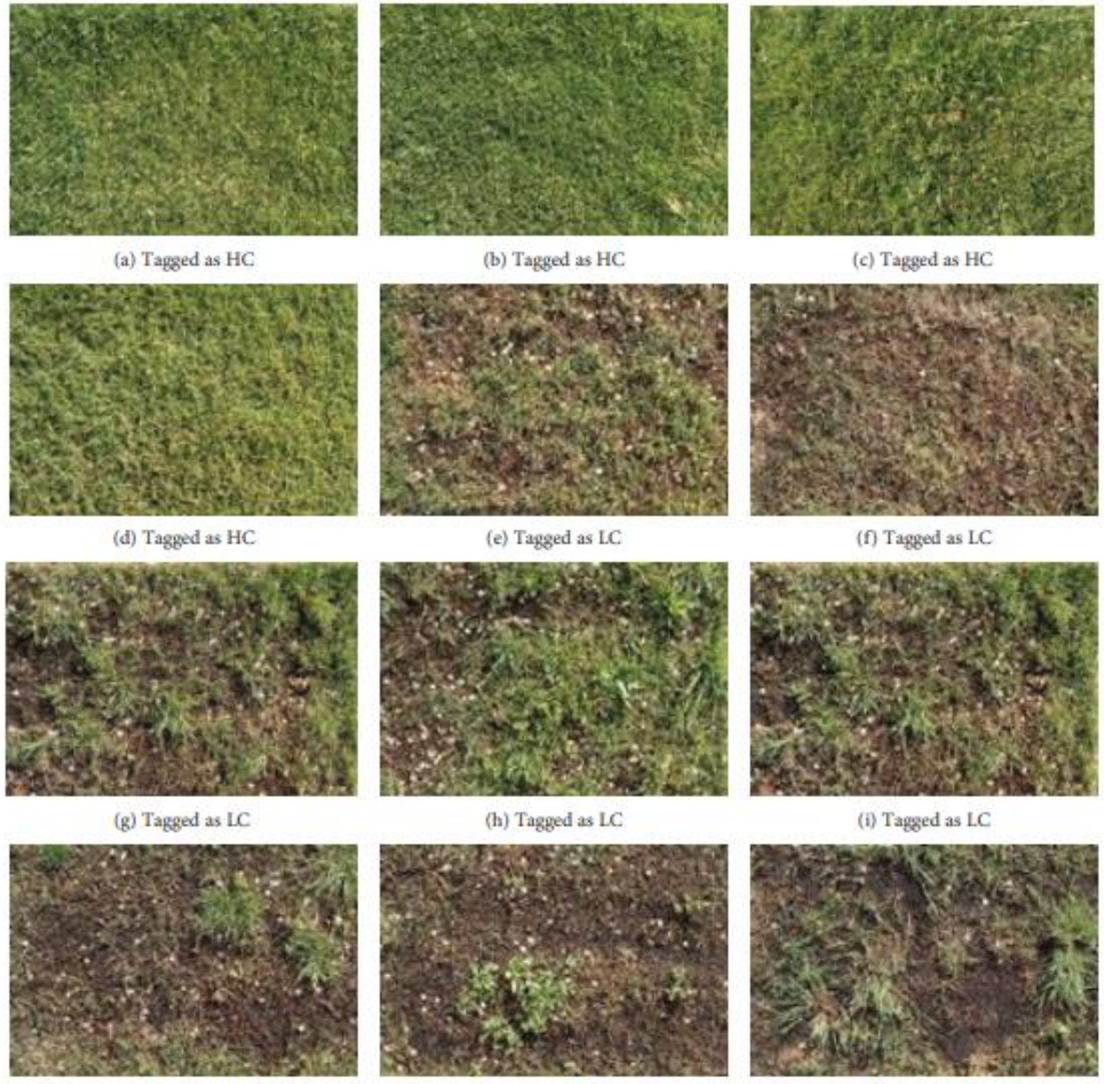
Task: Autonomous WSN for Lawns Monitoring

Objectives:

1. Compare the performance of a drone with a terrestrial vehicle

-Tested with plots with:
High Grass Coverage (HC) a);
Low Grass Coverage (LC) b);
Very Low Grass Coverage (VLC) c).


(a) Tagged as HC (b) Tagged as HC (c) Tagged as HC
(d) Tagged as HC (e) Tagged as LC (f) Tagged as LC
(g) Tagged as LC (h) Tagged as LC (i) Tagged as LC
(j) Tagged as VLC (k) Tagged as VLC (l) Tagged as VLC

Marín, J., Parra, L., Rocher, J., Sendra, S., Lloret, J., Mauri, P. V., & Masaguer, A. (2018). Urban lawn monitoring in smart city environments. Journal of Sensors, 2018.

