The Sixth International Conference on Advances in Sensors, Actuators, Metering and Sensing

ALLSENSORS 2021

Tutorial on Sensors and Pattern Recognition for Localized Control of Weeds in Agriculture

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Outline

1. Application technology for agricultural pest control
2. Precision agriculture (sensors, geomatics and image processing to plant control)
3. Example of a method for invasive plant control
4. Conclusions

Literature review (State of the Art)

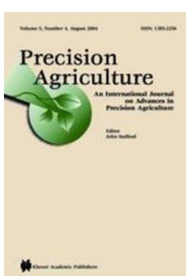
- Sensors, Digital image processing techniques related to image capture and acquisition, image quality metrics, filters and classifiers.
- search strings
- Bibliographic databases and search engines.

Sensors	Digital image processing	Classifiers	Plants Classifiers

WEB OF SCIENCE

Springer

IEEE Xplore® Digital Library



Google scholar

MENDELEY

Tutorial objective

To learn about the identification of plant´s families in agriculture based on sensors, image processing, and pattern recognition techniques.

Pests control in agriculture



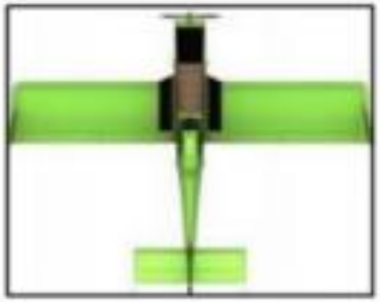




100,000 species of phytopathogenic fungi
30,000 species of invasive plants
10,000 species of herbivorous insects
15,000 species of Phytophagous Nematodes

Damage in the order of 40%

Application Technology for Control



The application technology consists on the adoption of all available technical knowledge to provide the correct placement of a biologically active product (agrochemical) on the target (which involves the complex plant, pest, soil, atmosphere and environment).

Standards

Droplet Size Measurement and Classification

ANSI/ASAE S572.1 MAR2009
Spray Nozzle Classification by Droplet Spectra

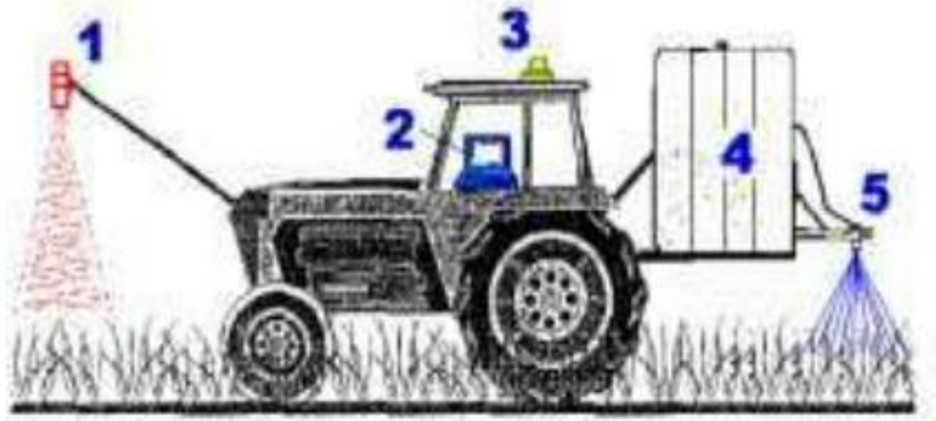
ASABE

American Society of
Agricultural and Biological Engineers

Terrestrial Application

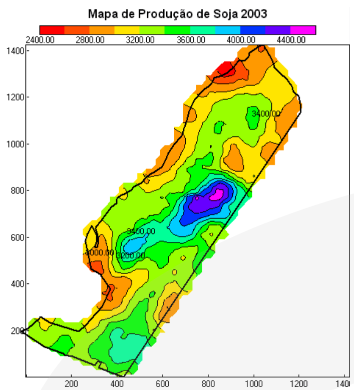
Self-propelled sprayers stand out, which are automotive equipment that develop very high operating performance in pesticide applications, reaching up to 50 ha./h.

- Conventional Application Technology with bar arrangement;
- Application Technology in Variable Doses with Digital Maps;
- Application Technology in Variable Doses with Sensors.

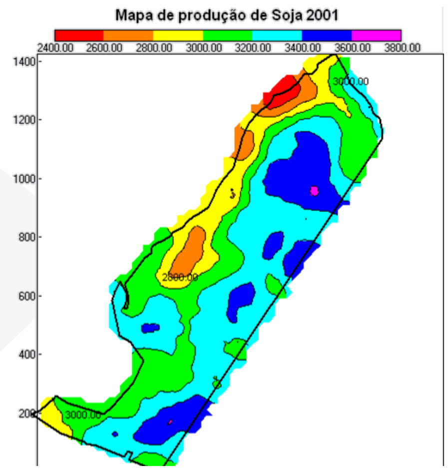


Terrestrial spraying equipment with embedded technology for application in varied doses based on the use of sensors, where:

(1). Biological target sensor (such as invading plant);
(2). On-board computer for general control of the application system;
(3). GPS receiver, connected to speed camera;
(4). Syrup reservoir (water + pesticide);
(5). System with spray nozzles.



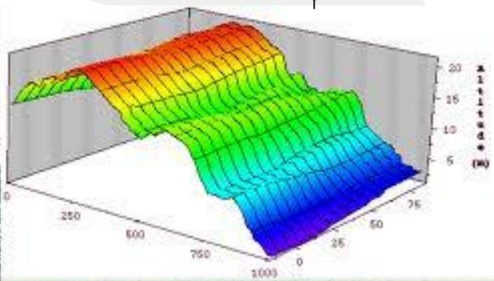
Mapa de Produção de Soja 2003



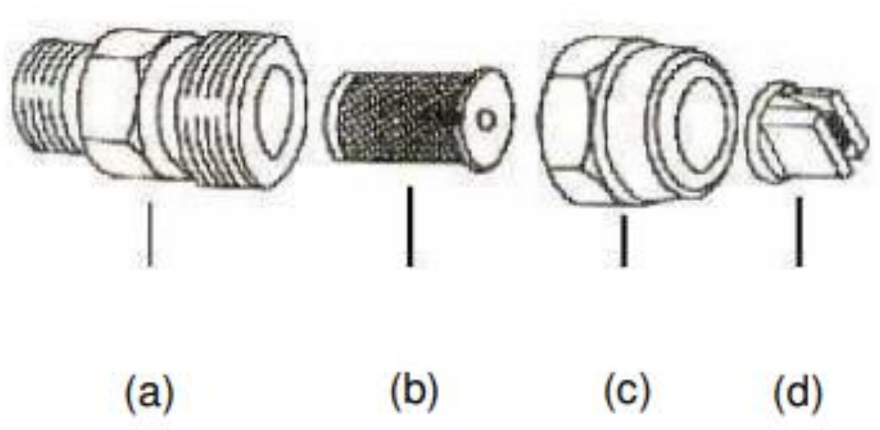
Mapa de produção de Soja 2001

Análise do solo para busca das causas da variação de produtividade
Aplicação de fertilizantes e corretivos a taxas variáveis
PREPARAÇÃO DO SOLO
Geração de Mapas de Produtividade
COLHEITA
1 safra
PLANTIO
Plantio a taxas variáveis, de acordo com o potencial produtivo de cada área
Colheita com máquinas com sensores de produtividade
ACOMPANHAMENTO DA LAVOURA
Aplicação localizada de defensivos agrícolas
Acompanhamento da lavoura para mapeamento de pragas e doenças

OK
EZ-Guide 500



Nozzles for Spraying and subsequent Application



The nozzles are the final components of the sprayer's hydraulic circuit. The solution to be applied, under pressure, is forced to pass through a small opening, forming a thin sheet that disintegrates into small particles or drops.

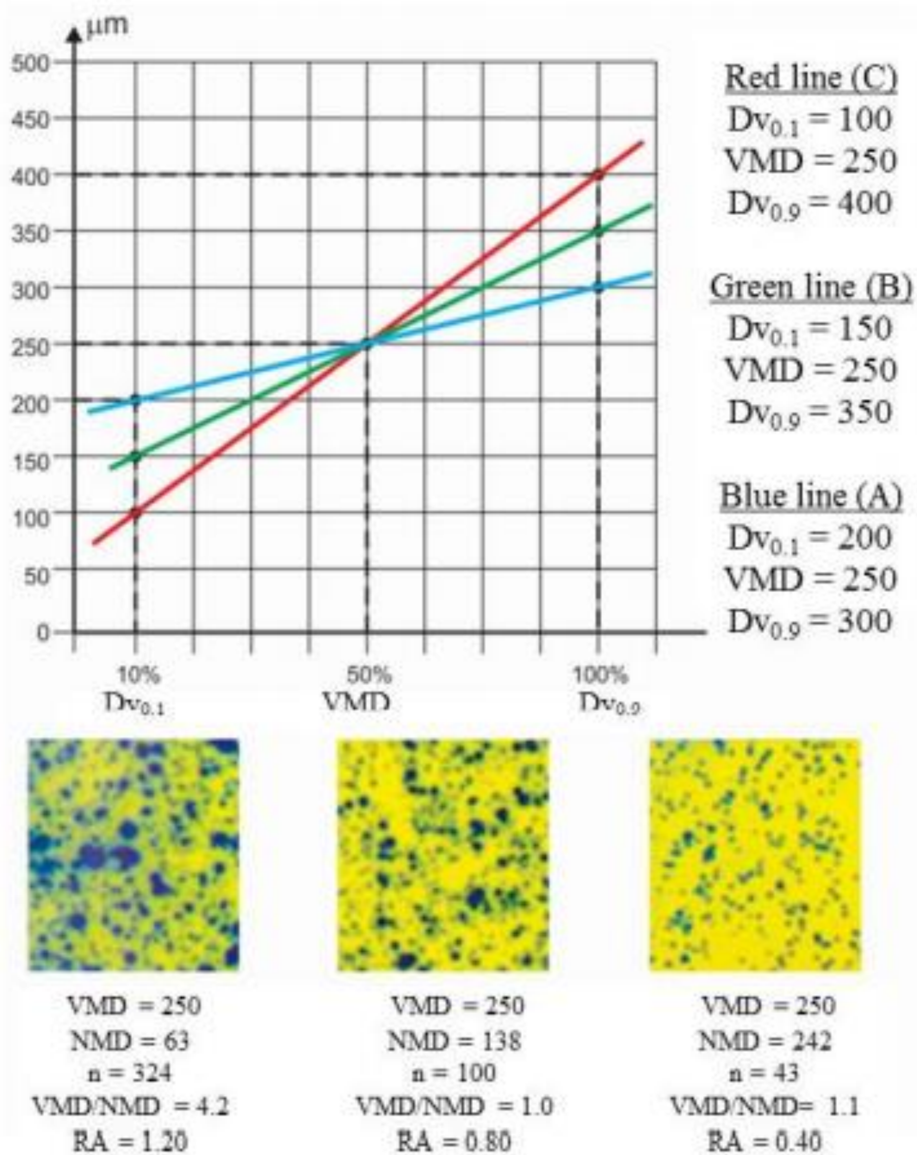
(a) - Body;

(b) - Filter;

(c) - Cover;

(d) - Tip.

