KAIST 東京工業大学 Tokyo Institute of Technology

Mechatronics, Systems and Control

Closing Ceremony 2014

Autonomous Guidance System for Weeding Robot in Wet Rice Paddy

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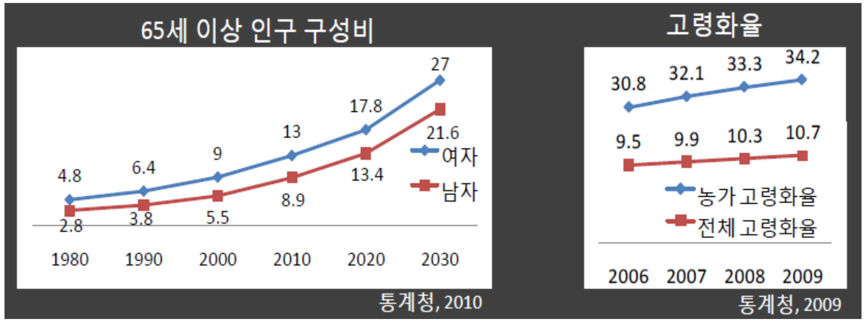
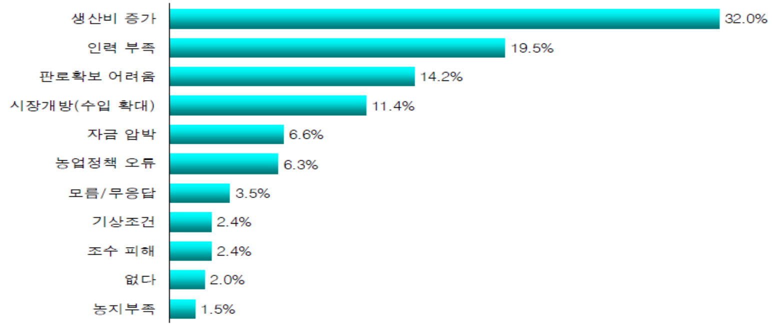
Need to the robot in agriculture

- Aging in agriculture population
- Decrease the productivity and shortage of manpower



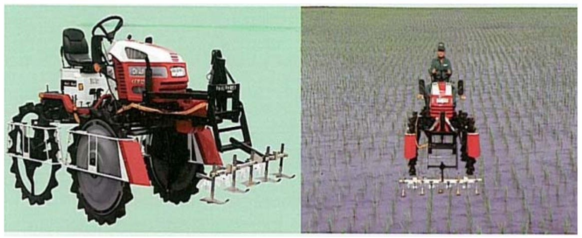


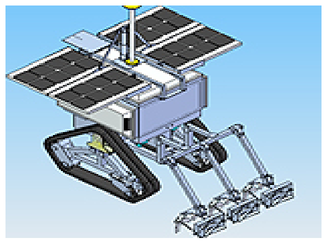
Weeding Robots

- Need to the robot, Problem of the hand weeder, riding weeder
- Mechanization rate for weeding control → 6.6%
- Environment-friendly organic agricultural

✓ **Autonomous**


[Hand weeder]


[Riding weeder]


[Weeding robot]

