THESIS APPROVAL

GRADUATE SCHOOL, KASETSART UNIVERSITY

Master of Engineering (Information and Communication Technology for Embedded Systems)

DEGREE

Information and Communication Technology for Embedded Systems	Electrical Engineering
FIELD	**DEPARTMENT**

TITLE: Precision Herbicide Applicator over Between-row of Sugarcane Fields

NAME: Mr. Apimuk Muangkasem

THIS THESIS HAS BEEN ACCEPTED BY

.... **THESIS ADVISOR**

(Assistant Professor Somying Thainimit,Ph.D.)

.... **THESIS CO-ADVISOR**

(Mr. Rachaporn Keinprasit, Ph.D.)

.... **THESIS CO-ADVISOR**

(Associate Professor Tsuyoshi Isshiki, Ph.D.)

.... **DEPARTMENT HEAD**

(Assistant Professor Srijidtra Charoenlarpnopparut, Ph.D.)

APPROVED BY THE GRADUATE SCHOOL ON ....

.... **DEAN**

(Associate Professor Gunjana Theeragool, D.Agr.)

THESIS

PRECISION HERBICIDE APPLICATOR OVER BETWEEN-ROW OF SUGARCANE FIELDS

APIMUK MUANGKASEM

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Master of Engineering (Information and Communication Technology for Embedded Systems)
Graduate School, Kasetsart University
2010

Apimuk Muangkasem 2010: Precision Herbicide Applicator over Between-row of Sugarcane Fields. Master of Engineering (Information and Communication Technology for Embedded Systems), Major Field: Information and Communication Technology for Embedded Systems, Department of Electrical Engineering. Thesis Advisor: Assistant Professor Somying Thainimit, Ph.D. 41 pages.

Uniform herbicide application system applied herbicide substances uniformly regardless of weed density. This increases farmer's production costs and is prone to ground water contamination. Precision herbicide application system is introduced to address this problem. More effective precision herbicide system is present in this paper. The proposed system is a vision based system. It consists of two main parts: weed detection part and controller part.

In this thesis, color-based weed detection is proposed. Background component of an input image is segmented using the proposed Non-Green Subtraction (NGS) technique. The NGS segregates an image into two classes, which are background and non-background. The non-background is further segmented into weed and non-weed pixels using Over Excessive Green (OEG) technique. The experimental results indicate significant improvement on the false accepted rate and overall correct segmentation rate, especially with sparse weed images comparing to the results obtained using only the OEG technique. In controller part, our experiments inspect a feasible processing time of our system. The system requires at maximum 106 millisecond of processing time including capturing an input image, detecting weeds and sending spraying command to the controller. The results indicate real-time processing capability. By providing constant speed of the system vehicle, our applicator can control sprayed area as minimum as nozzle's capacity. The minimum area is approximately 11.67 centimeters.

_____________________________ _____________________________ ___ / ___ / ___

Student's signature Thesis Advisor's signature

ACKNOWLEDGEMENTS

This research is financially supported by Thailand Advanced Institute of Science and Technology - Tokyo Institute of Technology (TAIST-Tokyo Tech), National Science and Technology Development Agency (NSTDA), Tokyo Institute of Technology (Tokyo Tech) and Center of Promoting Research and Development of Satellite Image Application in Agriculture, Kasetsart University.

Apimuk Muangkasem
June 2010

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF ABBREVIATIONS

B	=	Blue
CR	=	Correct Rate
CSR	=	Correct Spray Rate
DC	=	Direct Current
ExG	=	Excessive Green
FAR	=	False Accept Rate
FRR	=	False Reject Rate
G	=	Green
GDR	=	Group Detected Rate
M	=	an average value of the R, G and B value
MSP	=	Mixed Signal Processor
NGS	=	Non-Green Subtraction
OEG	=	Offset Excessive Green
OSR	=	Over Spray Rate
R	=	Red

PRECISION HERBICIDE APPLICATOR OVER BETWEEN-ROW OF SUGARCANE FIELDS

INTRODUCTION

Sugarcanes play an important role in export crops business in Thailand and South-East Asia (Singh and Abeygoodwardana, 1982). In sugar-crane fields, weeds often occur in patches and are spread non-uniformly (Shaw, 2005). Hence, uniformly applied herbicides used in fields increases cost of herbicide substances. It is also prone to ground water contamination. In order to achieve higher sugarcane productions, effective weed control system is essential. Additionally, precision herbicide system can apply massively without chemical harmful to humans.

In this research, a real-time precision herbicide system is developed. We separate our work into two parts: detection part and controller part. In detection part, a real-time algorithm of spatial weed detection is developed. Our approach is a vision-based system. Weed images are captured using a web camera attached to a moving vehicle. One of the basic problems in exploiting the herbicide applicator in a practical field is caused from variation of the natural light source during acquiring weed images In some previous research, a material such as a white plastic is used to cover acquired area to reduce illumination effects. Our proposed system is different from previous existing methods in that it requires no assistant devices during acquiring field images. We focus on detecting weeds in sugarcane field for real-time application. A fast color-based segmentation is developed under restriction of real-time processing. In sugarcane fields, all vegetations in its between-row are considered as weeds. Thus, a simpler technique can be used. In our work, the Offset Excessive Green (OEG) is utilized. The OEG technique is fast and simple. However, it requires parameter tunings when image acquisition conditions are changed. The Non-green subtraction technique is proposed in this work to improve the system accuracy and minimizing effects of chosen OEG threshold value. In controller part, we have to use the result of the detection system to control our herbicide nozzle. The system process are detecting weeds and spraying. Since it is the real-time process, time managements need to be concerned. We must provide some spaces between a camera and nozzles. We introduce this space in order to make sure that the detection part has enough time to analyze input image and to spray herbicide before reaching the next acquisition process. Limitations of our system are tested in this part such as minimum processing time, minimum sprayed area and vehicle speed. To maximize the precision of our system, two control techniques are introduced. Using these two control techniques with a constant vehicle speed, the sprayed area resolution is improved. It can reach the limitation of spray control which can spray as minimum as nozzle can do.