Liquid jet ligaments drops

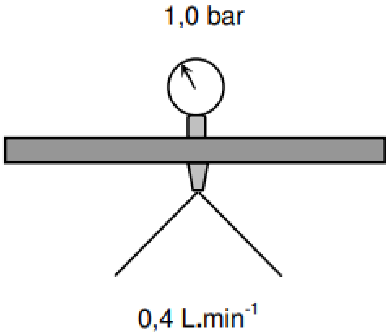


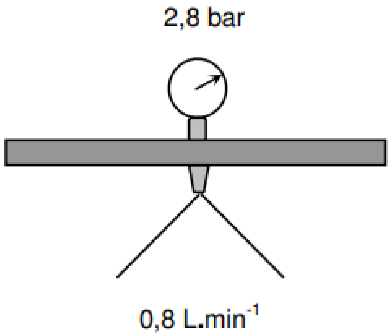
Applications that have the same VMD, however with different dispersion coefficients and relative amplitude, and the importance of the values of $DV_{0,1}$, VMD and $DV_{0,9}$

(Christofoletti, 1992 and Ozeki, 2006).

Flow Calculation

$$L \cdot min^{-1} = L \cdot ha^{-1} \times km \cdot h^{-1} \times W \times 60000^{-1}$$





where $L.min^{-1}$ is the Flow in liters per minute; $L.ha^{-1}$ is the volume of application given in liters per hectare; $km.h^{-1}$ is the Displacement Speed of the applicator in km per hour and W is the spacing between nozzles (cm).

Quality of the Application

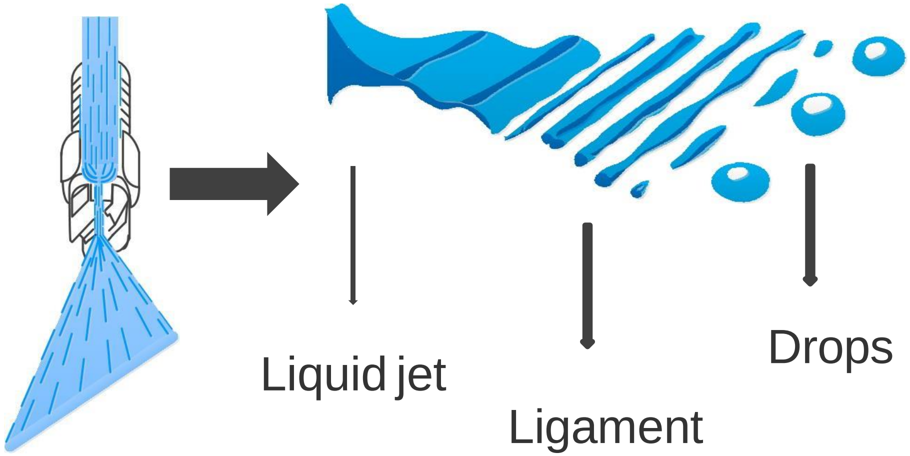
The drop formation in agricultural spraying is directly related to the application quality.

The nozzle type, the agrochemical physical properties, the drift produced by the wind and other climate factors affect the size, volume and distribution of drops.

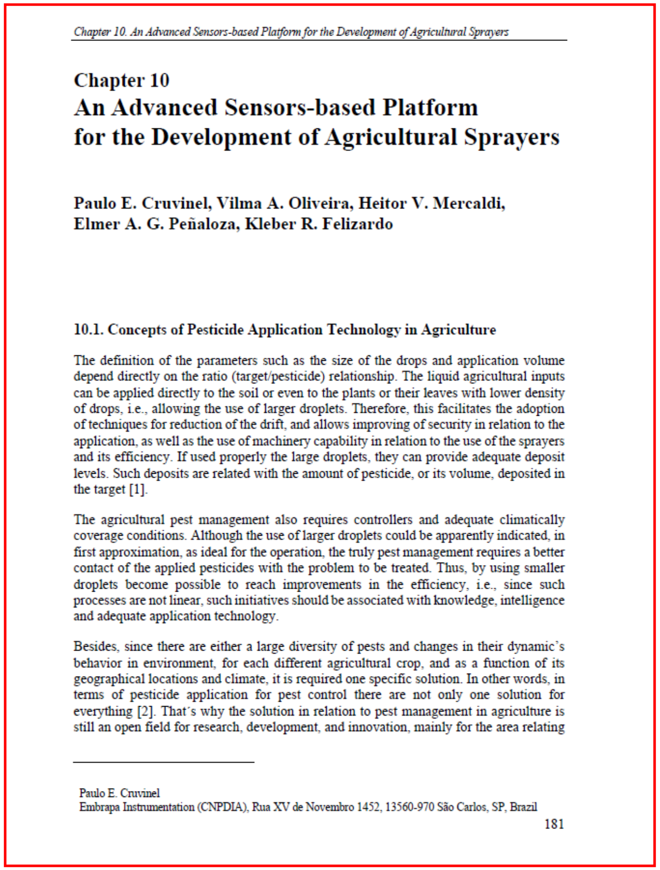
Also, variations in the nozzles fluidic resistance affect the quality of the application.

The fluidic hydraulic resistance:
function of the flow regime being dependent of the Reynolds number and the relative pipe.

$$[bar \cdot min \cdot L^{-1}]$$



Laboratory Infrastructure (Facilities)



Chapter 10. An Advanced Sensors-based Platform for the Development of Agricultural Sprayers

Chapter 10
An Advanced Sensors-based Platform for the Development of Agricultural Sprayers

Paulo E. Cruvinel, Vilma A. Oliveira, Heitor V. Mercaldi, Elmer A. G. Peñaloza, Kleber R. Felizardo

10.1. Concepts of Pesticide Application Technology in Agriculture

The definition of the parameters such as the size of the drops and application volume depend directly on the ratio (target/pesticide) relationship. The liquid agricultural inputs can be applied directly to the soil or even to the plants or their leaves with lower density of drops, i.e., allowing the use of larger droplets. Therefore, this facilitates the adoption of techniques for reduction of the drift, and allows improving of security in relation to the application, as well as the use of machinery capability in relation to the use of the sprayers and its efficiency. If used properly the large droplets, they can provide adequate deposit levels. Such deposits are related with the amount of pesticide, or its volume, deposited in the target [1].

The agricultural pest management also requires controllers and adequate climatically coverage conditions. Although the use of larger droplets could be apparently indicated, in first approximation, as ideal for the operation, the truly pest management requires a better contact of the applied pesticides with the problem to be treated. Thus, by using smaller droplets become possible to reach improvements in the efficiency, i.e., since such processes are not linear, such initiatives should be associated with knowledge, intelligence and adequate application technology.

Besides, since there are either a large diversity of pests and changes in their dynamic's behavior in environment, for each different agricultural crop, and as a function of its geographical locations and climate, it is required one specific solution. In other words, in terms of pesticide application for pest control there are not only one solution for everything [2]. That's why the solution in relation to pest management in agriculture is still an open field for research, development, and innovation, mainly for the area relating

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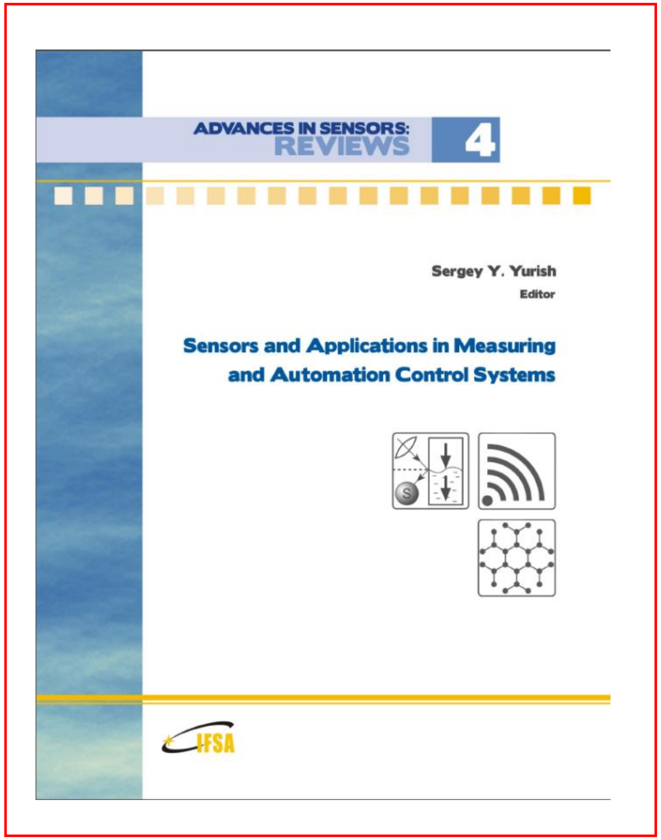
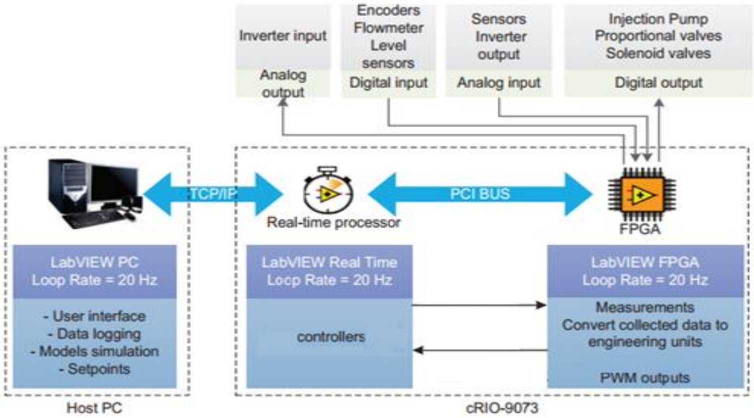
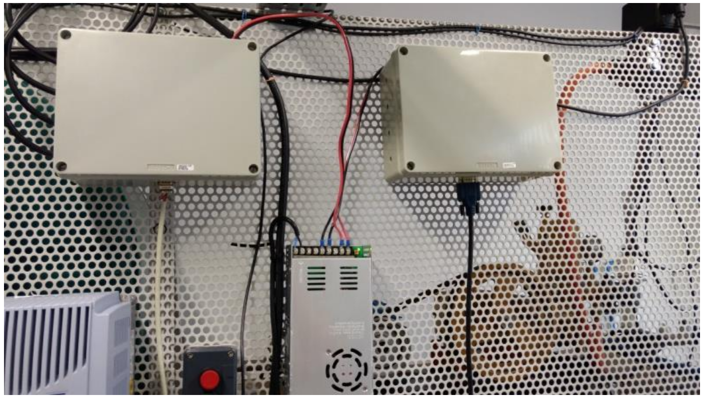


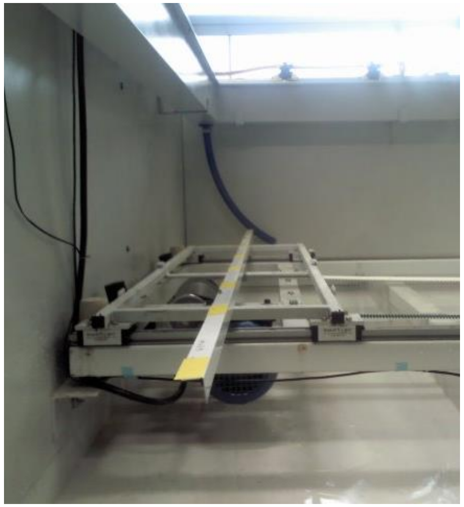
P. E. Cruvinel, V. A. Oliveira, H. V. Mercaldi, E. A. G. Peñaloza, K. R. Felizardo. An Advanced Sensors-based Platform for the Development of Agricultural Sprayers. In: Sensors and Applications in Measuring and Automation Control Systems (Book Series: Advances in Sensors: Reviews, Vol. 4). International Frequency Sensor Association (IFSA) Publishing, v. 4, p. 181-204, 2016.