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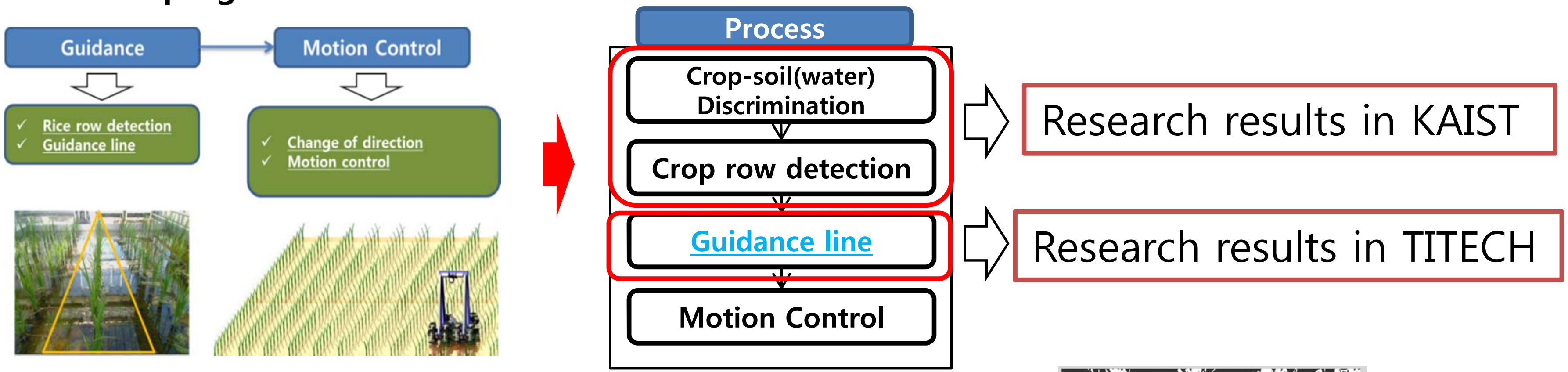
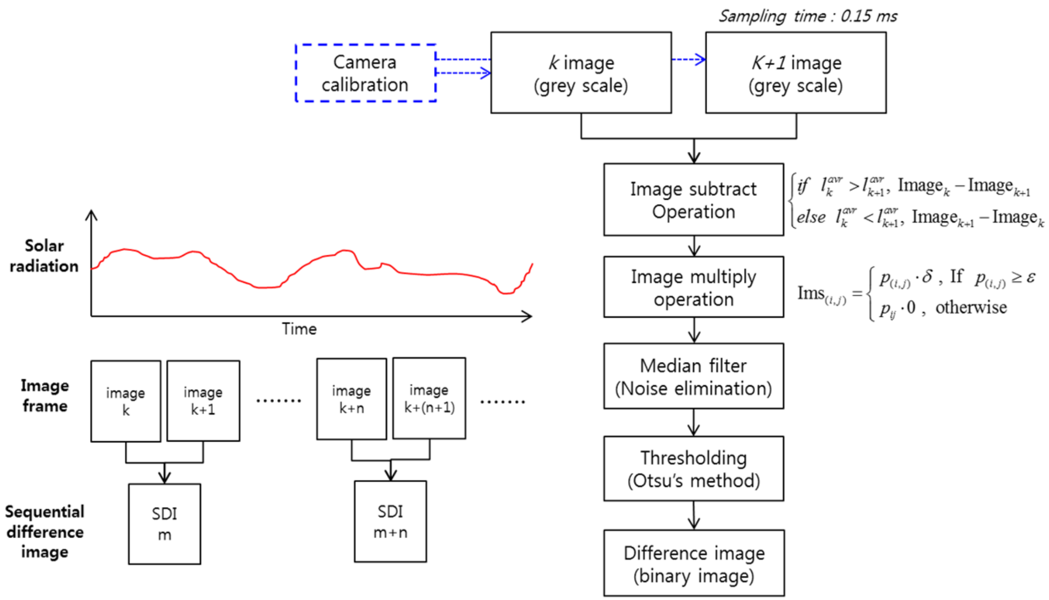
✓ **Autonomous Guidance System based-on IR Vision Sensor for Weeding Robot in Wet Rice Paddy**

- Robust to illumination condition
- Improve the accuracy of rice row and guidance line + Low cost and Simple system