Drones for Agriculture – Using a mobile node to gather the information

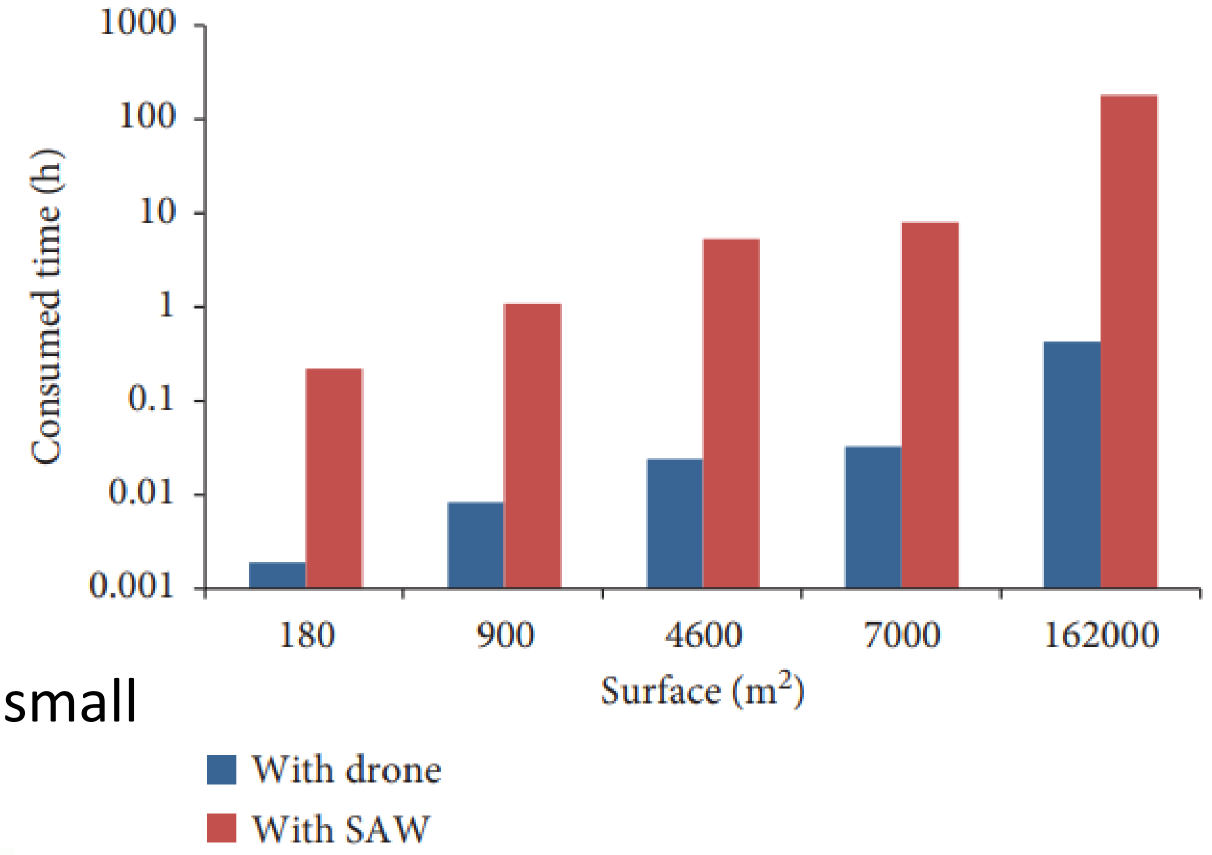
Motivation: Recognizing the status of grass

Task: Autonomous WSN for Lawns Monitoring

Objectives:

1. Compare the performance of a drone with a terrestrial vehicle

   -Results: Comparison of Drone vs. Terrestrial small automated vehicle (SAW)



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Drones for Agriculture – Using a mobile node to gather the information

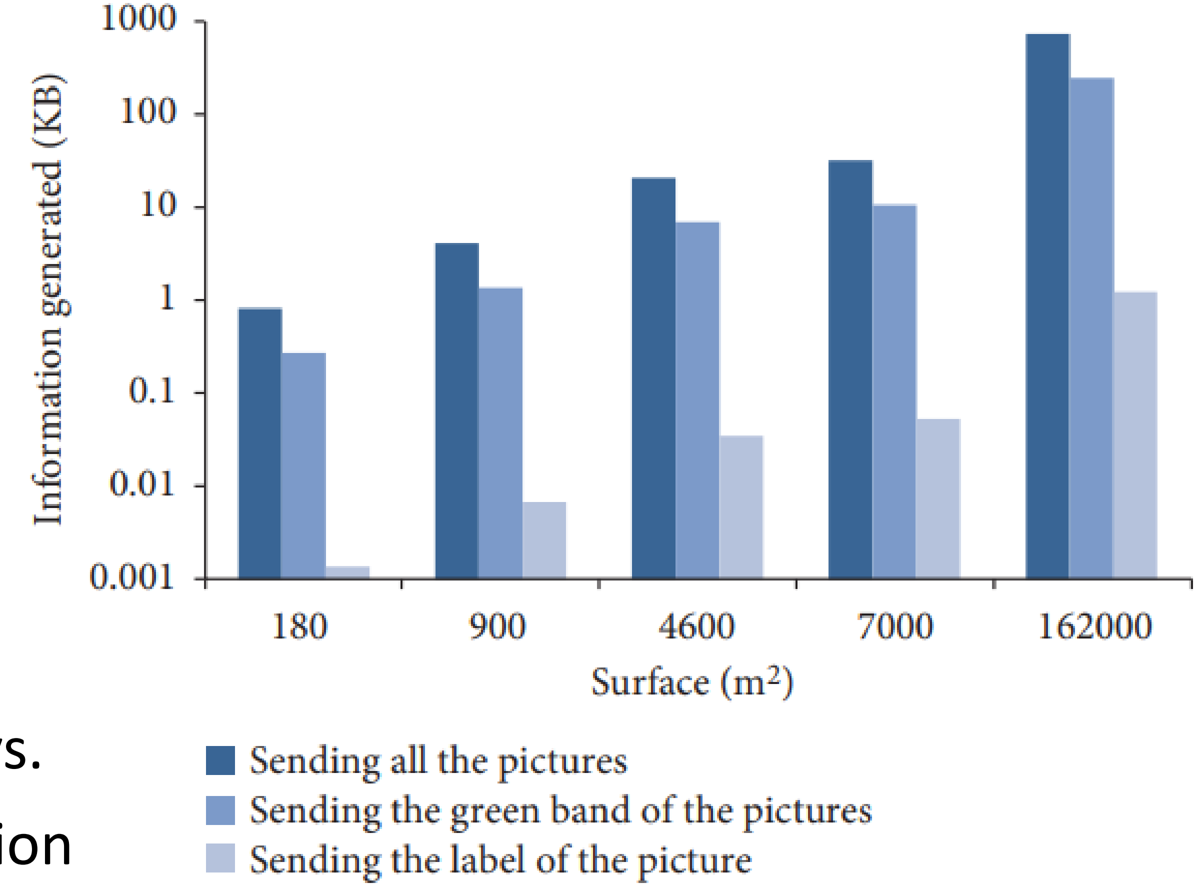
Motivation: Recognizing the status of grass

Task: Autonomous WSN for Lawns Monitoring

Objectives:

1. Compare the performance of a drone with a terrestrial vehicle

    -Results: Comparison of sending picture vs. analyze it offline and send the classification



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Drones for Agriculture – Using a mobile node to gather the information

Motivation: Recognizing the status of grass

Task: Autonomous WSN for Lawns Monitoring

Conclusions:

Analyzing data in the node before sending it reduces bandwidth and saves energy.