Precision Farming Application Laboratory





Experimental arrangement for data collecting



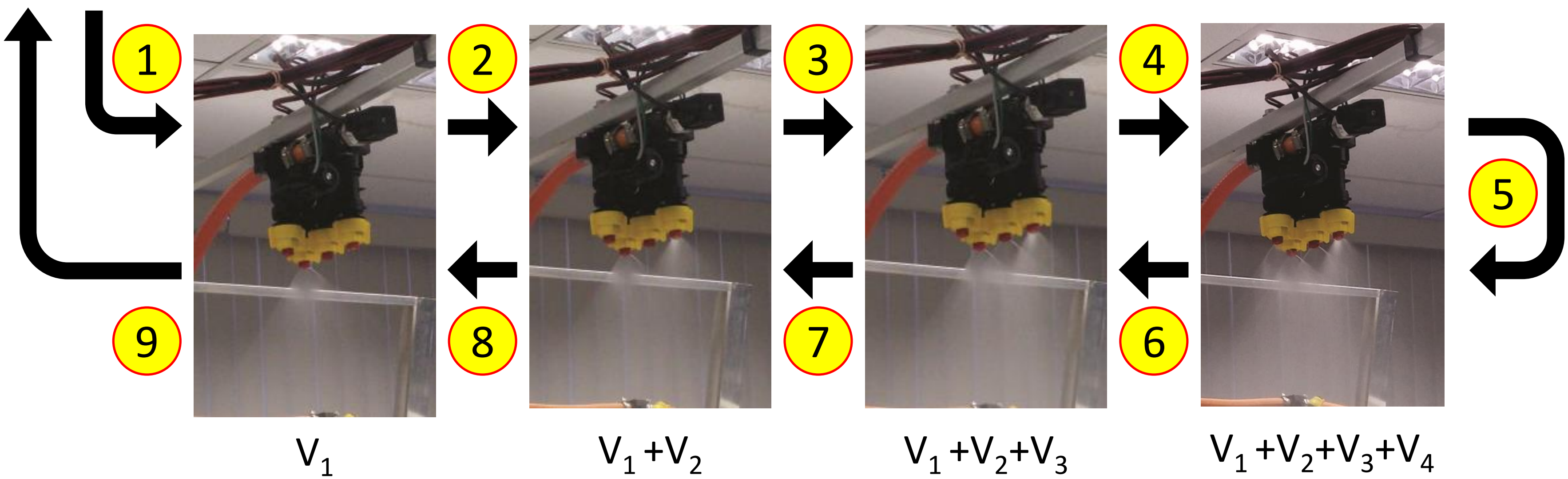
Communication using CAN network

A CAN communication was evaluated using one set of solenoid valves and a driving strategy.

All closed

10 seconds between transitions

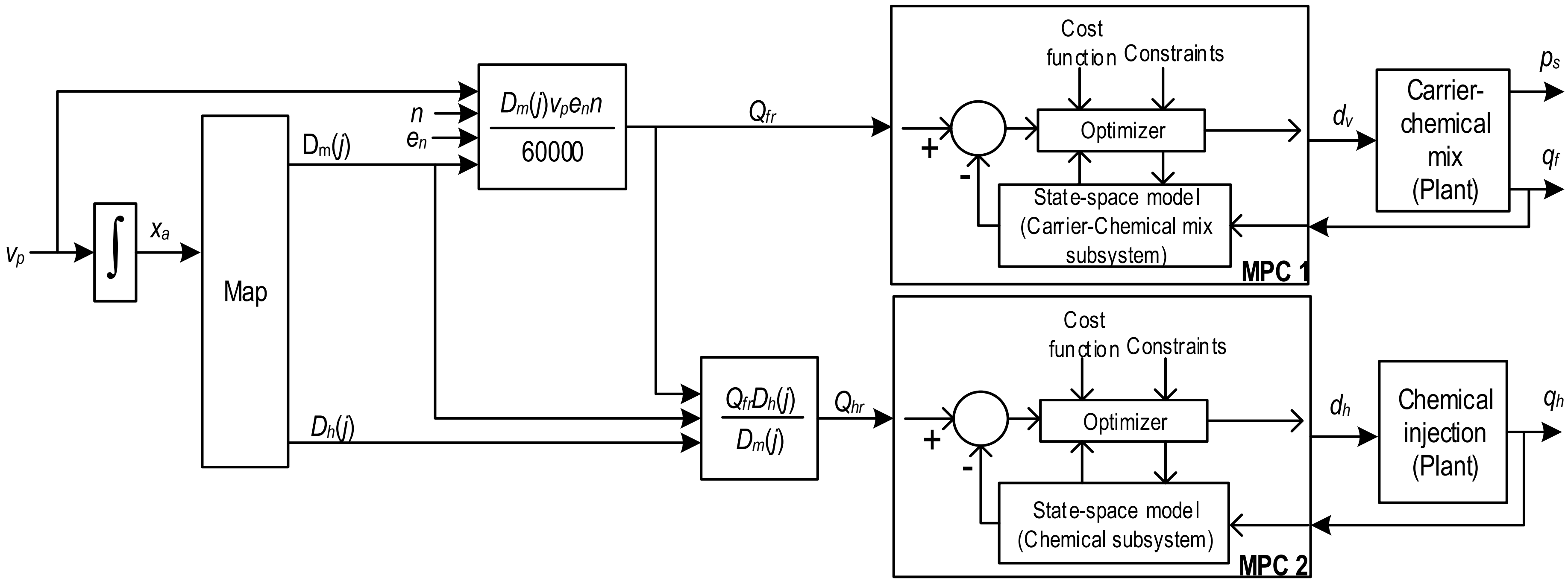
All the same nozzle types



The flow rate settling time was measured for regulated pressures 100kPa and 200kPa.

H. V. Mercaldi; E. A. G. Peñaloza; V. A. Oliveira; P. E. Cruvinel, Flow and pressure regulation for agricultural sprayer using solenoid valves, IFAC WC 2017, 2017, p.10902-10907.

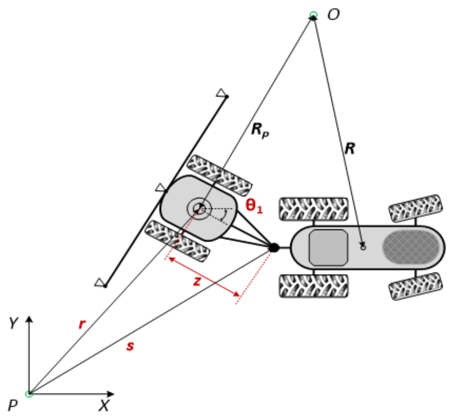
- Design control strategies, modelling the application errors, application rate response and transport delay.
- Variable-rate predictive control approach.

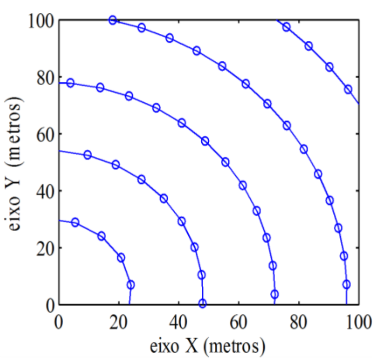


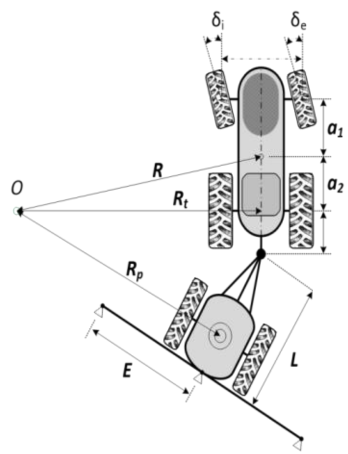
Control loop

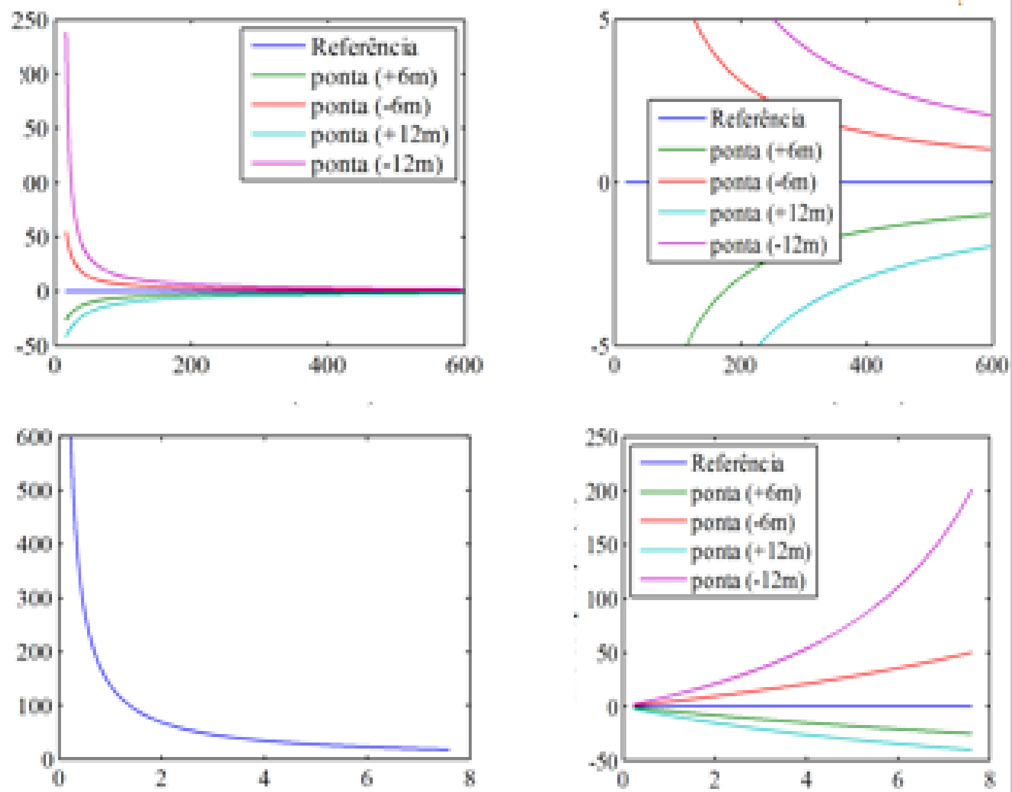
K. R. Felizardo, H. V. Mercaldi, P. E. Cruvinel, V. A. Oliveira, B. L. Modeling of a Chemical Injection Sprayer System Steward, ASABE (2016).