OBJECTIVES

The general objectives of this project are to develop a real-time vision-based algorithm and control techniques to detect weeds and spray herbicide over the detected weeds between-row of sugar-cane field. In our system, all greens in the rows are considered as weeds. The specific objectives of this study are:

1. Developing a color-based weed detection algorithm aimed to improve robustness of the algorithm under natural lighting condition without including assistant devices.

2. Developing real-time control techniques to increase precision of weed sprayers.

3. Testing the accuracy of the proposed real-time weed application system that attached to a moving vehicle in a practical field.

LITERATURE REVIEW

This part shall show the research about color-based segmentation methods using in agriculture fields and existing herbicide applicator using machine vision. Topics contain Offset Excessive Green algorithm and precision herbicide system.

1. Offset Excessive Green (OEG)

The OEG is a simple color-based segmentation approach for segmenting green pixels from the background. The approach calculates offset excessive green value of each pixel from its RGB value using following equation:

$$OEG = (G-R) + (G-B), \qquad (1)$$

where R, G and B are pixel intensity in its red, green and blue channel, respectively. This technique has been used by many researchers in detecting green pixels in an image. An example is the study about intensified fuzzy clusters (Meyer G.E. *et al.*, 2003). He utilized the OEG technique in his work but called it as Excessive Green (ExG). This algorithm found useful for identifying plant inside regions of interest (ROI) that contain bare soils and some residue backgrounds.

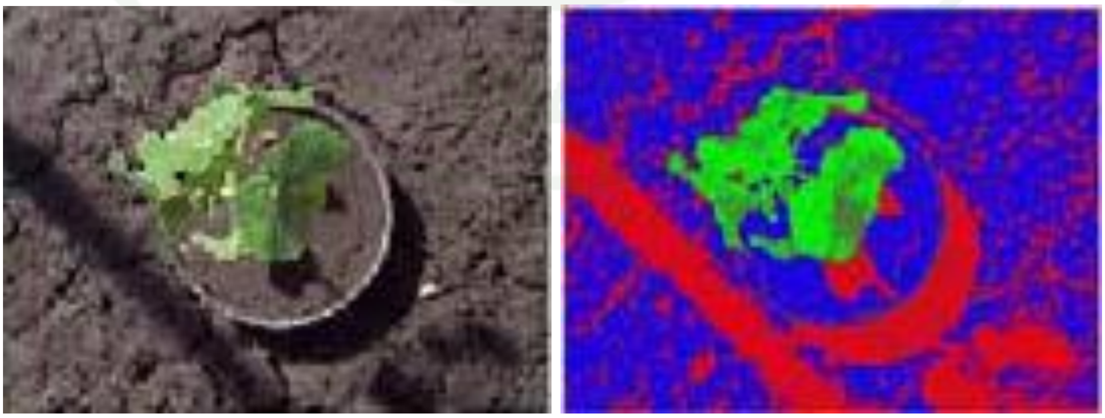


Figure 1 Result of identifying plant regions of interest (ROI) with bare soils

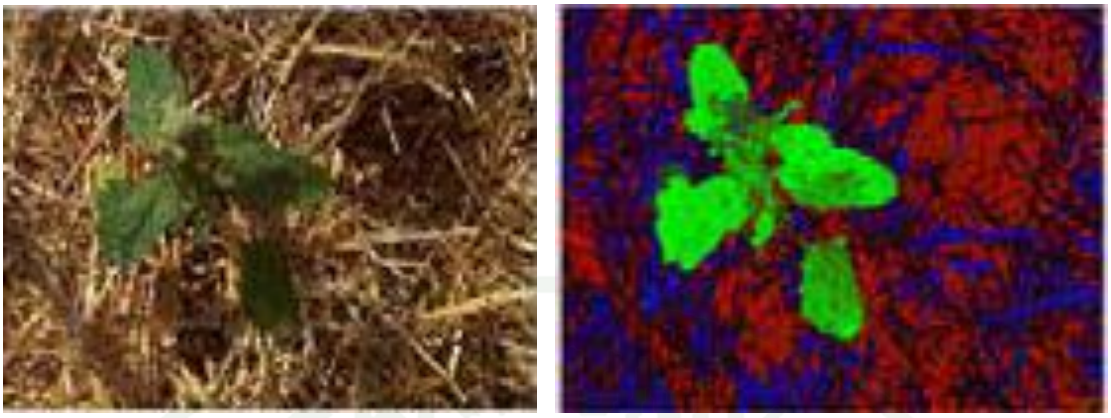


Figure 2 Result of identifying plant regions of interest (ROI) with some residue backgrounds

However, bright soil or residue pixels which contain high green content (although not appearing green to the human eye) tended to provide false plant information.

Abdul Muhamin (Naeem, A.M., 2007) also uses OEG technique in his work. His research paper talks about how to identify type of weed. To identify the weed, he needs to do a feature extraction. That's why those weeds in field images must be carefully segmented or else the feature extraction will yield unreliable results from analyzing soils and weeds. Thus, adequate image segmentation quality is necessary. One simple technique for separating pixels into weed or background class is to calculate an offset excessive green (OEG) value from the RGB image. He also put threshold into his equation. Each pixel in the RGB image is replaced with the following calculated value:

$$OEG = 128 + (G-R) + (G-B), \quad (2)$$

where R,G,B are red, green, and blue intensity value of a pixel respectively. After the OEG image was generated, a threshold value is selected to separate the weeds from the backgrounds.

2. Precession Herbicide System

Ratana (R. Tangwongkit, 2006) introduced the herbicide application based on a machine vision system in 2006. She proposed a variable rate applicator that mounted on a small 4-wheeled tractor for weed management as shown in figure 3. The weed detection is done using a conventional thresholding technique. The developed system is currently use in sugarcane fields in Thailand.