It becomes critical with images and video

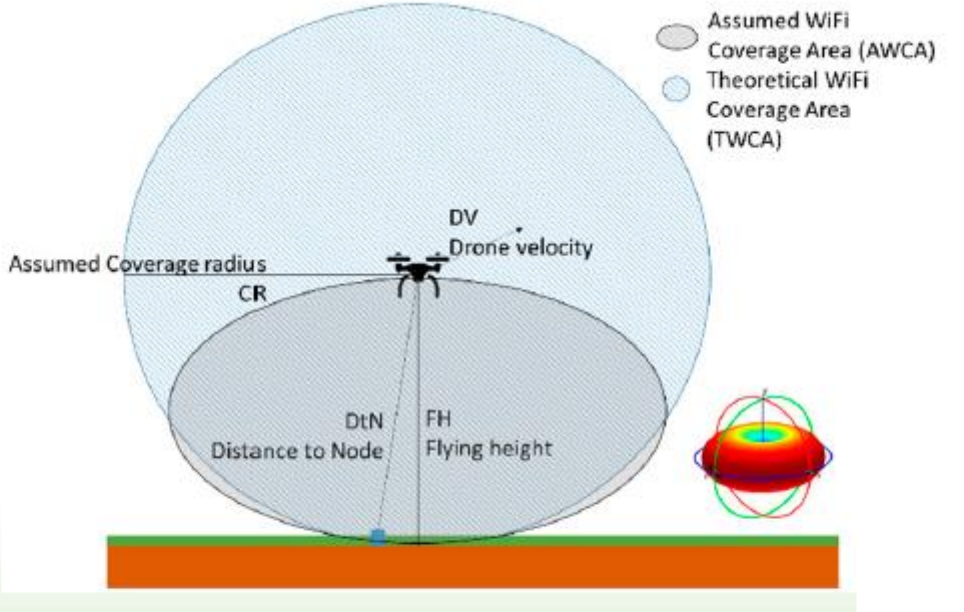
Sending the tag supposes a reduction of 99.8% of the data volume compared with sending the picture

Marín, J., Parra, L., Rocher, J., Sendra, S., Lloret, J., Mauri, P. V., & Masaguer, A. (2018). Urban lawn monitoring in smart city environments. Journal of Sensors, 2018.

Drones for Agriculture – Using a drone to gather data of terrestrial WSN

Motivation: To have a mobile gateway

Task: Determine if a drone with a predefined flying plan can be used as a mobile gateway.

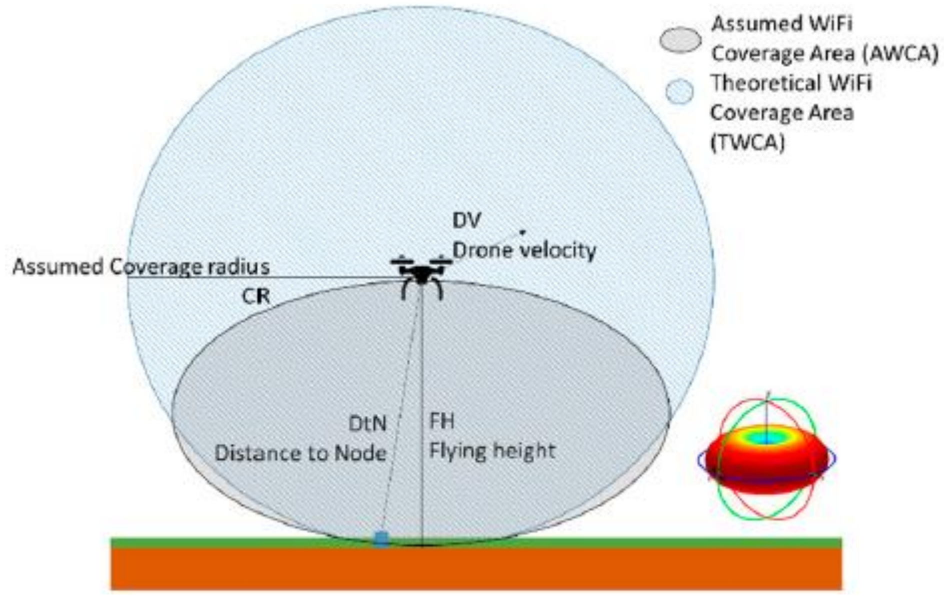


Objectives:

1. Estimate the time in coverage basing of flying parameters.
2. Determine the maximum density of the terrestrial network.

García, L., Parra, L., Jimenez, J. M., Lloret, J., Mauri, P. V., & Lorenz, P. (2020). DronAway: A Proposal on the Use of Remote Sensing Drones as Mobile Gateway for WSN in Precision Agriculture. Applied Sciences, 10(19), 6668.

Drones for Agriculture – Using a drone to gather data of terrestrial WSN



Motivation: To have a mobile gateway

Task: Determine if a drone with a predefined flying plan can be used as a mobile gateway.