Evaluation of applications errors based on kinematics model of an agricultural sprayer





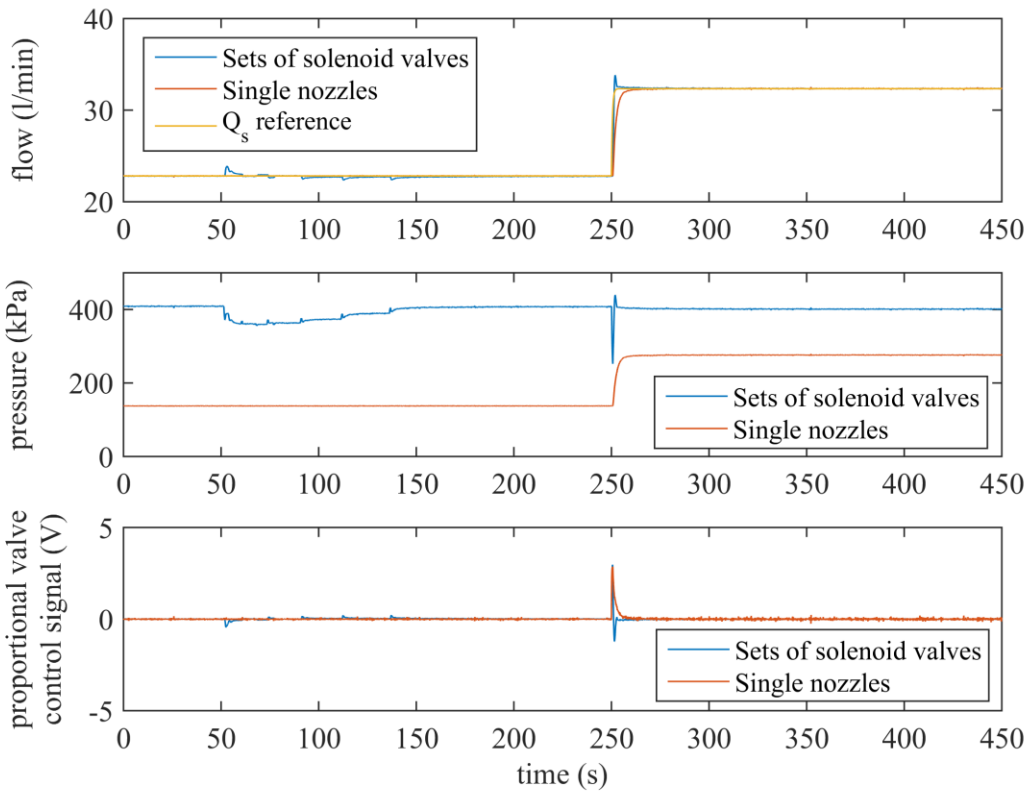




Steering angle (degree) versus Measurement error (%)

E. A. G. Penaloza, H. V. Mercaldi, K. R. Felizardo, V.A. Oliveira, P.E. Cruvinel. Modelo do Erro de Taxa de Aplicação em Função do Ângulo de Esterçamento de um Pulverizador Tratorizado. In: Simpósio Nacional de Instrumentação Agropecuária SIAGRO, (2014).

Illustrating the variable rate concept



Application rate (Dn)

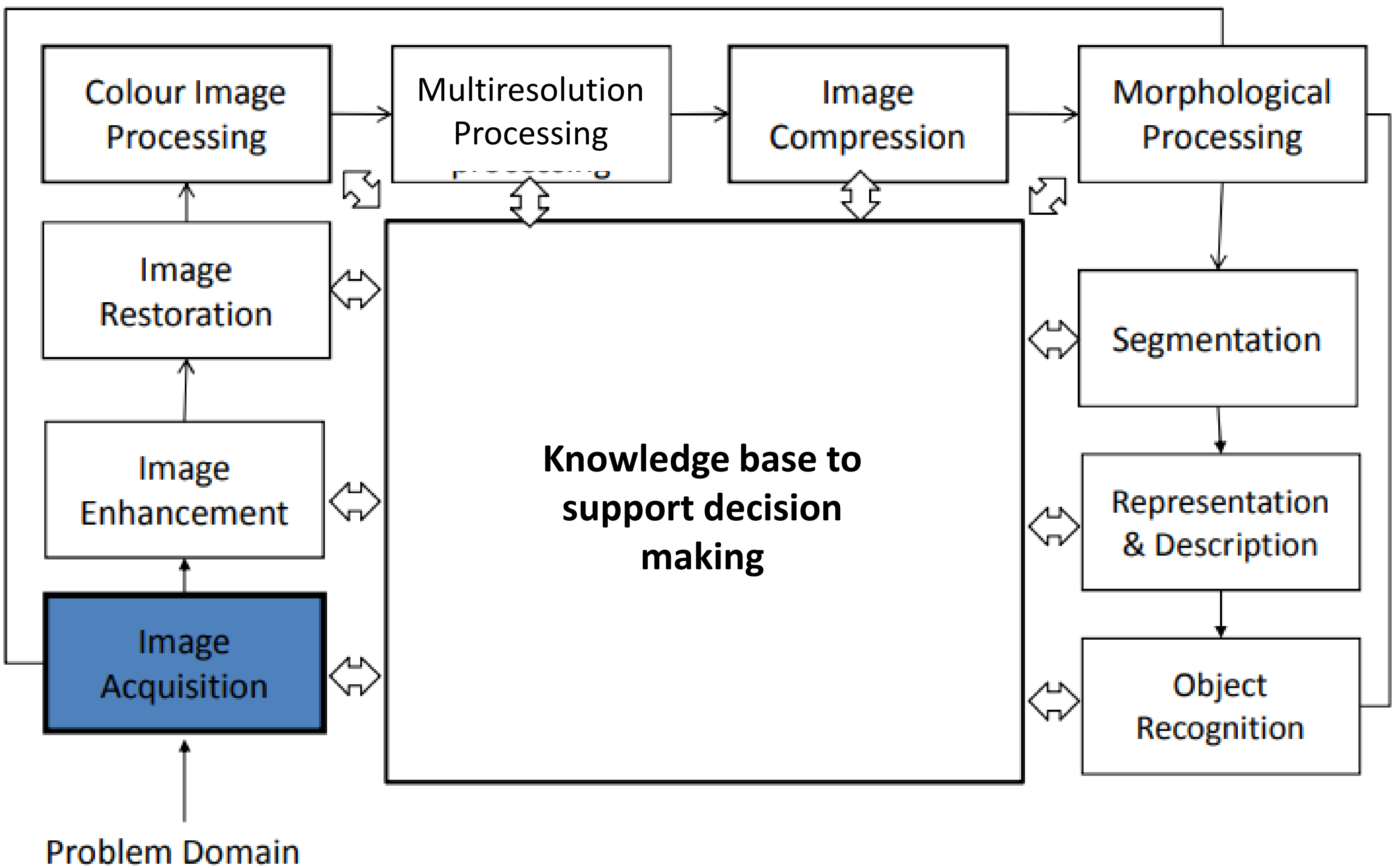
163	231

0s *250s*

Sprayer speed
12 km/h

H. V. Mercaldi; E. A. G. Peñaloza; V. A. Oliveira; P. E. Cruvinel, Flow and pressure regulation for agricultural sprayer using solenoid valves, IFAC WC 2017, 2017, p.10902-10907.

Fundamental in Digital Image Processing



Principal Component Analysis - PCA

Its general objective is to reduce the dimensionality of a dataset and improve the performance of the analysis process. For instance, grouping into a single feature vector of the results obtained by the HOG and Hu Invariant Moments methods. Extraction of relevant features avoiding information redundancy.

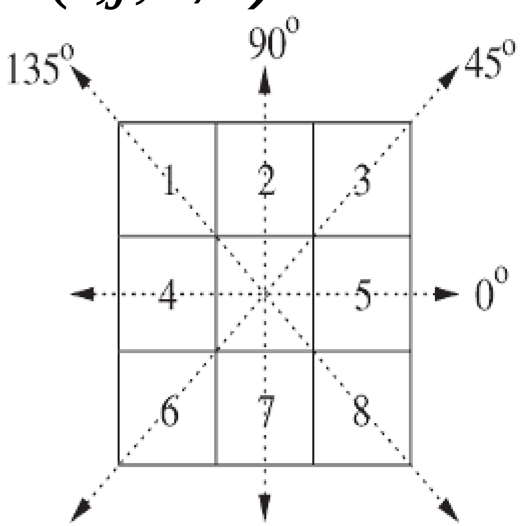
Feature extraction

Textural analysis

statistical approach

co-occurrence matrix

$P(i,j,\theta,d)$



0	0	0	1	2
1	1	0	1	1
2	2	1	0	0
1	1	0	2	0
1	0	1	0	0

	0	1	2
0	8	8	2
1	8	6	2
2	2	2	2

Feature extraction

$$\text{Energy} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} P_{\delta,\theta}(i,j)^2$$

Feature extraction

$$\text{Entropy} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} P_{\delta,\theta}(i,j) \log\left(P_{\delta,\theta}(i,j)\right)$$

Feature extraction

Contrast $= \sum_{k=0}^{N_{g-1}} K^2 \left[\sum_{i=1}^{N_g} \sum_{j=1}^{N_g} P_{\delta,\theta}(i,j) \right], se\ |i-j| = k$

Feature extraction

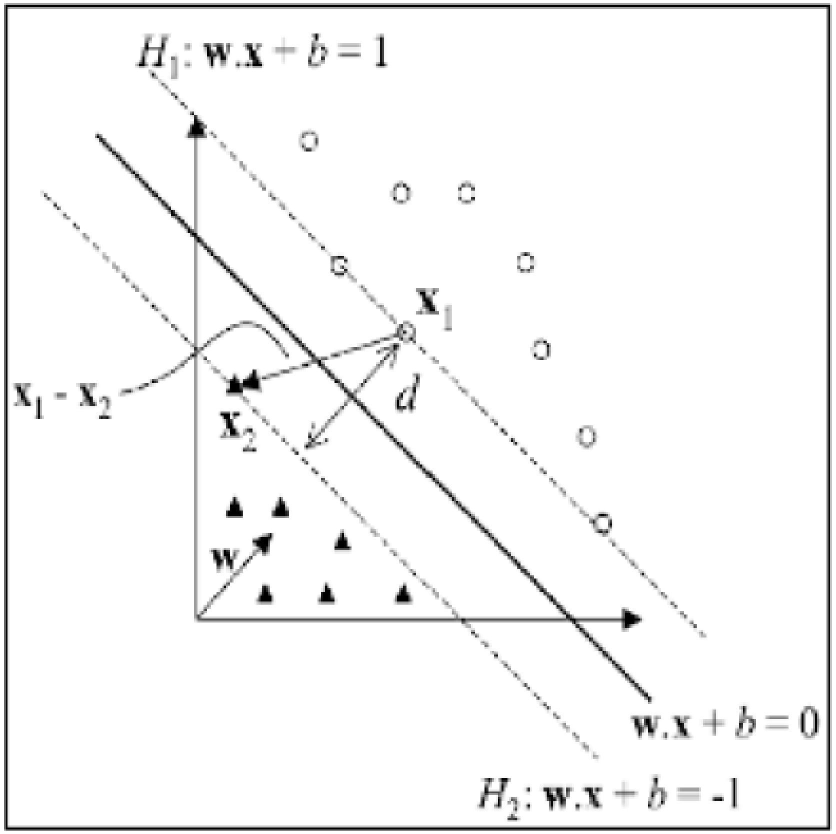
$$\text{Homogeneity} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} \frac{1}{1 + (i - j)^2} P_{\delta,\theta}(i, j)$$