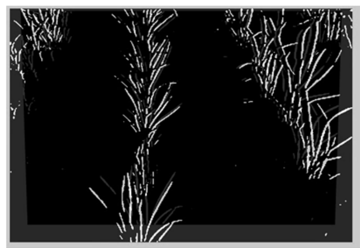
➢ Research progress



➢ Crop row detection

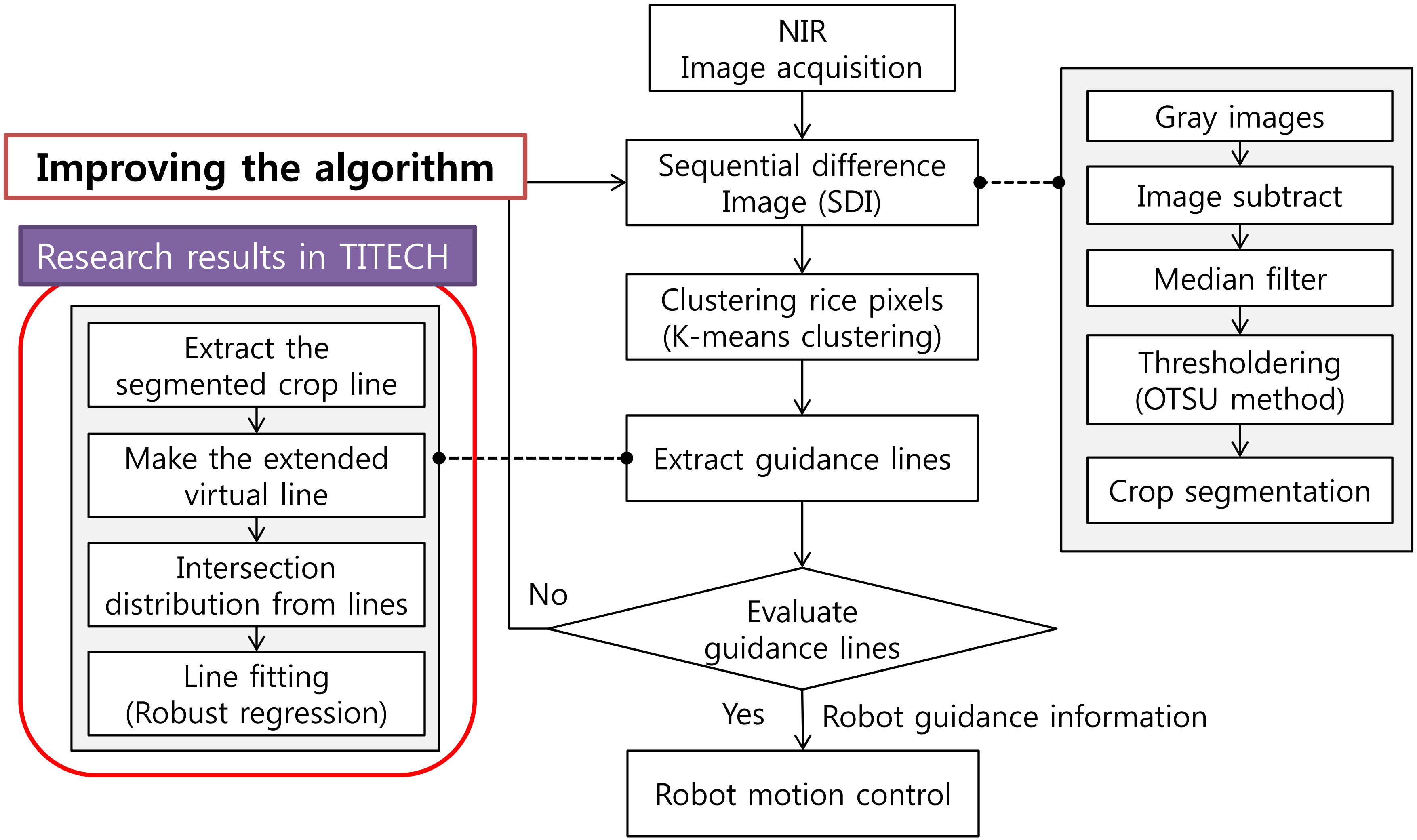


[Single image / Static thresholding]