Objectives:

1. Estimate the time in coverage basing of flying parameters.

Parameter	Fixed Parameter	Acronym	Units	Range
Flying height	Yes	*fh*	(m)	4 to 104
Flying velocity	Yes	*fv*	(m/s)	1 to 20
Drone coverage	No	*dc*	(m)	25 to 200
Node density	Yes	nd	(nodes/m^2)	60 to 5000
Time in coverage	No	-	(s)	Calculated
Required time for communication	Yes	-	(s)	5
Nodes in coverage	No	-	(nodes)	Calculated
Connection feasibility	No	-	No Units	Calculated

García, L., Parra, L., Jimenez, J. M., Lloret, J., Mauri, P. V., & Lorenz, P. (2020). DronAway: A Proposal on the Use of Remote Sensing Drones as Mobile Gateway for WSN in Precision Agriculture. Applied Sciences, 10(19), 6668.

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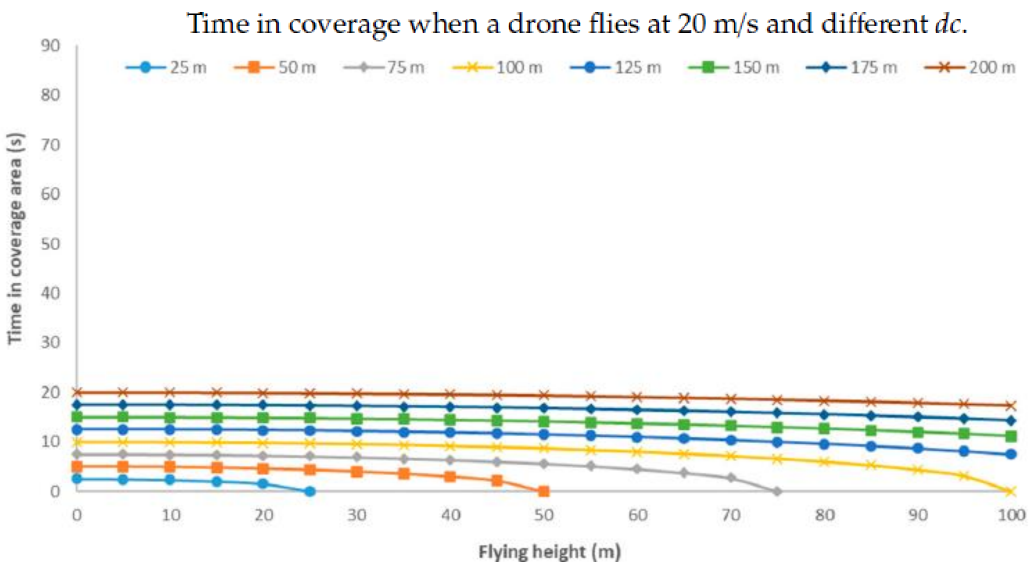