Feature extraction

Correlation $= \sum_{i=1}^{N_g}\sum_{j=1}^{N_g}\frac{(i-\mu_x)(j-\mu_y)P_{\delta,\theta}(i,j)}{\sigma_x\sigma_y}$

Classification

Support Vector Machine (SVM)



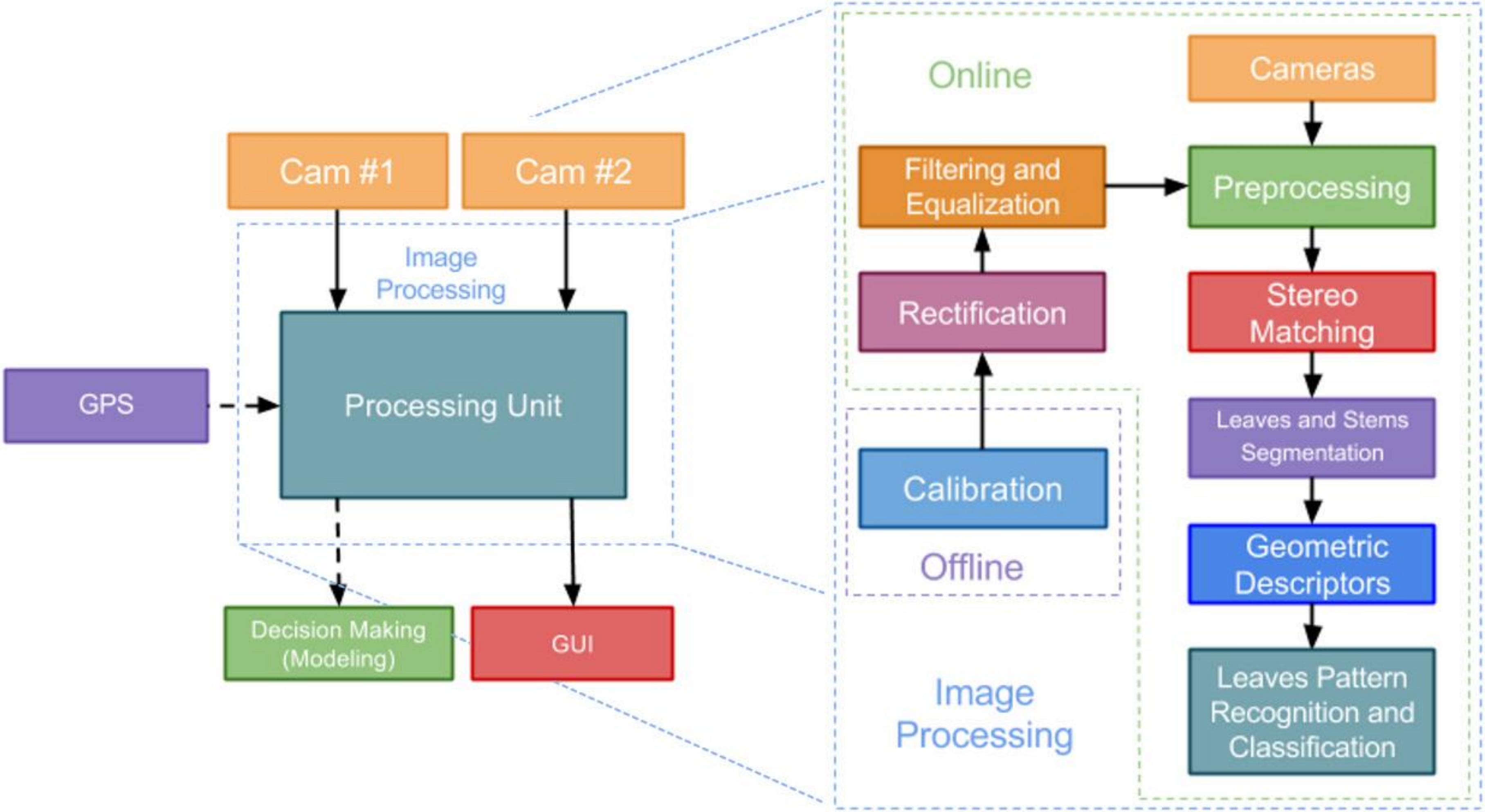
$$w \cdot x + b = 0$$

$$\Downarrow$$

$$w \cdot x_i + b \geq 1 \quad se \quad y_i = +1$$
$$w \cdot x_i + b \leq 1 \quad se \quad y_i = -1$$

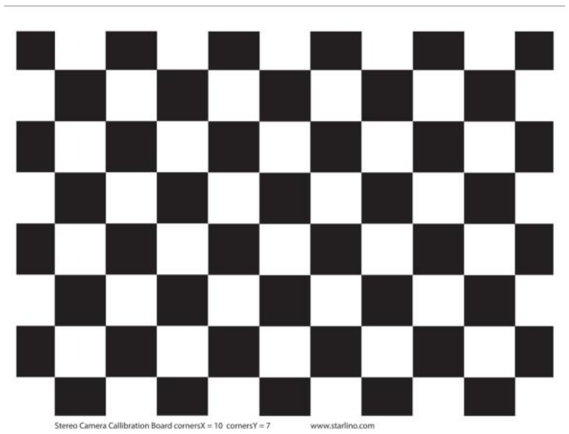
$$\Downarrow$$

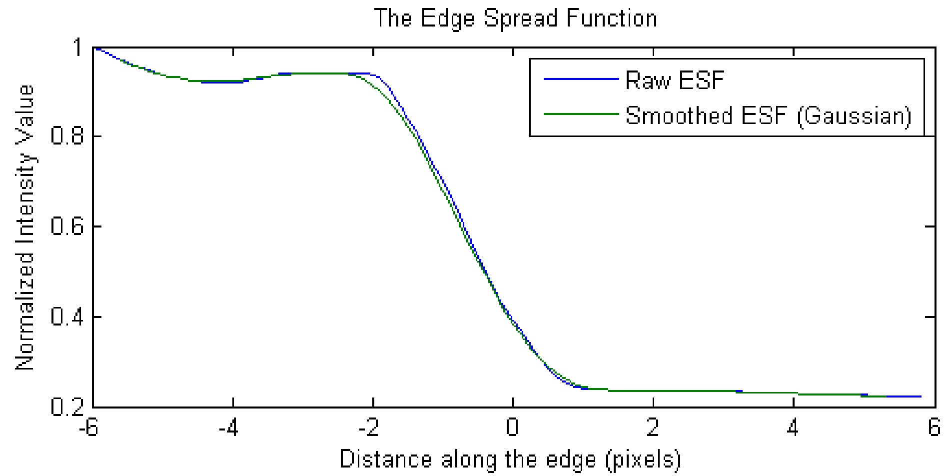
$$y_i(w \cdot x_i + b) - 1 \geq 0, \quad \forall (x_i, y_i) \in X$$

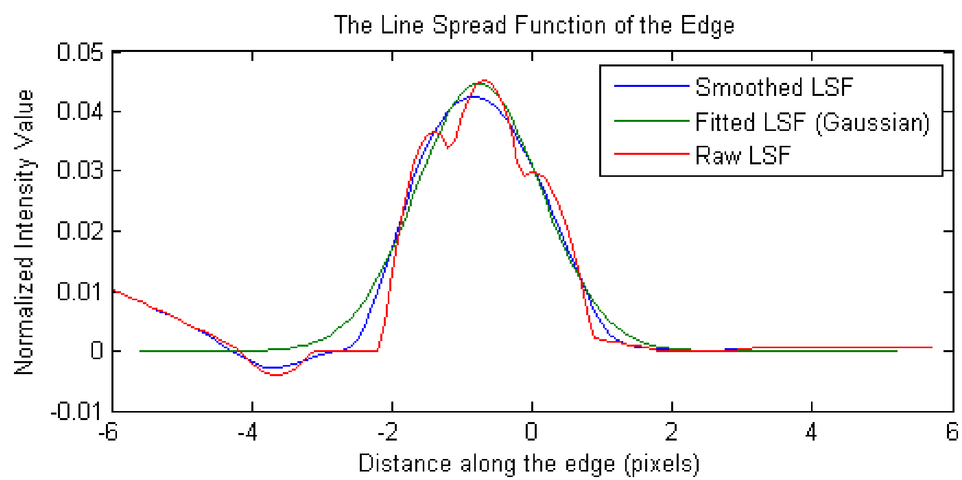


Cam #1
Cam #2
Image
Processing
GPS
Processing Unit
Decision Making
(Modeling)
GUI
Online
Cameras
Filtering and
Equalization
Preprocessing
Rectification
Stereo
Matching
Leaves and Stems
Segmentation
Calibration
Offline
Geometric
Descriptors
Image
Processing
Leaves Pattern
Recognition and
Classification