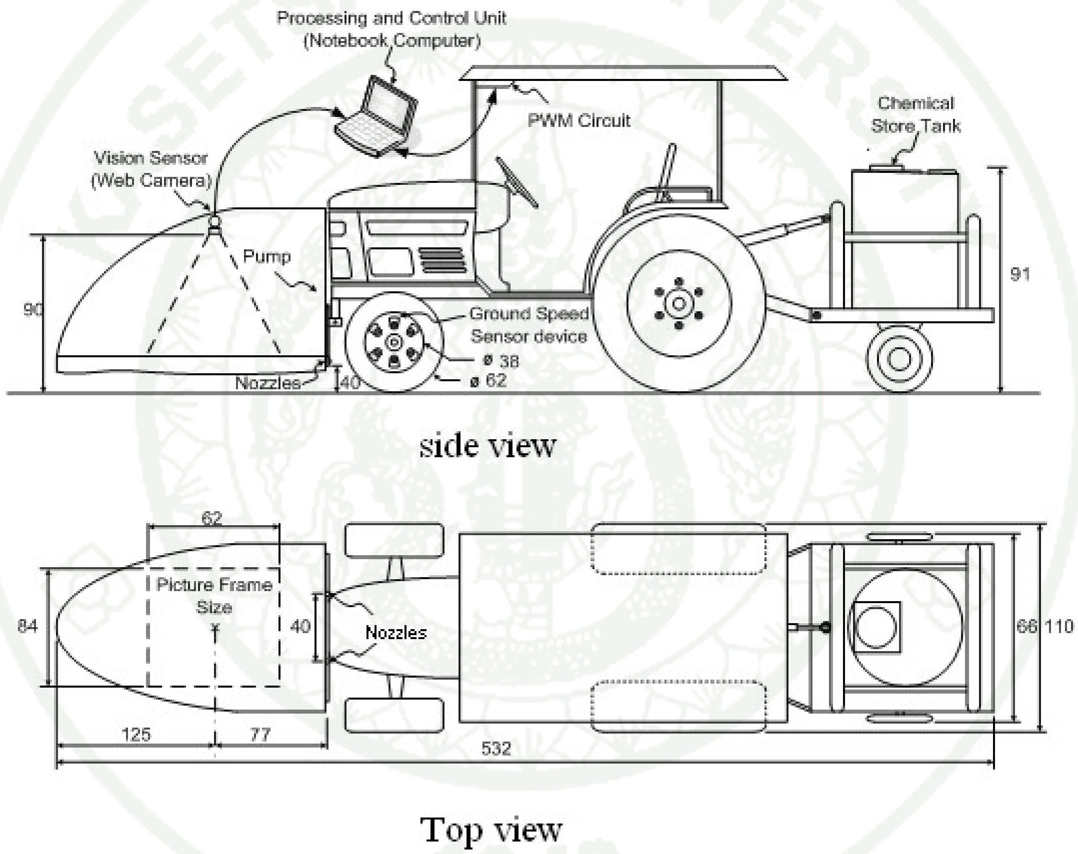


Figure 3 A schematic of a variable rate applicator system developed by Tangwongkit (all dimensions in cm)

The picture frames captured by a web camera attached to the front wheel of the vehicle. A material such as a white plastic is used to cover acquisition area. This is to handle effects of natural light source over the acquired images (Zhang et al, 2002). A conventional thresholding technique is exploited on green chromatic information of the images in order to segment weeds from the background (Slaughter). The output image is analyzed and used to actuate the controllers of a sprayer pump system. The sprayer system is sprayed herbicides depending on density of detected greenness level. In this thesis, we aim to improve the herbicide application system by using a new color-based segmentation algorithm. Additionally, two control techniques are introduced to improve sprayer area.

MATERIALS AND METHODS

Materials

1. Computer with Windows system
2. Quick Cam with Carl Zeiss Lens
3. Borland C++ builder program
4. MSP430 micro-controller
5. 12-volt DC electrical pump
6. Adjustable two fan type nozzles
7. 100-liter capacity tank
8. Proximity switch
9. Green Plastic Plate

Methods

The development of the proposed herbicide application system is divided into two phases: detection and control part. The weed detection algorithm and program is developed at the first phase to detect weeds in an image. In this project, all greens pixels in the input image are considered as weeds. Once the weed detection algorithm is validated, the control part is developed. All synchronization signals required by the micro-controller and sprayer systems are tested and implemented.

1. Detection Part

The proposed weed detection algorithm aims to separate weeds from the image backgrounds, which are mainly soil components. The algorithm inspects and decides each pixel whether it is a green pixel or not. The inspection uses chromatic information of the input pixel corresponding with appropriate threshold, Offset Excessive Green (OEG) and Non Green Subtraction (NGS). Figure 4 illustrates our proposed weed detection algorithm. The OEG is denoted by equation (1). The NGS is computed using following equation:

$$NGS = M - (|M-R| + |M-B| + |M+G|), \quad (3)$$

where R, G and B are red, green and blue intensity value of a pixel, M is an average value of the R,G and B values of the image. This equation is derived based on histogram of non-green pixels obtained using OEG technique, in which deviations of the three triplets (red, green and blue) from its average value of weeds and background are significantly discriminating.