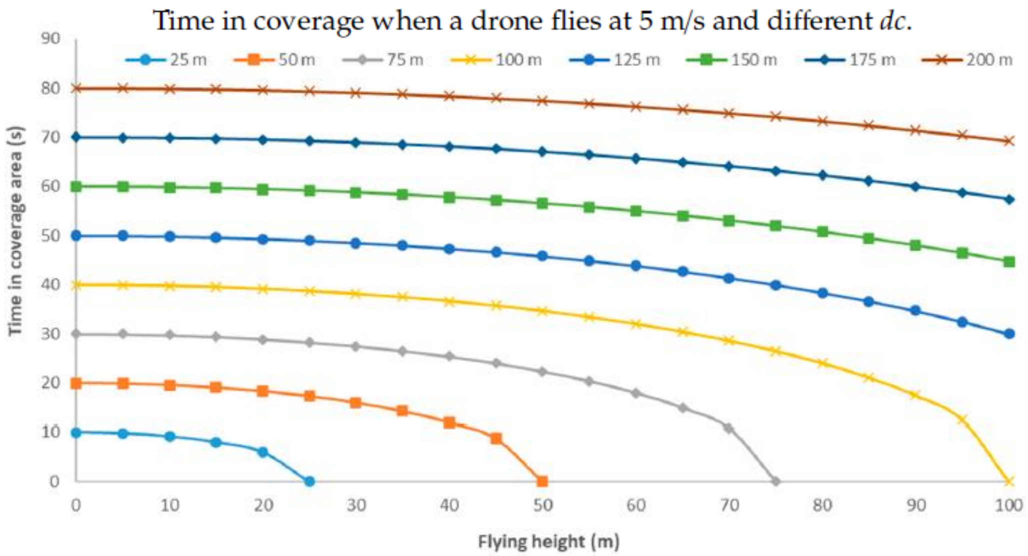

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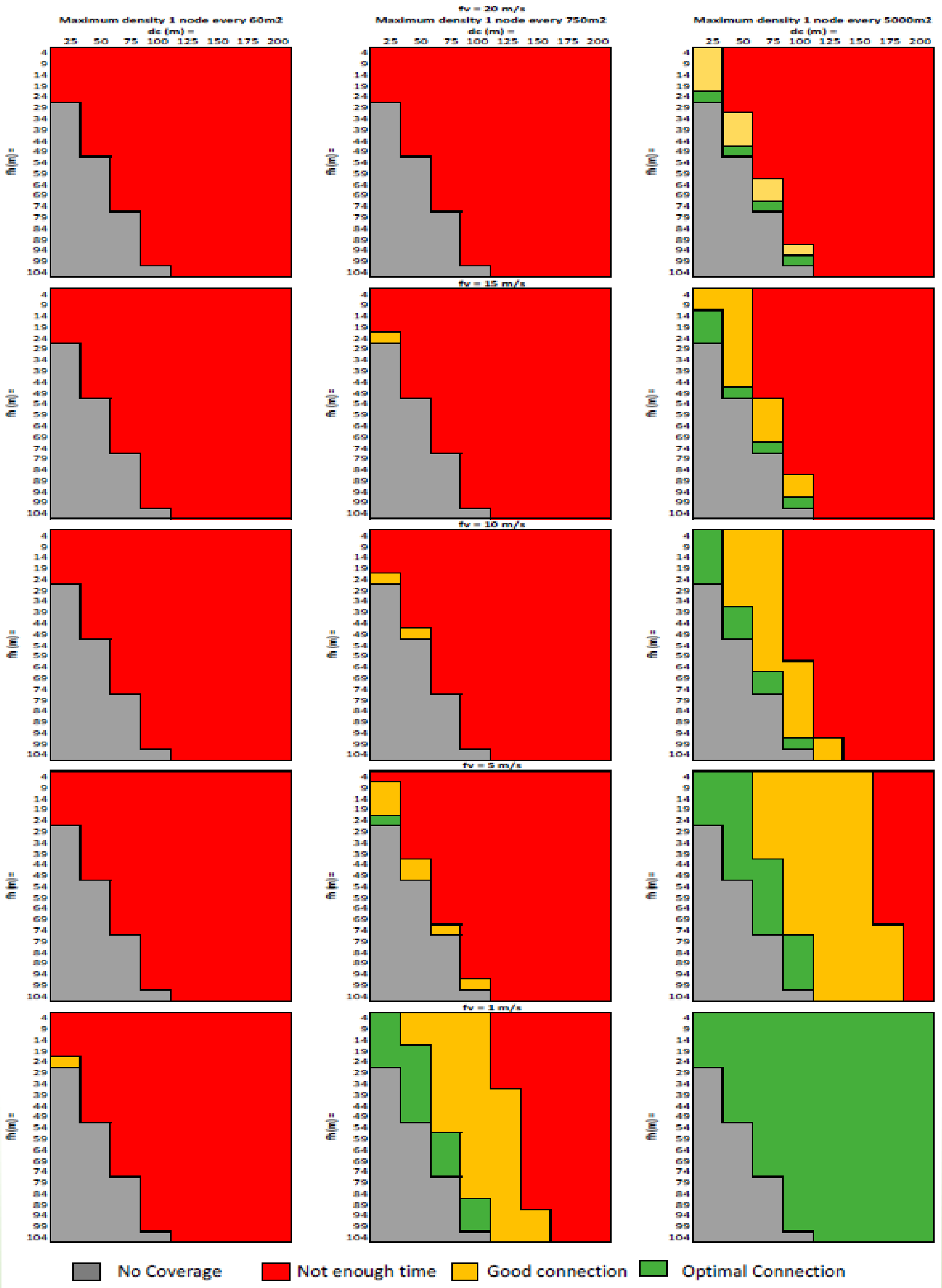
Drones for Agriculture – Using a drone to gather data of terrestrial WSN

Motivation: To have a mobile gateway

Task: Determine if a drone with a predefined flying plan can be used as a mobile gateway.

Objectives:

2. Determine the maximum density of the terrestrial network.



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Drones for Agriculture – Using a drone to gather data of terrestrial WSN

Motivation: To have a mobile gateway

Task: Determine if a drone with a predefined flying plan can be used as a mobile gateway.

Conclusions

For dense networks, the velocity must be drastically reduced to allow using the drone as a mobile gateway.

Nonetheless, most of WSN for precision agriculture have relative low node densities.

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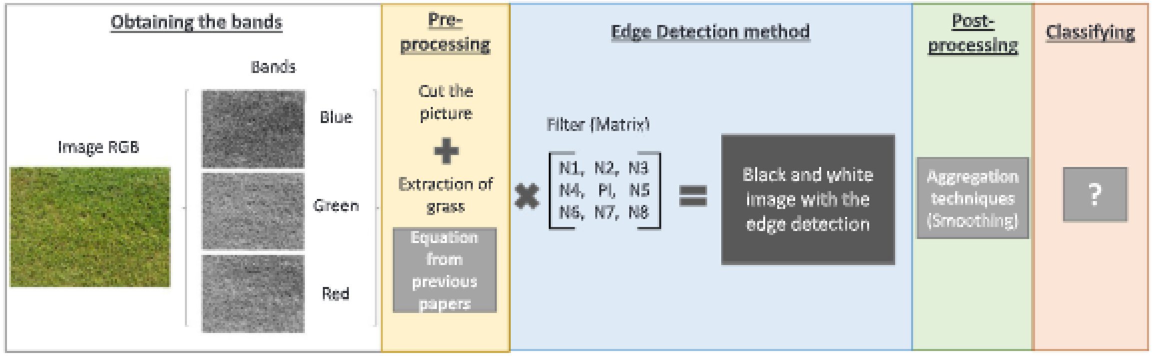
Drones for Agriculture – Recognizing Weed Plants in Golf Course

Motivation: Simple image processing to recognize weeds

Task: Determine if edge detection can be use to detect weed plants

Objectives:

1. Define a methodology based on edge detection to identify weed plants in turfgrass



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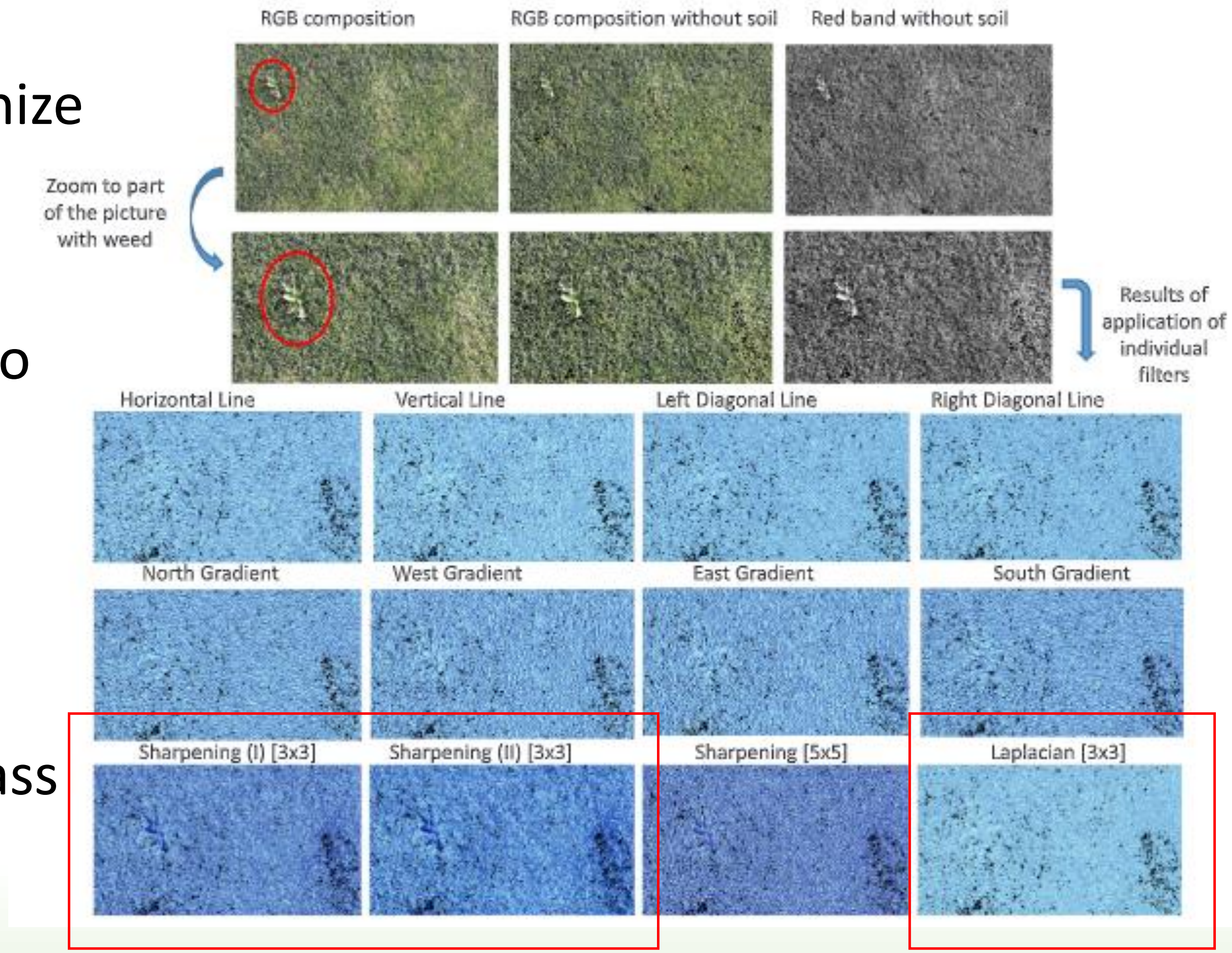

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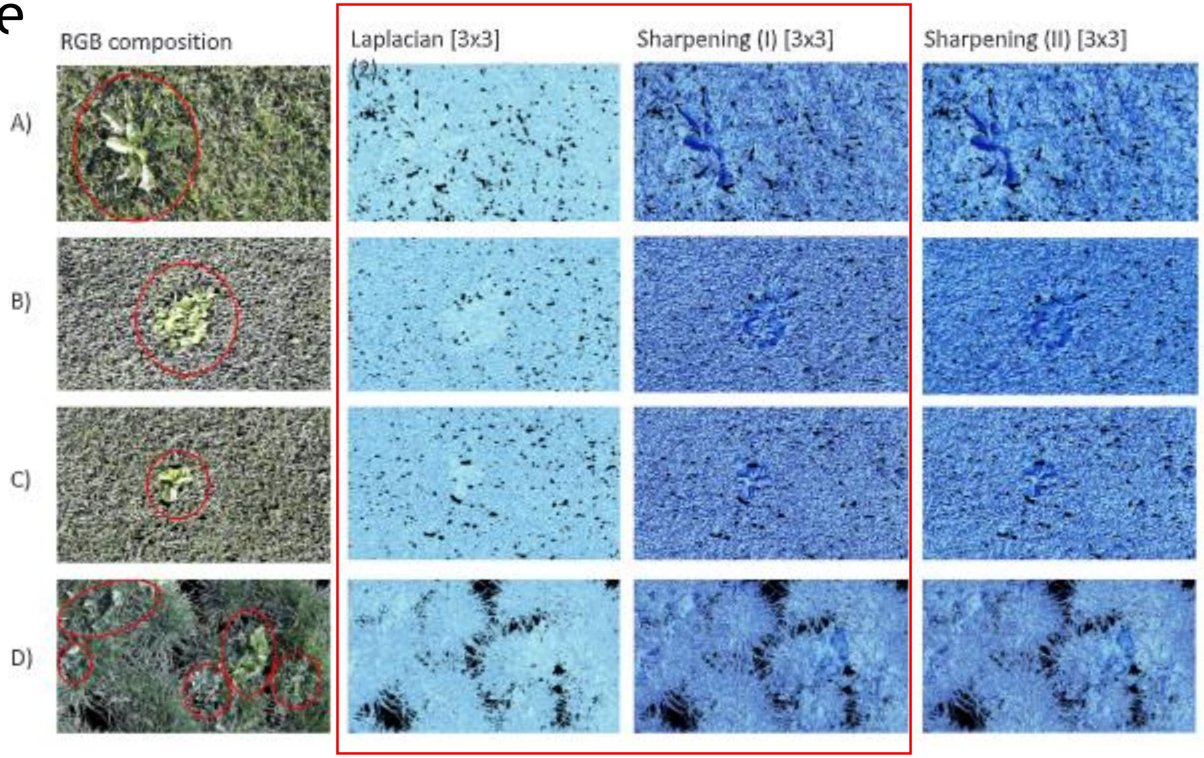