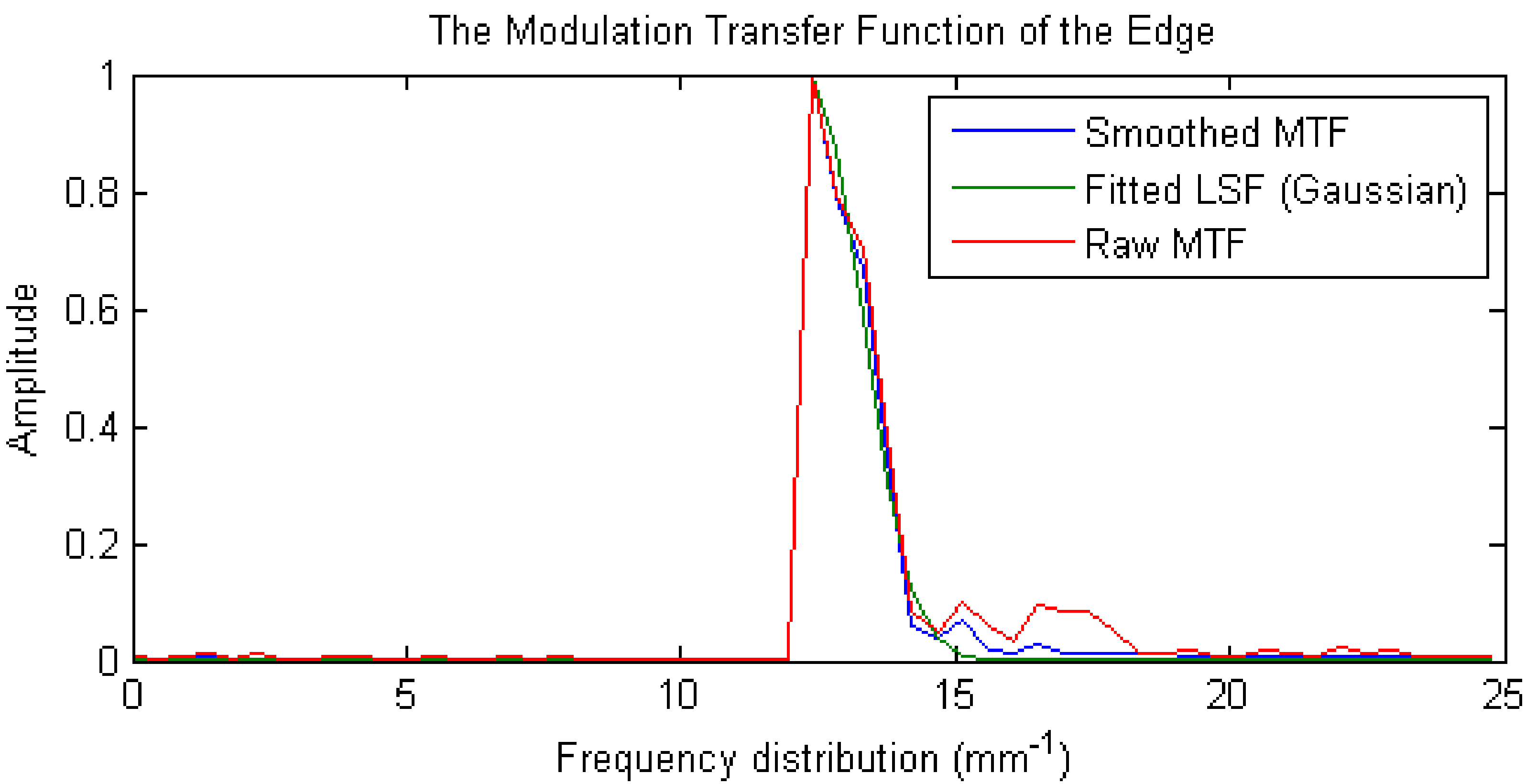
Edge Spread Function and Line Spread Function







Modulation Transfer Function



Camera Parameters

With a narrow MTF (around 3 mm^{-1}), it was also desirable to verify whether the values of the field of view provided by the manufacture are in agreement. It was considered the pixel size of 1.4 µm x 1.4 µm, the focal length 3.6 mm and the sensors resolution of 2592 x 1944 pixels.

Calculated values:

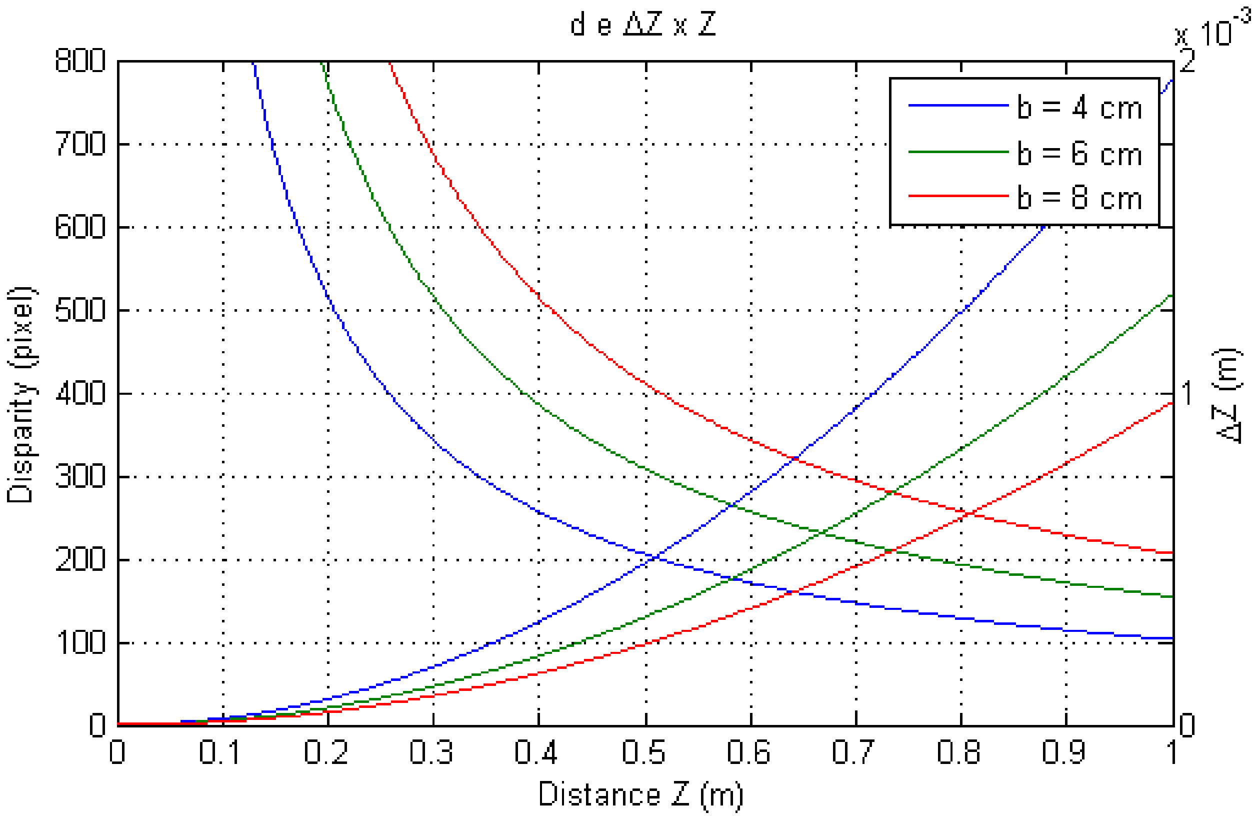
$$W_s = (s_x)(W) = (1.4\mu)(2592) = 3.63\ m$$
$$H_s = (s_y)(H) = (1.4\mu)(1944) = 2.72\ m$$
$$D_s = \sqrt{W_s^2 + H_s^2} = 4.54\ mm$$
$$HFOV = 2\arctan(W_s 2f) = 53.5^\circ$$
$$VFOV = 2\arctan(H_s 2f) = 41.4^\circ$$
$$DFOV = 2\arctan(D_s 2f) = 64.4^\circ$$

Manufacture values:

$$W_s = 3.76\ m$$
$$H_s = 2.74\ m$$
$$D_s = 4.65\ mm$$
$$HFOV = 53.50^\circ \pm 0.13^\circ$$
$$VFOV = 41.41^\circ \pm 0.11^\circ$$
$$DFOV = 65.7^\circ$$

The cameras have a good response with a MTF near a Dirac delta function and with a wide field of view.

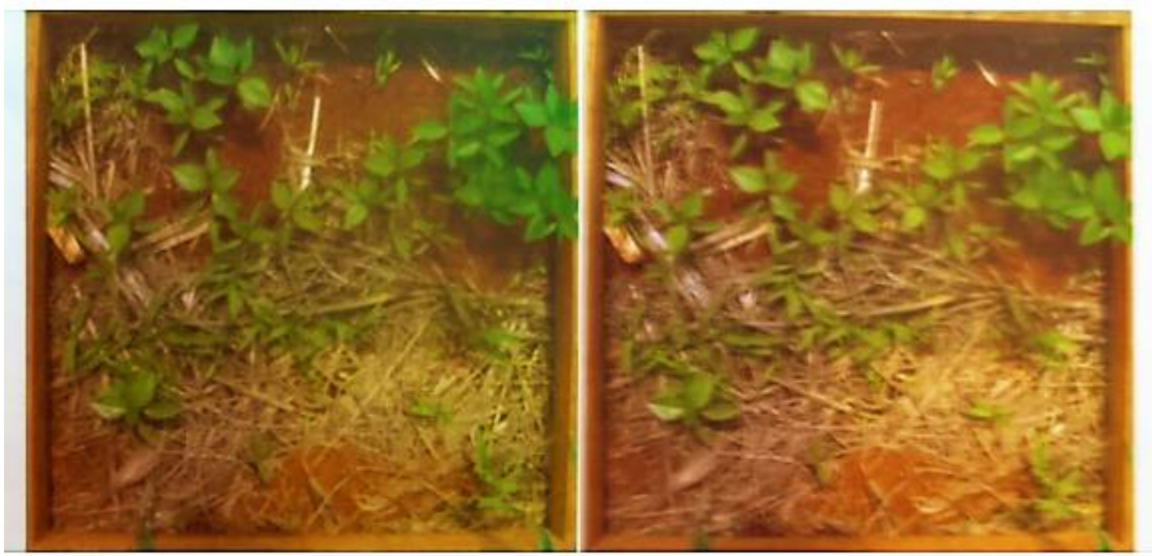
Disparity and depth resolution against distance

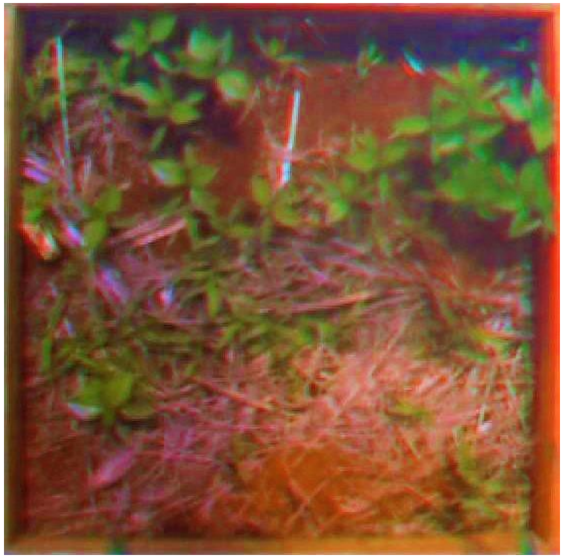


$$Z = \frac{bf}{d} \qquad \Delta Z = Z - \frac{bf}{d + \Delta d} = \frac{Z^2 \Delta d}{bf + Z \Delta d} \approx \frac{Z^2 \Delta d}{bf}$$

Image capture

From the graphic, the stereo parameters were set. Considering that the distance between the camera plane and the captured image is equal to 50 cm, a good baseline to avoid distortions and to ensure a good stereo representation can be considered as equal to 6 cm, with maximum disparity around 300 pixels.