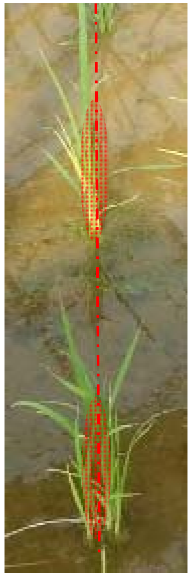
[SDI]

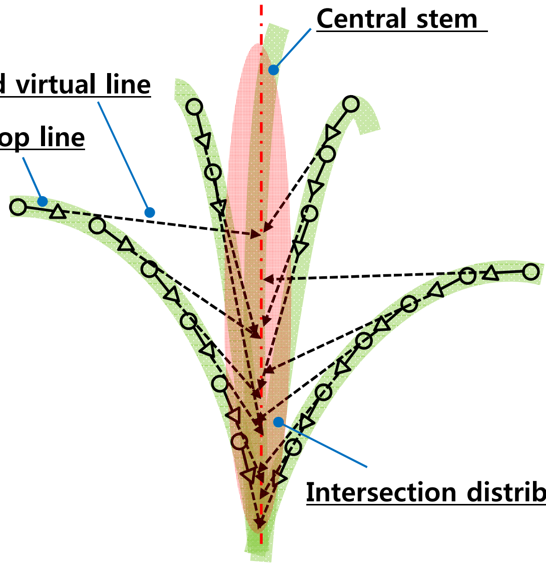
System Architecture



Concept : Rice Morphology Characteristic

- ✓ Convergence of rice stem : leaf originate from a central stem symmetrically
- ✓ Find the algorithm which is represented the convergence of central rice stem





- Step 1. Extract the segmented crop line from crop image
- Step 2. Extend each segmented crop lines → Make the extended virtual lines
- Step 3. Compute the intersection from lines → Intersection distribution
- Step 4. Extract the guidance lines from intersection distribution
- Step 5. Evaluate the guidance lines

➢ Convergence line = Segmented crop line + Extended virtual line

IV. Process of Algorithm

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Step 1. Extract the segmented crop line from crop row image

✓ Preprocess of crop row image

SDI image (binary image) → Remove small blob noise → Skeletonization (*Zhang-Suen thining*)

$p_{(i,j)}$ = pixel value is 1 (white pixel).

$P = \{ p^{area}_{(m,n)} \mid \text{all pixels of } P^{area}_{k} \}$

$$\text{Bolb noise elimination} = \begin{cases} P = 0, & \text{If } P^{area}_{(i,j)} < \xi \\ P = 1, & \text{otherwise} \end{cases}$$

, where $P^{area}_{(i,j)}$ = number of pixels in the region which is connected each $p(i, j)$.

✓ Clustering using K-means algorithm

$X = \{ x_n \mid p(i, j) = 1 \}$

$C = \{ c_{1, \dots,} c_k \}$ where k = centroid locations of initial cluster

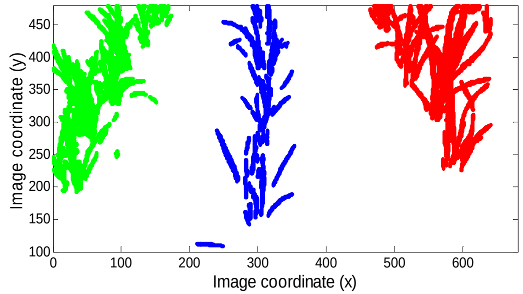
k = the number of local peaks on sum of white pixels reference to y

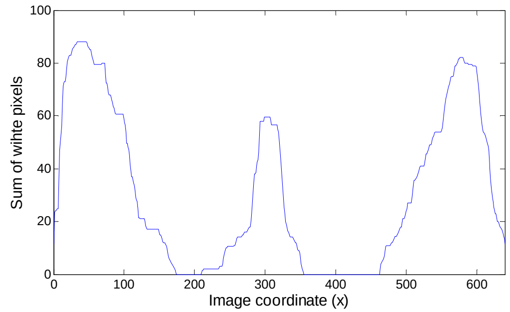
$X_i = \{ x_n \mid d(x_n, c_i) \le d(x_n, c_j), j = 1, \dots, \mathrm{k} \}$