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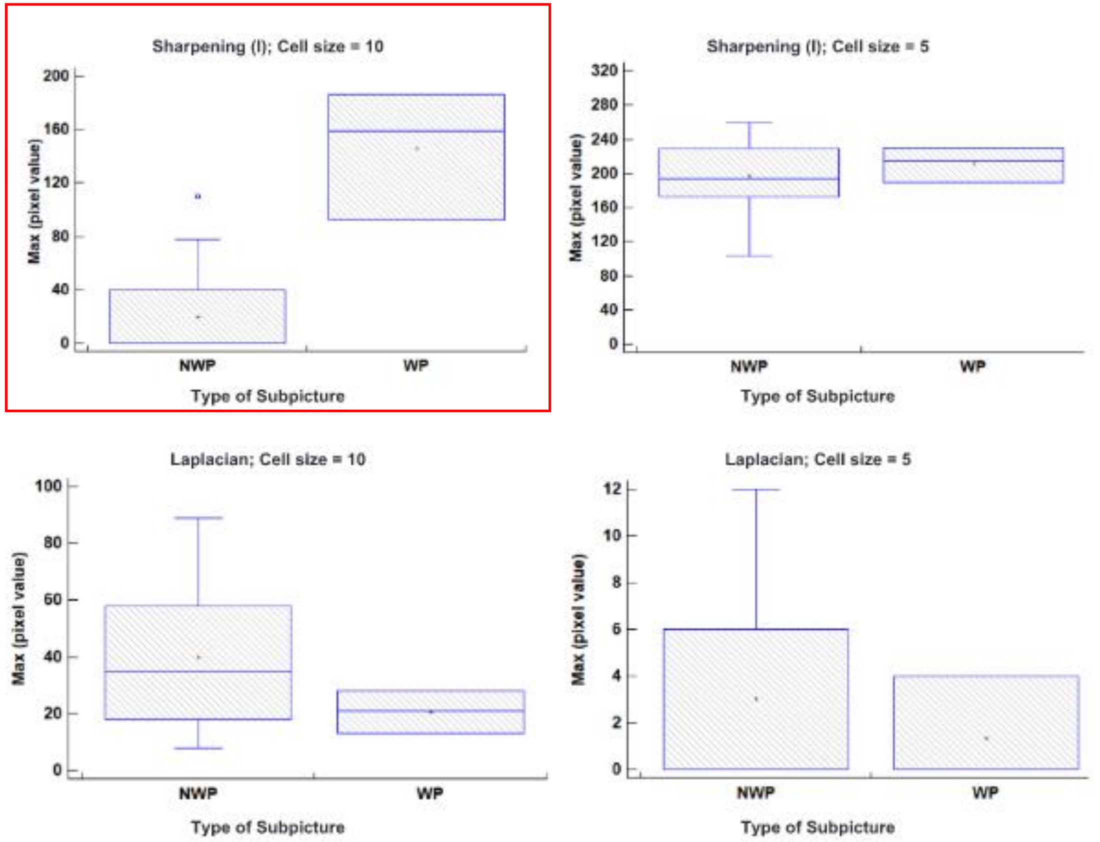

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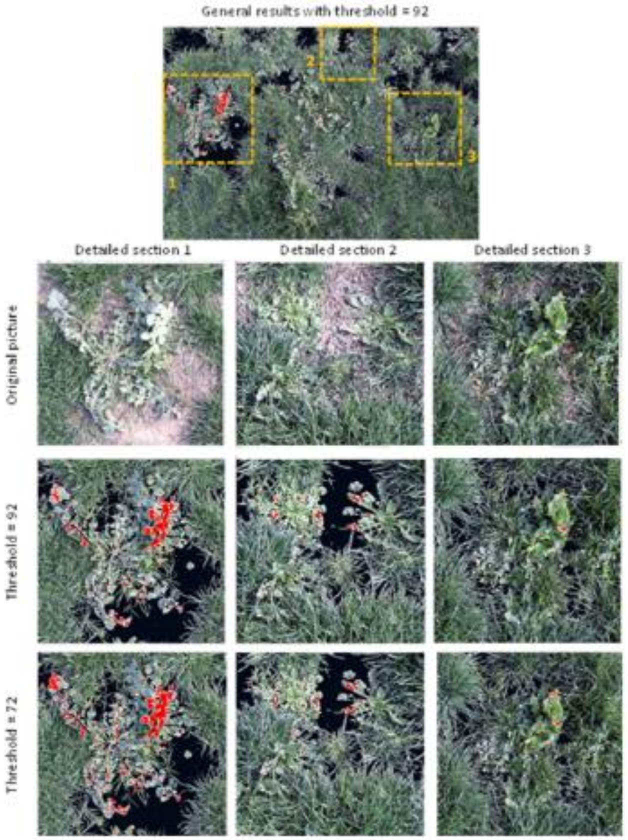

Value of Precision (Pre), Recall (Rec) and F1 Score (F1) for the different thresholds.

	Threshold = 78			Threshold = 85			Threshold = 92		
	Pre	Rec	F1	Pre	Rec	F1	Pre	Rec	F1
Picture D)	80%	86%	83%	83%	68%	75%	84%	57%	68%
Picture E)	67%	86%	75%	71%	71%	71%	75%	43%	55%