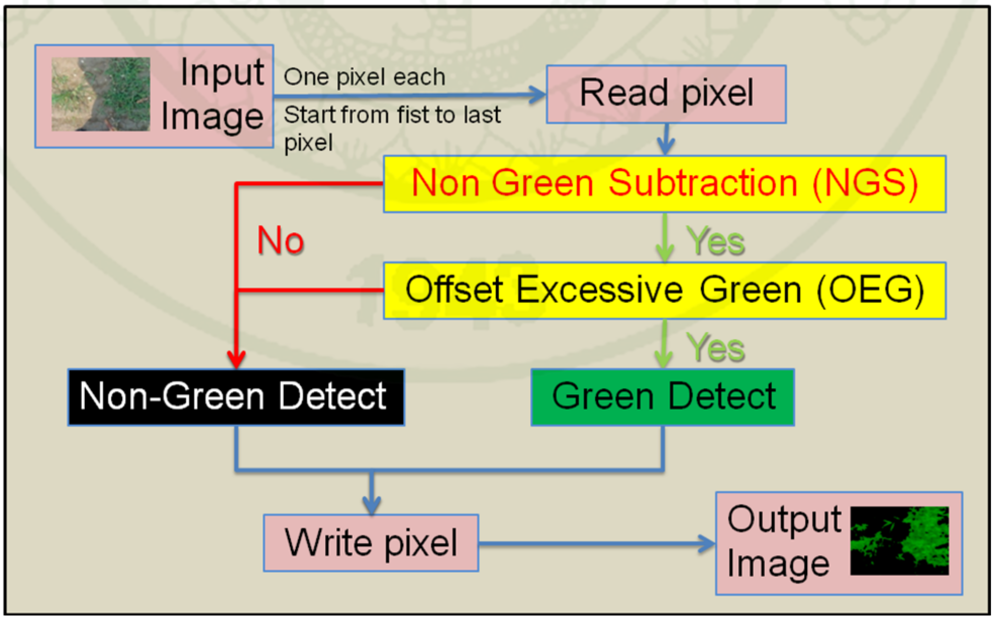
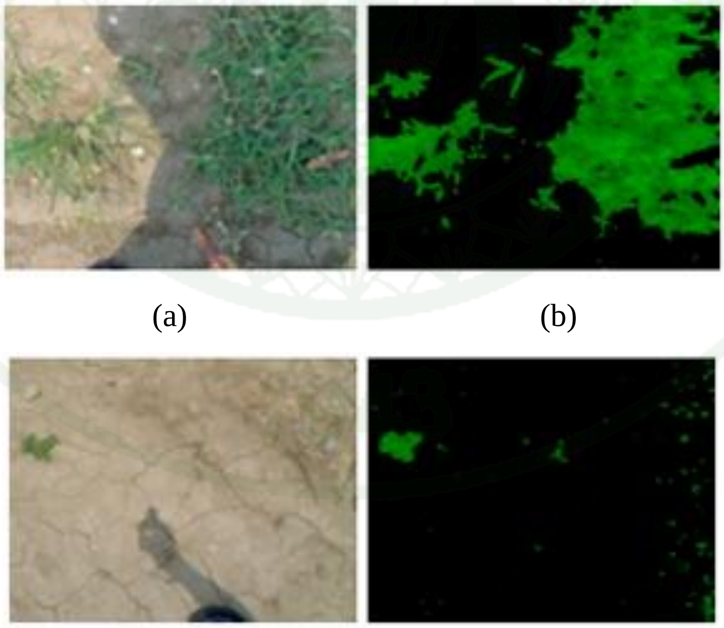


Figure 4 The flow chart of the NGSxOEG algorithm

To detect weeds, the OEG of every pixel is firstly computed. Then, an appropriate threshold value is applied to segregate weeds from the background. Several threshold values are experimented in our research. Fig 5 present segmentation output obtained from the OEG with threshold value of 20. This threshold value gives the best segmentation output for Fig 5a. From experimental results, the OEG works nicely in high density weed images such as shown in Fig 5b. However, in the sparse, low density weed image, the OEG has an over-segmentation problem. Soil background is segmented as weeds in several areas. Fig 5d shows an example over-segmentation problem in low density weed image of Fig 5c. This over-segmentation problem leads to excessive usages of herbicide, rising cost of operations and pollution problem. Reducing these falsely classified areas can be done using higher threshold value. However, under-segmentation will occur in high density weed images. Additionally, the OEG technique is highly sensitive to illumination level of an image. Therefore, appropriate threshold value for field application must be searched beforehand.

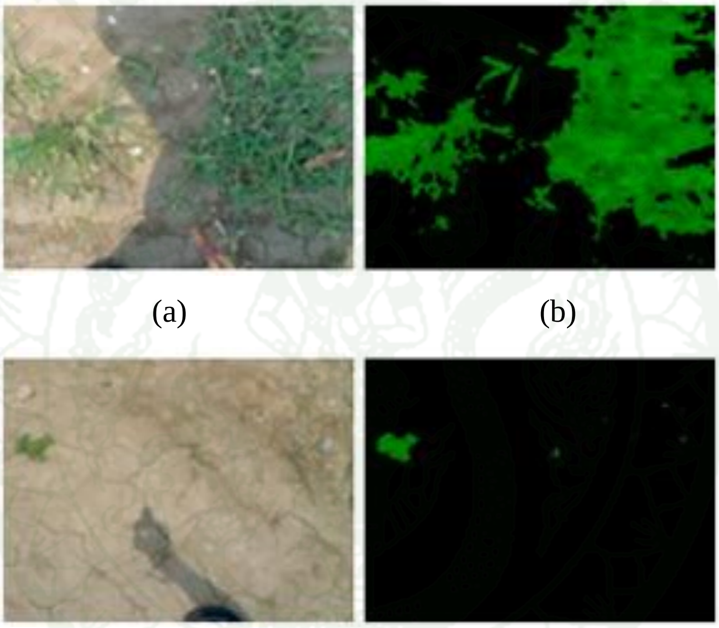


(a) (b)

(c) (d)

Figure 5 (a) A high density weed image (b) Its corresponding result of the OEG (c) A low density weed image (d) Its corresponding result of the OEG.

In order to address an over-segmentation problem of the OEG, The Non-Green Subtraction (NGS) is introduced. The NGS aims to detect background pixels which mainly are soils in the image. To classify weeds of an input image, background pixels of the image are firstly segmented using the NGS. Then, the non-background pixels are re-classified as weeds or backgrounds using the OEG. This can prevent wrongly classifying non-green objects as weeds. Hierarchically filtering image this way improves segmentation accuracy.



(a) (b)

(c) (d)

Figure 6 (a) A high density weed image (b) Its corresponding result of the proposed method (c) A low density weed image (d) Its corresponding result of the proposed method.

Figure 6 illustrates example results of our proposed weed detection method. It is clearly seen that the misclassified regions in Fig. 5d are removed.

2. Controller Part

A prototype of our real-time herbicide applicator system is mounted on a tractor as shown in Fig7.