$C_i = c(X_i)$, i = 1, … , k

$$D = \sum_{n=1}^{N} d(x_n, c_{i(n)})$$

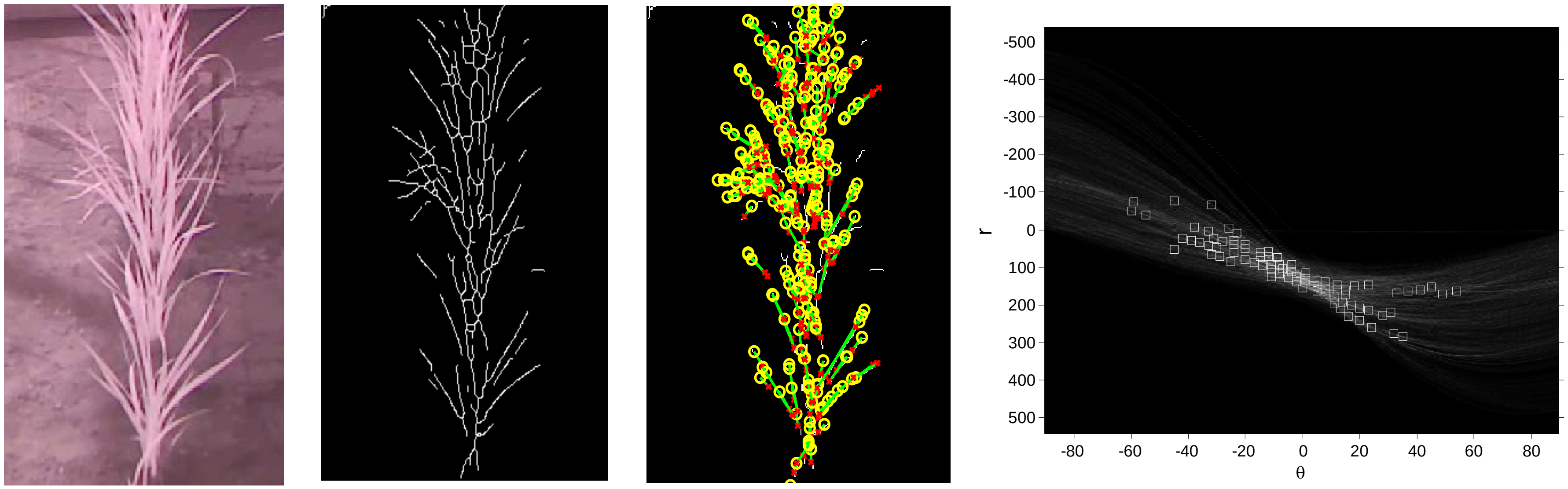
$$\Delta D = \frac{D_{pre} - D_{cur}}{D_{pre}} < 10^{-4}$$