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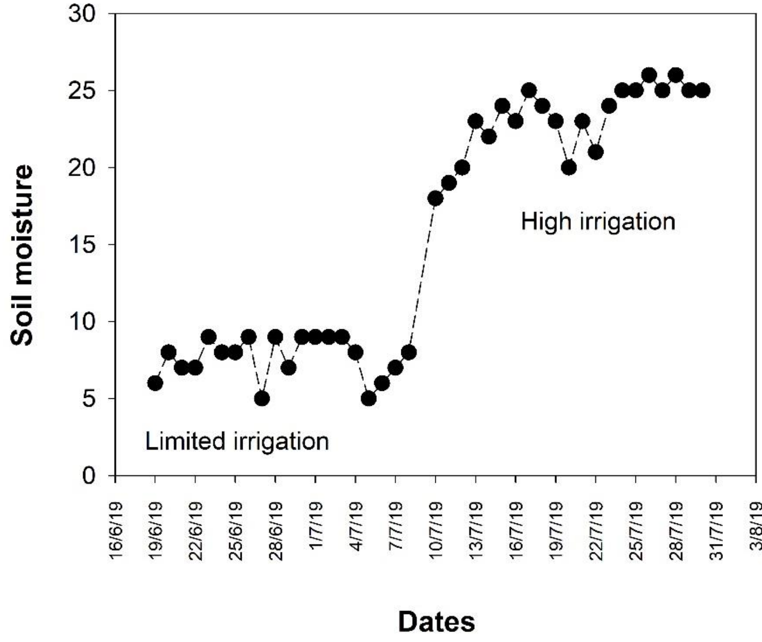
Drones for Agriculture – Identifying plant stress

Motivation: Recognize plant stress with RGB and thermal cameras

Task: Determine which camera offers better results. Plants with reduced irrigation

Objectives:

1. Compare the performance of both cameras in the drone and sensors in soil



Mauri, P. V., Yousfi, S., Parra, L., Lloret, J., Marín, J. F. (2020 Decembre). *The usefulness of drone imagery and remote sensing methods for monitoring turfgrass irrigation.* The International Conference on Advanced Intelligent Systems for Sustainable Development - AI2SD'2020 -

Drones for Agriculture – Identifying plant stress

Motivation: Recognize plant stress with RGB and thermal cameras

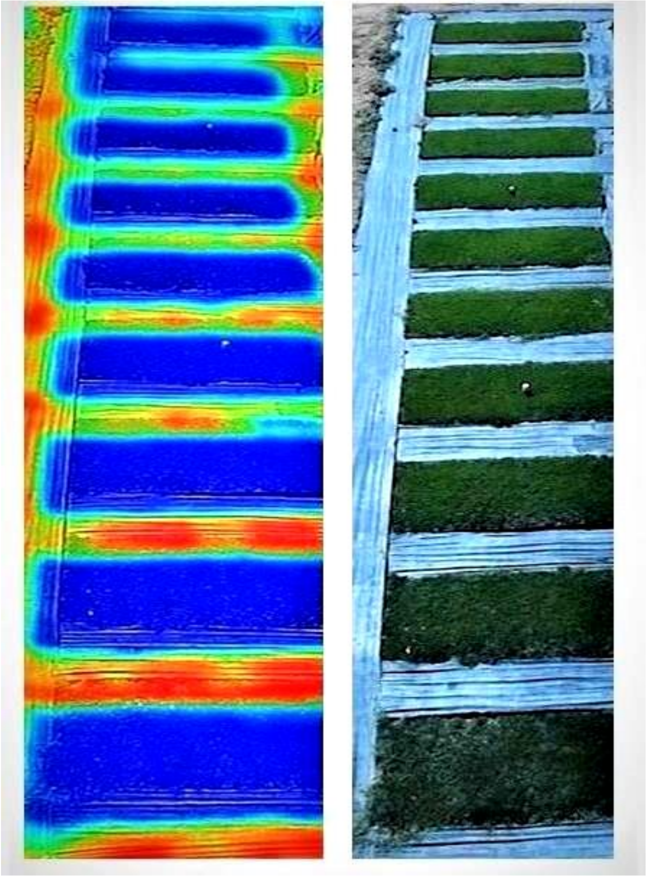
Task: Determine which camera offers better results. Plants with reduced irrigation

Objectives:

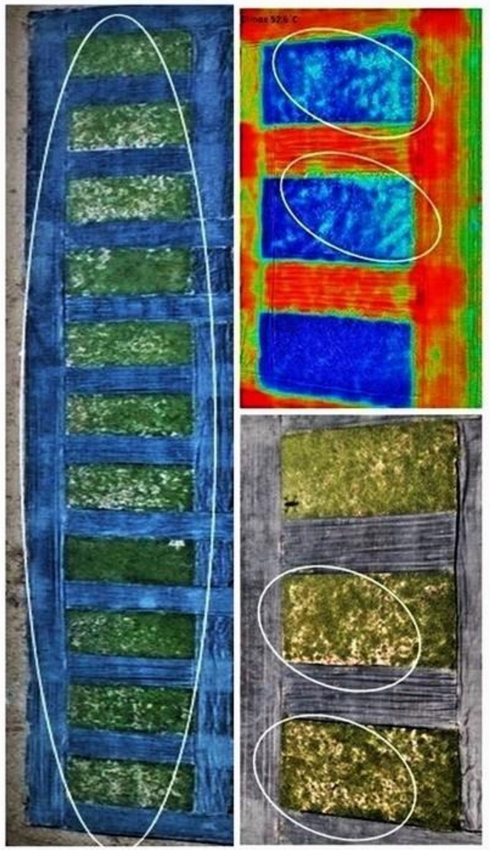
1. Compare the performance of both cameras in the drone and sensors in soil

→RGB cameras are more representative

→But it can generate false positives



Plots without stress



Plots with stress

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Limitations or barriers to be overcome

The technology is ready to be used

Several authors are proposing systems based on sensors for agriculture

Why are farmers not adopting them?

Other sectors, as Golf Courses, are adopting these technologies



Limitations or barriers to be overcome

In general, the cost of proposals (commercial ones) are still high

→ We need to develop new low-cost (and useful) systems

Farmers do not trust these systems

→ We need to show them the performance and usability of them

Some commercial systems are still working to improve (battery limitations, not waterproof cases, coverage problems with wet soil, coverage problems during irrigation…)

→ They are offering new versions

Replacing soil moisture sensors in Golf Course

The role of sensors in Agriculture 4.0

Lorena Parra
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