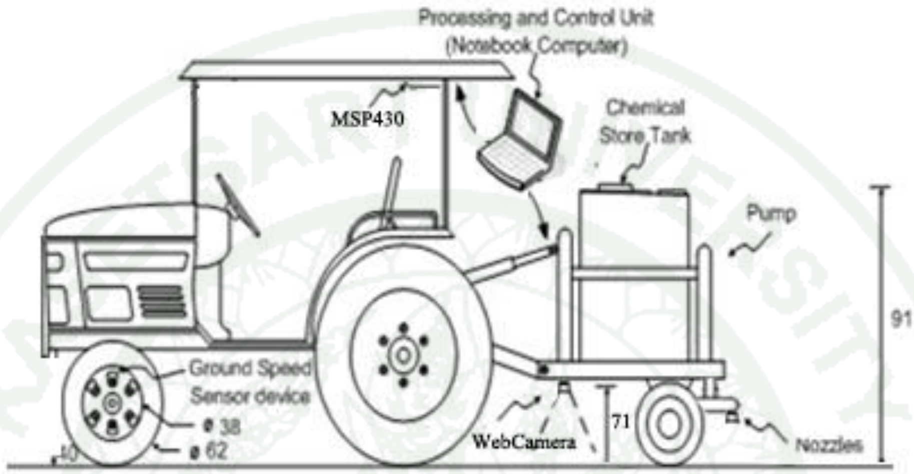


Figure 7 A schematic diagram of the proposed system (measure as centimeter).

The system is equipped with spray-boom with height adjustable. Two fan-type nozzles are arranged on adjustable 75 cm. spacing, a 100-liter capacity tank and 2-support wheels for the rear frame. Each nozzle is connected with a 12-volt DC electrical pump having maximum flow rate 3.785 l/min at an operating pressure of 275.8 KPa. The pump is controlled by a pulse width signal generated by the MSP-430 micro-controller. The pulse width duty cycle associates to weed density result computed by a main computer at each interrupt signal. The interrupt signal is generated by a ground speed sensor that attached on a wheel of the vehicle. The components' relationship of the system is shown in Fig.7.

The design of our real-time herbicide sprayer consists of a web camera, ground speed sensor, nozzles and its controller and a main computer. Its details are elaborated as follows.

Main Computer and Web Camera

To reduce speed of our prototype development cycle, we decide to use a notebook computer as the main computer of our system. The notebook can be replaced with a smaller industrial embedded computing device in our future work.

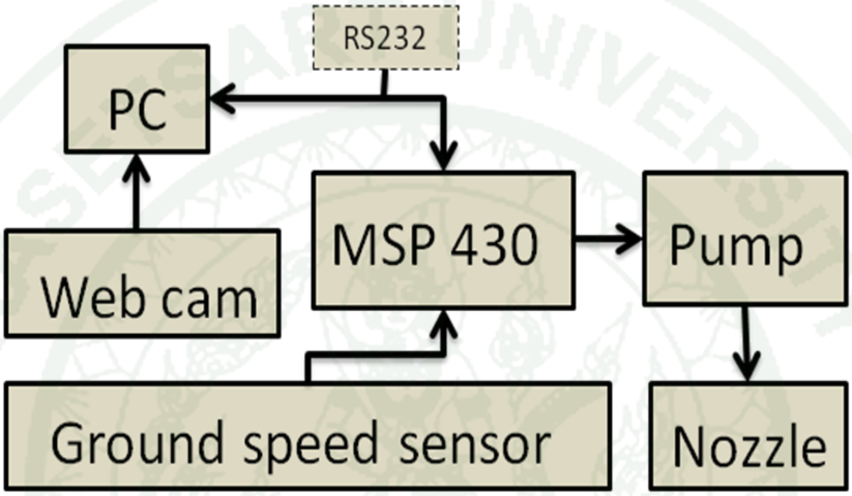


Figure 8 A block diagram of our proposed system.

The notebook is equipped with a Logitech Quick Cam Notebook Pro with Carl Zeiss Lens, web camera (Baker, 1991). The camera is attached under the chemical storage tank of nozzle, which is 71 centimeters above the ground. The captured frame area of the image is set to 70 cm × 32cm. The image resolution is 240×320 pixels. Acquiring an image is controlled by the micro-controller and the ground speed sensor. The image is captured when there is a signal from ground speed sensor. The captured images are transmitted to the notebook via a USB port as shown in Fig 8.

The transmitted image is analyzed for weed distribution map using the proposed weed detection algorithm. The algorithm is developed using Borland C++ builder program. Briefly, the algorithm reads a BMP image format and analyzes all pixels, pixel by pixel, starting from the first pixel on the left-topmost to the last pixel on the right bottommost pixel. Each pixel is classified and labeled as green or non-green. The output is measured in terms of percentage of greenness of weeds in the captured frame area (70 cm × 32 cm). The obtained information will send to MSP430 to generate the control signal for the nozzle. The flowchart diagram of the system is shown in Fig 9.

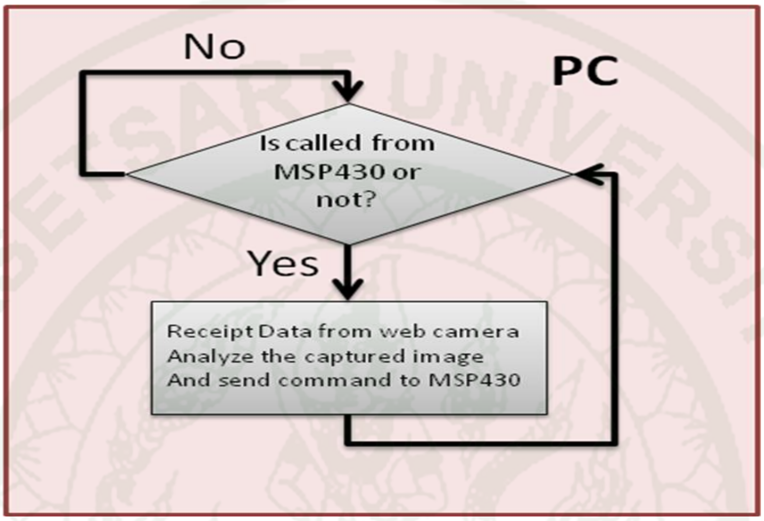


Figure 9 A flowchart of the main program.