Pseudo-code Algorithm and Resulting Disparity Map

Begin

Set parameters (window size w and number of disparities n);

Read image sizes; they must have the same height and width;

Initiate the disparity map, matching cost, pixel cost and window cost with zero values;

Calculate pixel cost for the n disparities using the absolute difference of two images;

Calculate integral cost of the pixel cost with cumulative sums;

Calculate window cost using the integral cost convoluted with a matrix h (h is a square matrix of size w with $h(1,1) = h(w,w) = 1$, $h(1,w) = h(w,1) = -1$ and otherwise equal to zero);

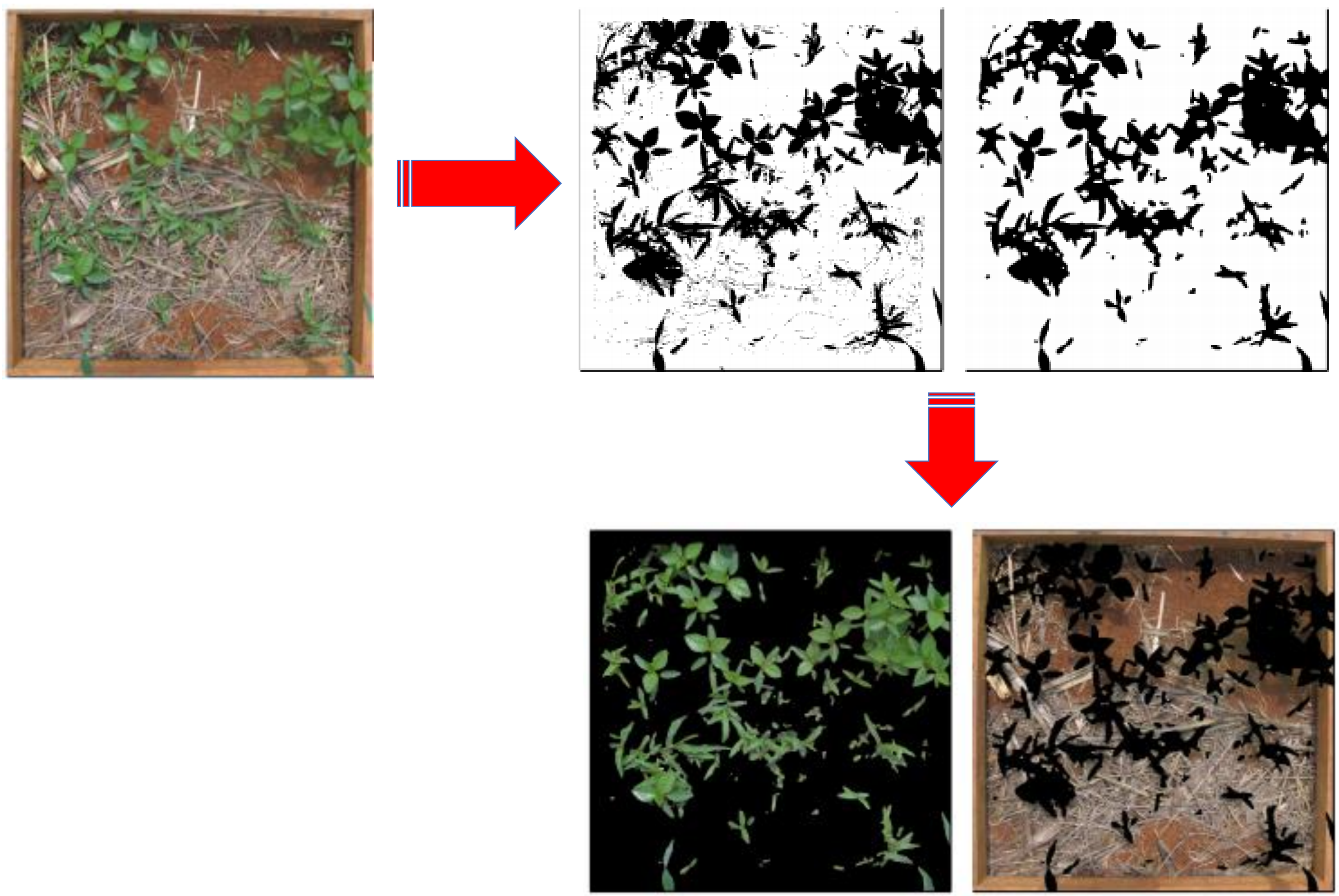
Search disparity value by finding the minimum window cost;

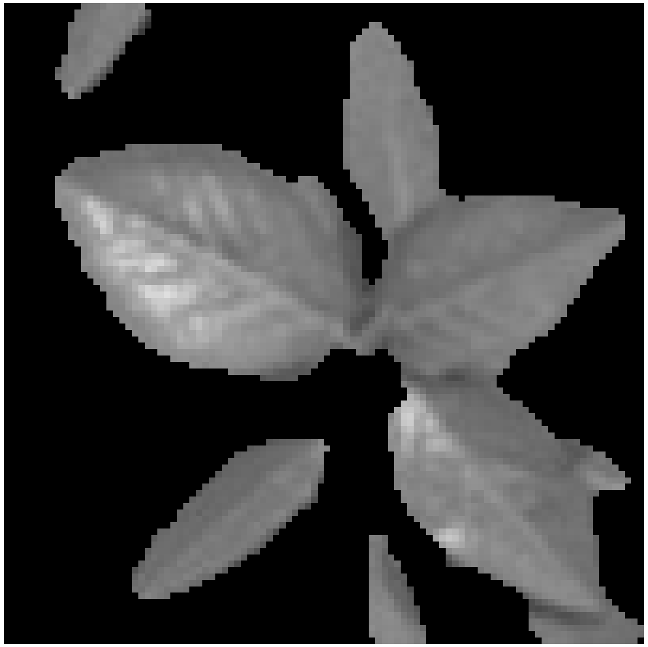
If specified, do the subpixel interpolation using polynomial fit;

end.

It was used w = 5 and n = 300.

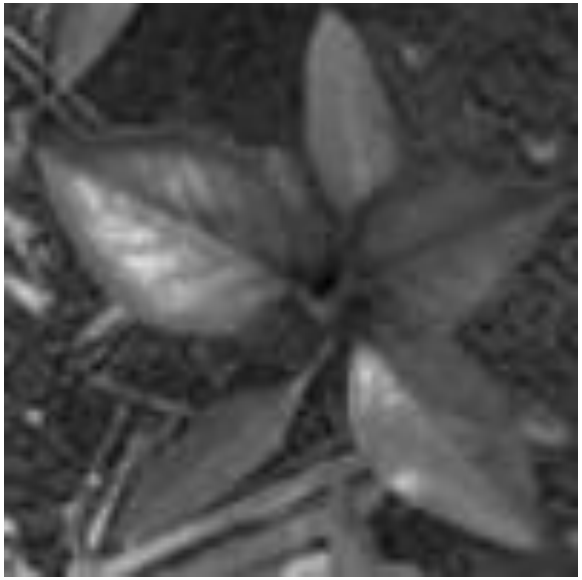
Image processing process for each plot





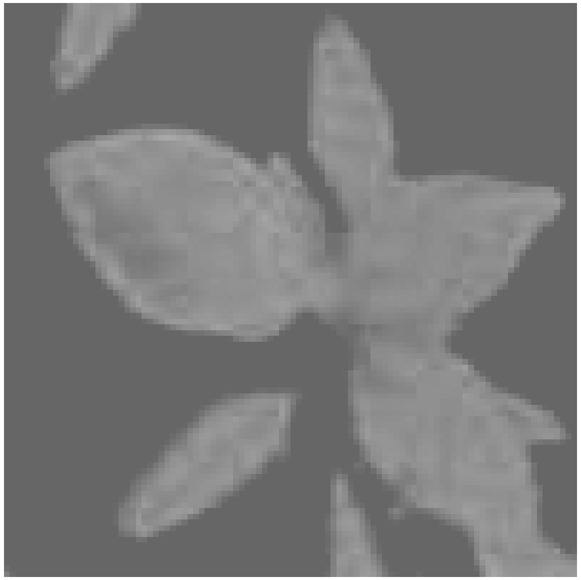
R component

G component



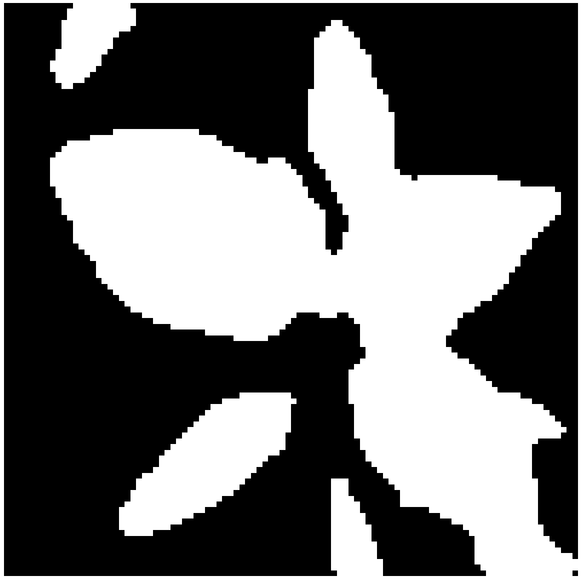
B component

Component (R – G)