✓ Segmented crop line

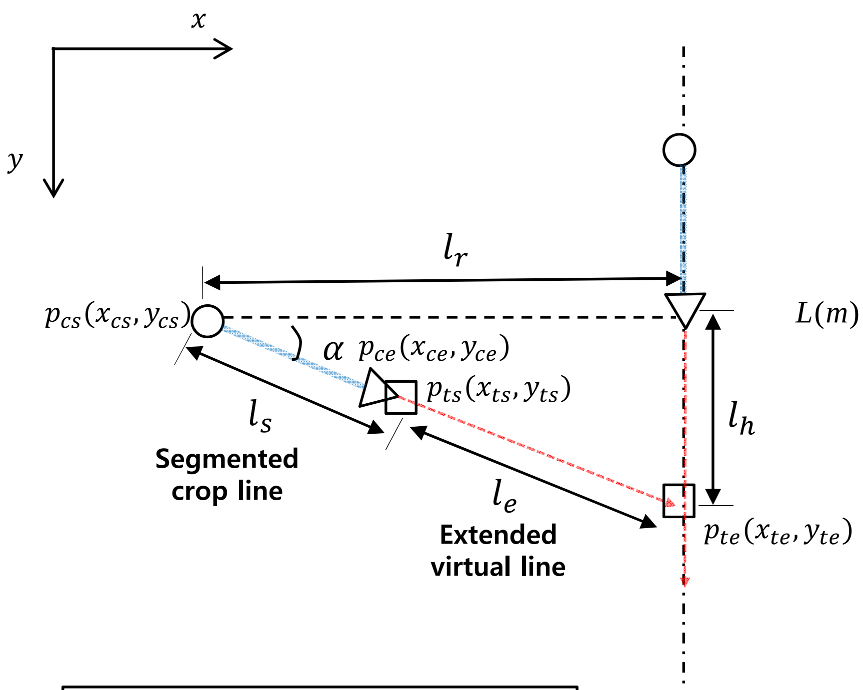
- Hough transform(Paul Hough, 1962)
  - The classical Hough transform was concerned with the identification of lines in the image



a) Original image, (b) Skeletonized image, (c) Segmented lines (start point: circle, end point: cross, length: green line), (d) Extended virtual lines (start point: rectangle, end point: cross, length: blue line)

Step 2 : Extend each segmented crop lines

✓ Extended virtual line



$$l_e = \begin{cases} l_h & , \text{ if } \alpha \approx 90^\circ \\ l_r / |\cos(\alpha)| - l_s, & \text{else} \end{cases},$$

where $l_r = \tau \cdot e^{\varepsilon \cdot \alpha}$, l_s = length of segmented line

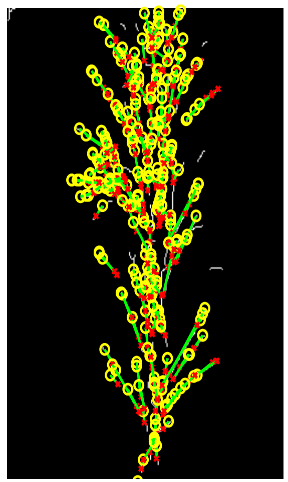
$$L(m) = \begin{cases} p_{ts} = p_{ce},\ p_{te} = p_{ce} + (l_e \cos(\alpha), l_e \sin(\alpha)) & \text{if } y_{cs} \geq y_{ce} \text{ and } 0 \leq \alpha < \pi/2 \\ p_{ts} = p_{ce},\ p_{te} = p_{ce} + (-l_e \cos(\alpha), l_e \sin(\alpha)) & \text{if } y_{cs} \geq y_{ce} \text{ and } \pi/2 < \alpha \leq \pi \\ p_{ts} = p_{cs},\ p_{te} = p_{cs} + (l_e \cos(\alpha), l_e \sin(\alpha)) & \text{if } y_{cs} < y_{ce} \text{ and } 0 \leq \alpha < \pi/2 \\ p_{ts} = p_{cs},\ p_{te} = p_{cs} + (-l_e \cos(\alpha), l_e \sin(\alpha)) & \text{if } y_{cs} < y_{ce} \text{ and } \pi/2 < \alpha \leq \pi \\ p_{ts} = p_{ce},\ p_{te} = p_{ce} + (l_h, 0) & \text{if } y_{cs} \geq y_{ce} \text{ and } \alpha \approx \pi/2 \\ p_{ts} = p_{cs},\ p_{te} = p_{cs} + (l_h, 0) & \text{if } y_{cs} < y_{ce} \text{ and } \alpha \approx \pi/2 \end{cases}$$