Ground speed sensor

A ground speed sensor is a set of proximity switches attached on the strake wheel, as shown in Fig. 10. A free rolling strake wheel was arranged near one of the front wheels of the tractor as such it rotated with tractor wheel. The proximity sensor could pick up pulse signals (6 pulses per revolution) and feed to the application software loaded in the controller. The application software incorporates the speed changes and compensates the position. My program integrate an adaptive decision within in order to handle vehicle speed inconsistency. If the vehicle moves too fast, a control technique that issue 3 commands per pulse cannot response the system on time. In this case the system will automatically exploit the control technique with 1 command per pulse instead.

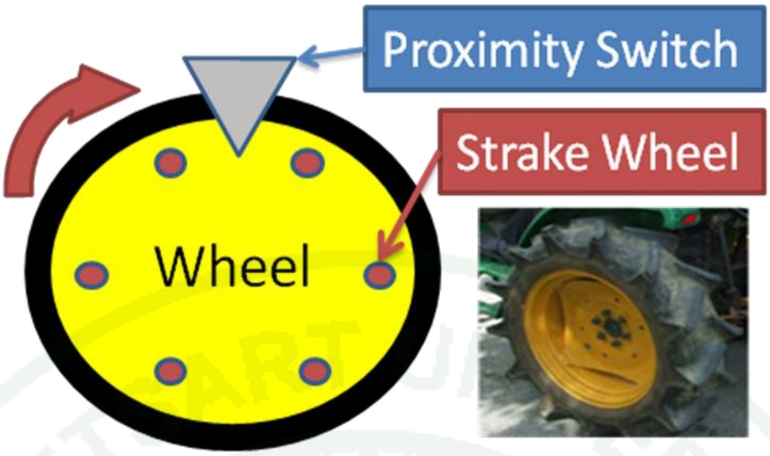


Figure 10 Ground Speed Sensor (at the wheel of the tractor).

MSP430 Controller

The MSP430 family is a microcontroller family, which is widely used among developers. This is because of it provides low-cost development tools based on JTAG-based programming and debugging in flash-based devices. The MSP430 controller handles three communication lines from the notebook, ground speed sensors and nozzle's pump.

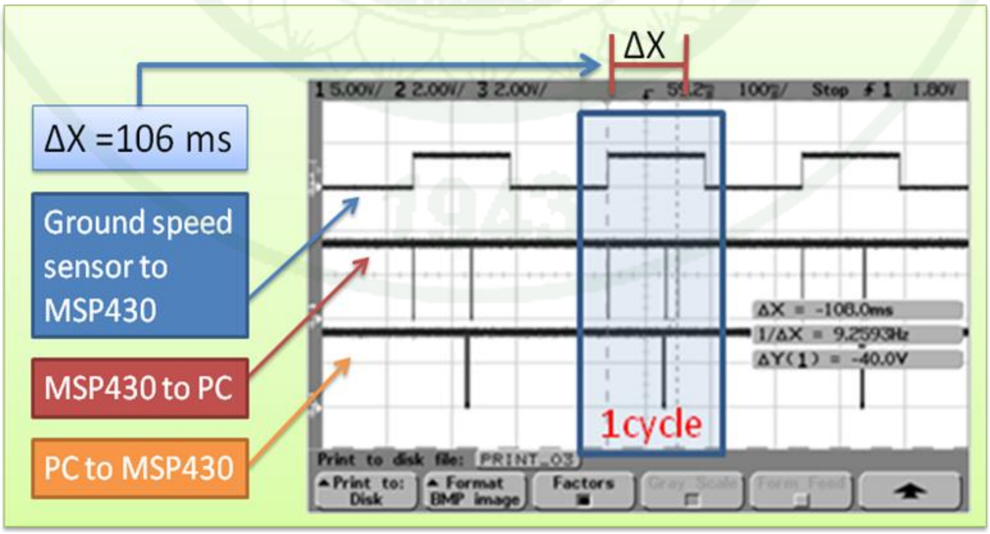


Figure 11 Timing diagram of our system.

A timing diagram of our system is shown in Fig 11. There are three lines in this figure. The top line represents a signal generated by a ground speed sensor. This signal acts as a triggering signal of a camera. Whenever the controller receives this signal, a weed image is taken by the web camera. Corresponding response signal of the MSP 430 is depicted in middle line of Fig 11. In one cycle, two signals are shown. These signals are an initial massage and an acknowledge massage. The initial massage is sent to a PC or notebook when the MSP430 receives the triggering pulse from the ground speed sensor. The acknowledge massage is send when the MSP430 successfully receives respond massage back from the PC. The bottom line represents the respond signal of the PC. The PC communicates back to MSP430 via RS232 right after processing the acquired weed image. The respond massage contains a command to communicate with the controller to set an appropriate duty cycle of pulse width modulation based on the image processing's result. The pulse width modulation circuit (PWM) in MSP430 then generates and sends the signal to the 12-volt DC electric motor to drive the nozzle's pump corresponding to the input signal.

Control's techniques

This section discusses how to make the precision control for the system. To make a quality result, we must concern relationship between the sprayer and the detection system during moving a vehicle. The detection process requires a short period of time before making decisions whether it will spray herbicides or not. Therefore, we cannot attach the web camera adjacent to the nozzle. Some spaces are required.