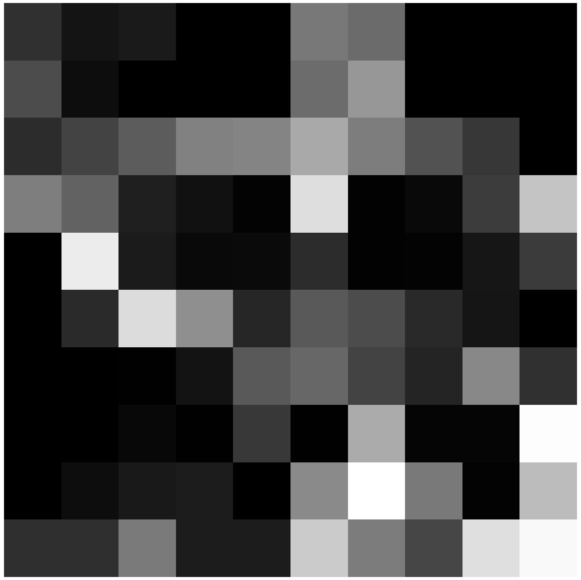


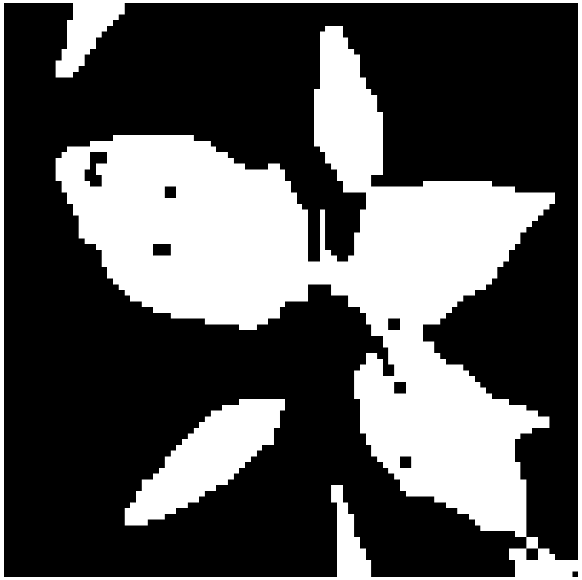
Median Filtering

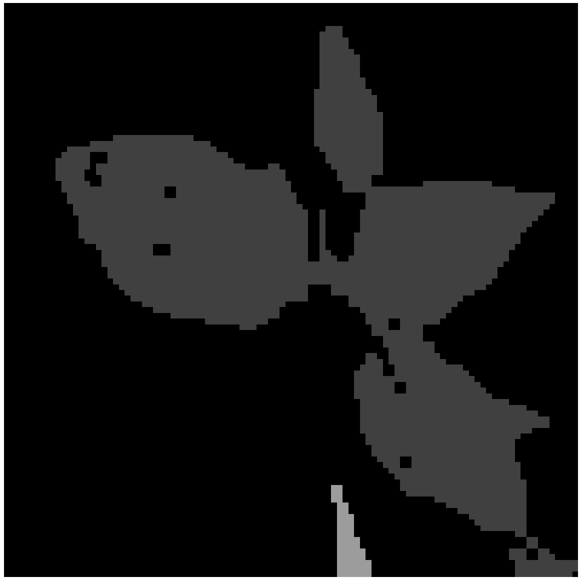
Binary image



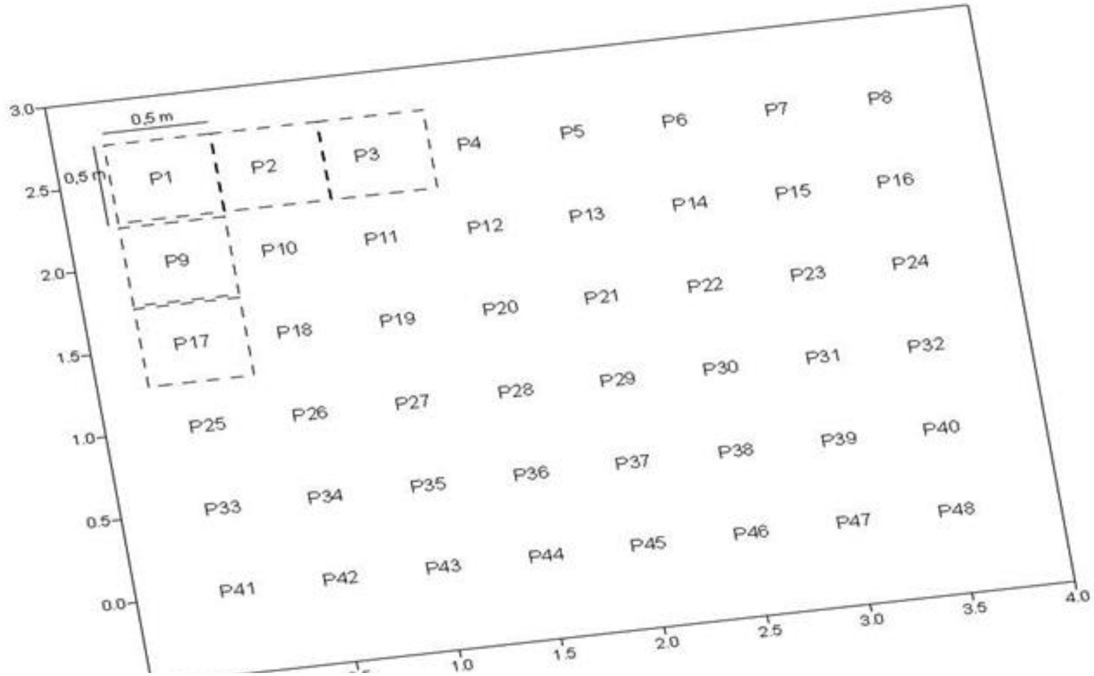
Textural mapping for the leaves **ROI** **Segmented image**

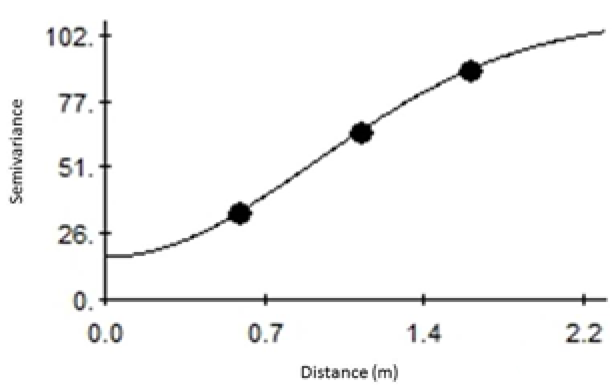




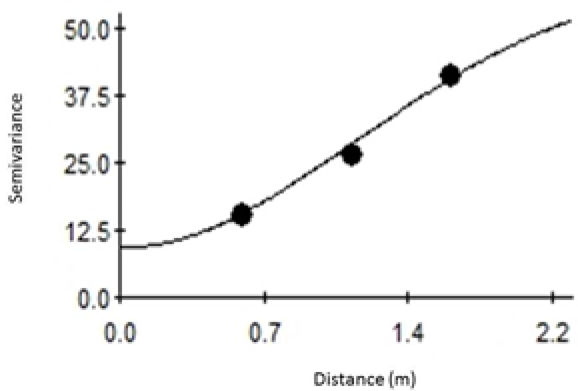


Plots and an experimental agricultural field





Model: Gaus (C_0=16,5; C_1=92,3; A=1,3)
(a)

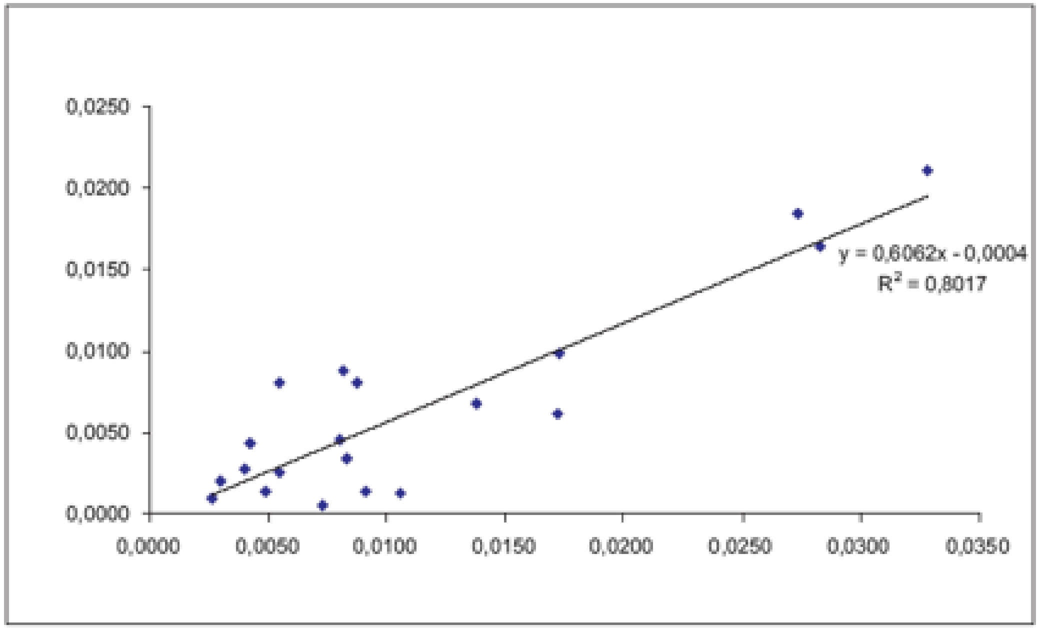


Model: Gaus (C_0=9,2; C_1=50,2; A=1,6)
(b)

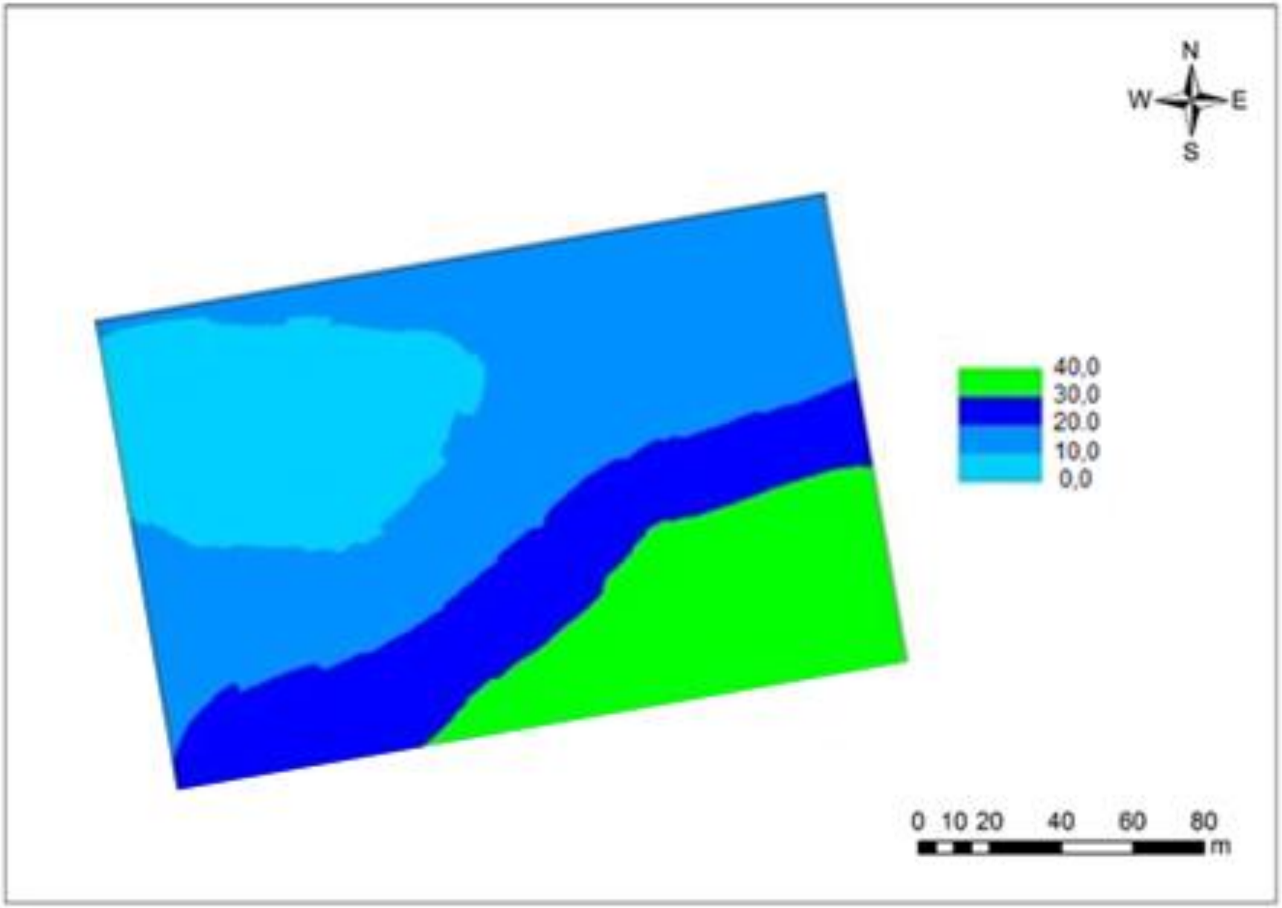
Method validation

Validation on the agricultural field

Computational vision versus Expert vision



Map of % occupancy of *Cenchurus echinatus* L. **(Narrow leaf) in corn planting area**



Conclusion

This example of a project shows that there was a gain for the figure of cost/benefit merit, as well as for the rational use of pesticides based on the identification of the invasive plant family species. Additionally, the determination of the occupancy rate and its spatial distribution allowed the definition of application maps based on a new approach considering zones for the management of the invasive plant. Future works allow us to aim for real-time control with the use of architectures that can bring greater computational performance and operation based on the developed method.

Thank you for your attention!