l_r : *average width of rice*

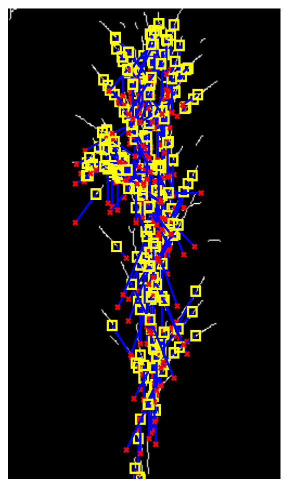
α : *slope of segmented line*

l_s : *length of segmented line*

l_e : *length of extented vitual line*

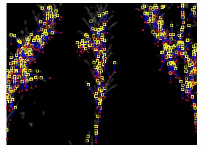


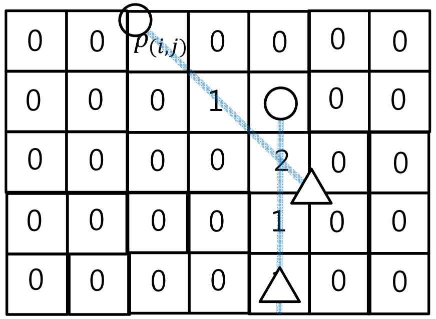
[Segmented line]



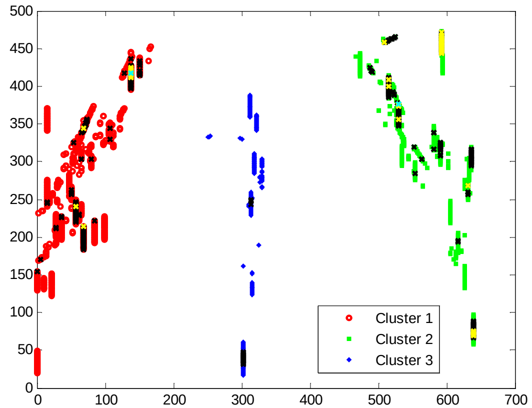
[Extended virtual line]

Step 3 : Compute the intersection from lines





- ✓ Pixels = Moneybox
- ✓ Pixel which pass through the extended Line
  → Put money('1') in a moneybox
- ✓ Intersection point = {money > 1}



Step 4 : Extract the guidance lines

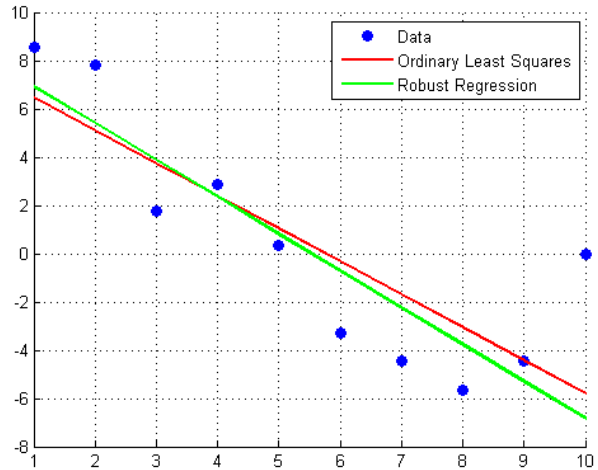
✓ Intersection distribution → Robust regression (James O., 1988)

- Least squares estimates for regression models are highly sensitive to (not robust against) outliers.

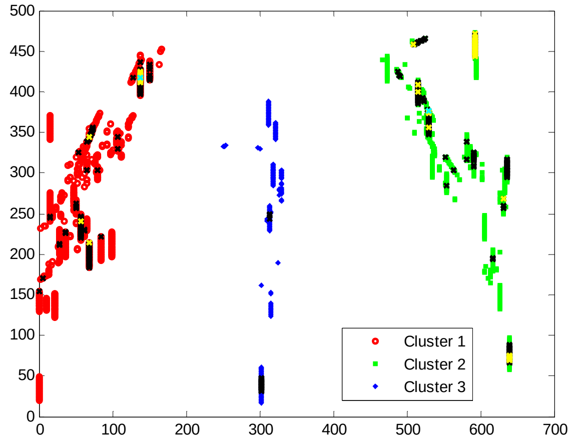
$$y_i = x_i^t \beta + \sigma \varepsilon_i \qquad 0 = \sum_{i=1}^{N} x_i w[(y_i - x_i^t \hat{\beta}) / \hat{\sigma}]$$

$$w_i = \begin{cases} e^{(-r_i^2)} & \text{for } |r| \le \xi \\ 0 & \text{for } |r| > \xi \end{cases} \qquad \text{where} \quad r_i = \lambda_i (y_i - x_i^t \hat{\beta}) / \hat{\sigma}_i$$