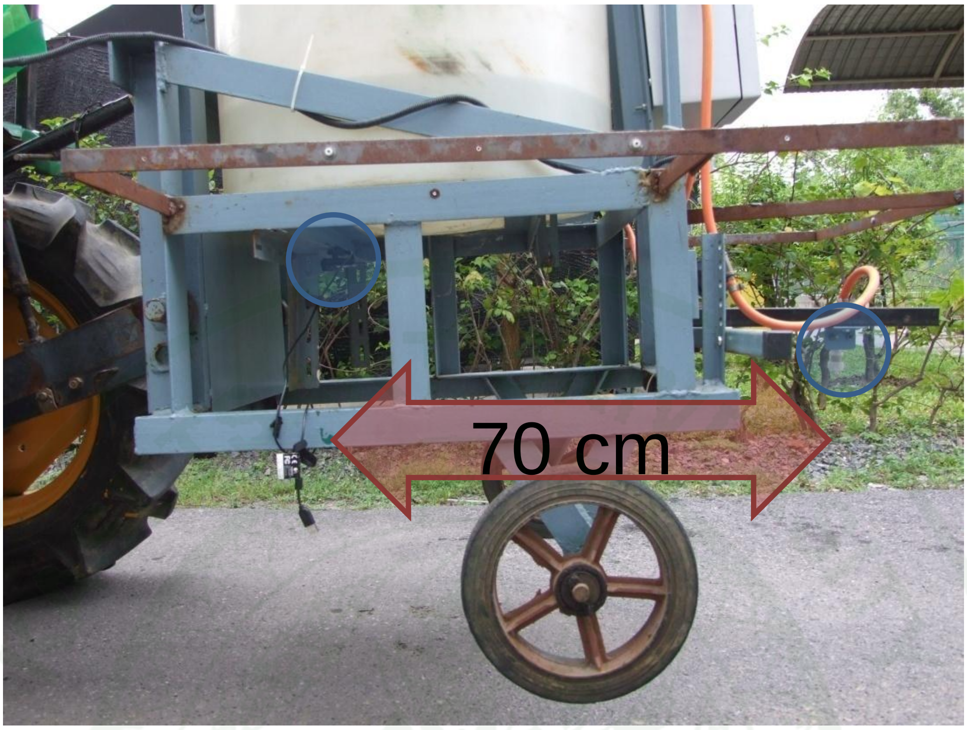


Figure 12 A 70 centimeters distant from camera to nozzle.

In this research, the nozzle is separated from the camera by 70 centimeters. Their setting is shown in Figure 12. Based on data obtained from ground speed sensor, the estimated distant of each move is approximately 35 centimeters. This means that every time the sensors pass the stake wheel, we will receive the interrupt pulse. We use this pulse as a sign to begin a process. First, we capture an input image. Second, we analyze the image and send the command according to the analysis to control nozzles. At last, we store the results. Since the system works on real-time situation, the synchronization of the captured image and the nozzles are controlled by setting proper relationship between the camera and the nozzle. We name this technique “1 pulse 1 capture 1 command”.

Figure 13 “1 pulse 1 capture 1 command”.

However, if we manage different sets of a process, it leads to a difference outcome. So we further implemented “1 pulse 3 captures 3 commands” and “1 pulse 1 capture 3 commands” control techniques. Both techniques are built to increase a command rate. In every given pulse, these techniques provide 3 commands instead 1 command. By increasing the commands with a current speed to create the predicted pulses, we can scale down the width of processing area by three times. The sprayed region of these two techniques is reduced form 35 cm. to approximately 11.67 cm.

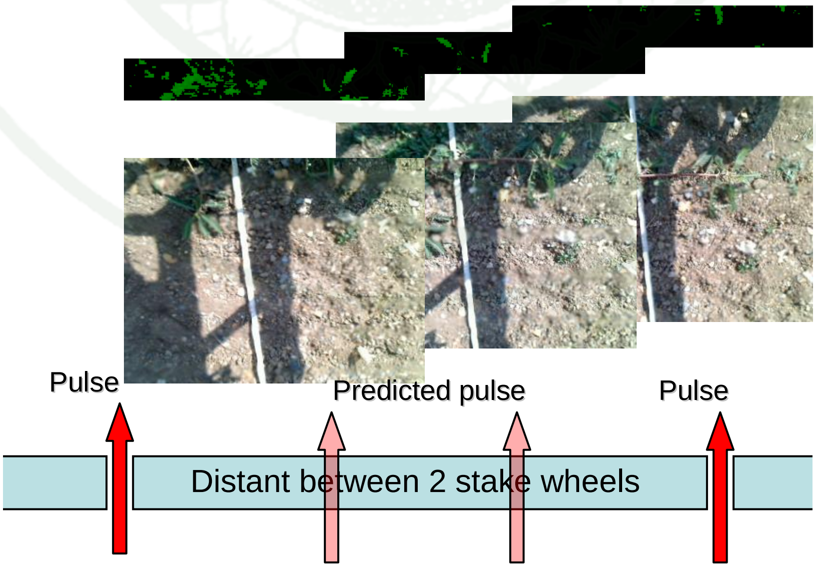


Figure 14 “1 pulse 3 captures 3 commands”.

The different of these two techniques is a number of times to capture input images. For each pulse interval, the 1 pulse 3 captures 3 commands teachnique captures field image three times as shown in Fig.14. Thus, the input images are udpated before detecting weeds in the image. Instead of capturing images three times, the 1 pulse 1 captures 3 commands teachnique captures field image only once. The image is then divided into 3 separate regions. Each region is fed to the detection algorithm for weed classification as shown in Figure 15. Since we separate the processing area into specific zones, these zones can be analyzed independently.

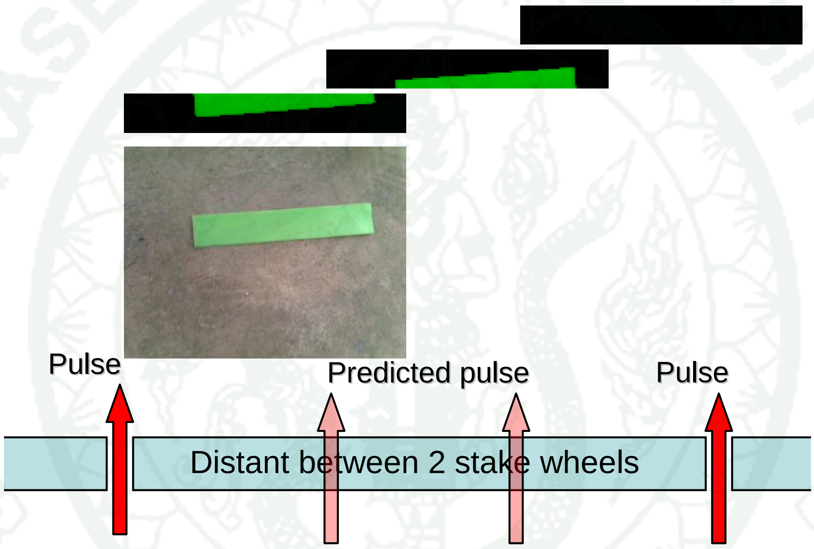


Figure 15 “1 pulse 1 capture 3 commands”.