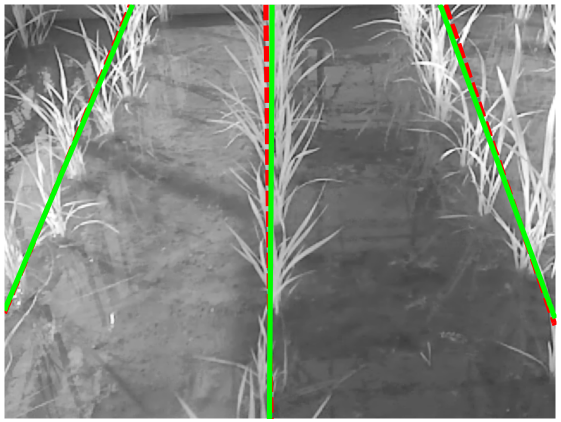
$$\hat{\sigma}_i = \text{Med}\{|y_i - x_i^t \hat{\beta}|\} / .6745 \qquad \lambda_i = n / \max(n)$$



Results



[Intersection point]



[Guidance line]
(red: LSE, green: robust regression)

Error \ Samples (number)		S1(100) Angle	S1(100) Initial point	S2(100) Angle	S2(100) Initial point	S3(100) Angle	S3(100) Initial point	S4(100) Angle	S4(100) Initial point	S5(100) Angle	S5(100) Initial point	Total(500) Angle	Total(500) Initial point
Center line	RMS	0.67	1.87	0.60	2.84	0.95	3.40	0.96	1.40	0.71	1.82	0.79	2.58
	S.D	0.82	2.38	0.76	3.50	1.22	4.36	1.09	1.76	0.92	2.20	0.99	3.38
	Max	3.55	10.01	3.28	12.82	5.22	23.18	4.16	7.41	4.31	8.71	5.22	23.18
	Min	0.03	0.02	0.02	0.00	0.01	0.15	0.01	0.26	0.01	0.04	0.01	0.00
Right Line	RMS	1.00	2.18	1.82	3.47	2.08	7.50	2.93	8.01	3.11	5.76	2.67	5.69
	S.D	1.19	3.01	2.15	4.58	2.86	10.50	4.08	13.89	3.87	6.94	3.49	8.92
	Max	4.67	15.31	7.62	18.69	13.75	45.98	23.39	84.22	16.38	24.85	23.39	84.22
	Min	0.04	0.23	0.00	0.71	0.01	0.48	0.25	0.42	0.47	0.71	0.00	0.23
Left line	RMS	0.84	1.36	0.98	4.68	2.93	9.02	2.24	6.07	3.56	5.06	2.76	5.91
	S.D	1.07	1.76	1.45	5.92	3.87	11.89	3.17	7.20	4.42	6.51	3.64	8.11
	Max	4.29	8.11	6.80	22.71	18.27	48.60	13.79	27.86	17.61	26.38	18.27	48.60
	Min	0.05	0.03	0.05	0.06	0.02	0.47	0.11	0.28	0.02	0.06	0.02	0.03
Rice size (width/height)		10~15 cm / 20~25 cm		20~25 cm / 30~25 cm		25~35 cm / 40 ~ 45 cm		30~45 cm / 45 ~ 50 cm		30~45 cm / 45 ~ 50 cm			

VI. Campus life in TITECH

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Friends

Advisor

Healing!

Travel