RESULTS AND DISCUSSION

Our experiments are designed based on our system development. Two phases of experiments are conducted. The first phase is to validate our proposed weed detection algorithm including a threshold sensitivity of the OEG technique. In these phase, a set of still images taken under different lighting conditions are used in the experiments. The second phase experiment is to validate our herbicide application system. Real-time potential of the system is tested. The robustness of our system is experimented under natural lighting condition.

1. Weed Detection Part

Te goal of weed detection is to verify whether an input image has pixels belong to weeds or not. Since our research focuses on using color-based classification, a main problem is how to verify greenness by using only chromatic information. For example, giving a set of pixels: "A(R,G,B) ={149,166,112}", "B(R,G,B) = {128,131,142}", "C(R,G,B) = {208,191,165}" and "D(R,G,B) = {64,112,88}", we do not know at the first glance whether those pixels are green or not. To make decision, we can use the OEG's algorithm to analyze the information at hand. Applying the OEG to the set of given pixels results in "OEG(A) = 71", "OEG(B) = 10", "OEG(C) = 9" and "OEG(D) = 72". As we know that this algorithm provides higher OEG value to green pixels than to other color pixels. The problem becomes clearer. However, the threshold is required in order to make a decision.

In this part, we shall describe our results obtained from the OEG, NGS and a combination of the OEG and NGS. To evaluate our proposed method, the detected greens are compared with its corresponding ground-truth image. Fifty ground-truth images are manually segmented. For each image is labeled by three volunteers. Majority voting scheme is used to finalize the ground-truth image. The detection system accuracy is measured in terms of false accept rate (FAR), false reject rate (FRR) and correct segmentation rate (CSR). False accept rate (FAR) is a ratio of falsely accepted backgrounds as weeds and a total number of classified pixels. False reject rate (FRR) is a ratio of falsely rejected weeds as backgrounds and a total number of classified pixels. Correct segmentation rate is a ratio of correctly classified pixels and a total number of classified pixels.

Effects of the threshold value over the OEG algorithm

This experiment aims to study effects of chosen threshold value over the detected green pixels using the OEG algorithm. We did the experiment on a set of different threshold values. The test is conducted by giving these threshold values to the OEG equation. The experiment threshold values are 10, 20, 30 and 40. The obtained results as shown in Figure 16 illustrate effects of the chosen threshold values over the detected regions.

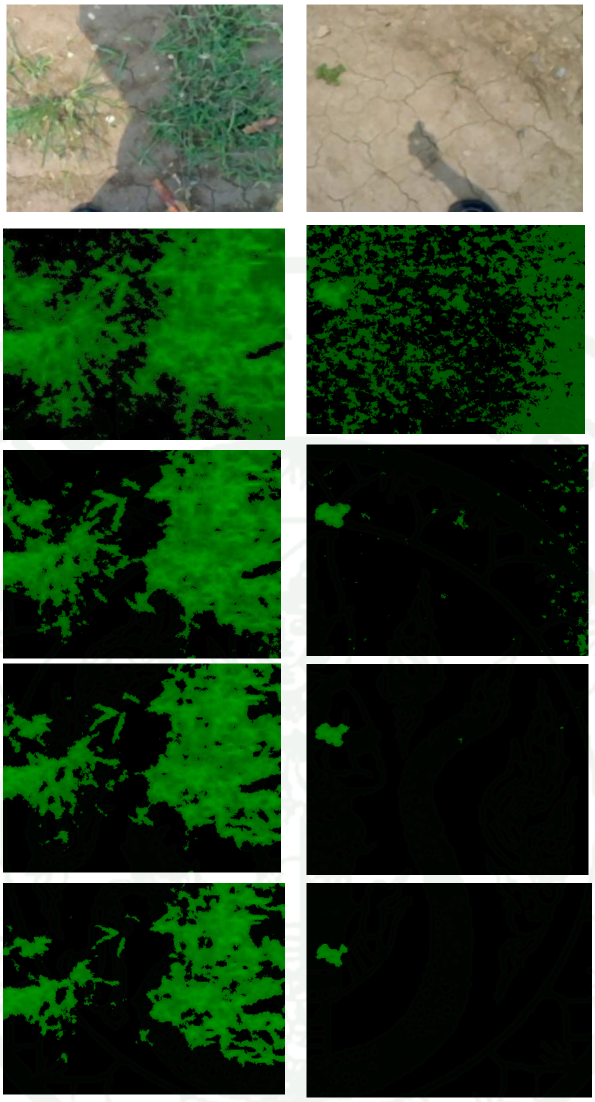


Figure 16 Results of detecting green pixels using the OEG algorithm with various threshold values.

In Figure 16, the two top pictures are input images. The following images are represented as the outcomes of OEG with different threshold values, which is indicated in the right column. Green regions are pixels that have the OEG value higher than the threshold value. The different outcome from each threshold value is put to our research study.

In each image, it appears that the best threshold value exists as a constant value. This value provides highest accuracy for color-based segmentation under the experiment setup. Then, what will happen if we give another value from the best one is put into our focus. Let assume that we use higher threshold value than the best one. With this value, the accuracy drops down due to increasing of misclassifications. By study the forms of the error, it is clearly shown that most falsely detections came from under segmentations, green pixels are considered as non-green. The research found that the outcomes of OEG from green pixels are not high enough to suppress given threshold. Those falsely segmented pixels have the OEG value less than the threshold value. This is because of the lack of chromatic information in pixel is usually caused by shadowed area of image. On the other hand, if the threshold value is lower than the best one, false detections come from over segmentations instead. These are caused from non-green pixels considered as green pixels. Some bright pixels will give the high OEG outcome due to the high value of their chromatic information. The main problem of the OEG algorithm is that it is not tolerate to bright pixels caused by natural light conditions, the environment that most effect to OEG. Most of bright pixels are detected as green if threshold value is set lower than the best one. Anyways, we cannot just increase threshold to solve this problem. As, under segmentations are occurred instead.

Table 1 System performance of the OEG

Threshold value	OEG algorithm		
	FAR (%)	FRR (%)	CSR (%)
20	2.692	0.611	94.71
25	1.66	1.163	96.83
28	1.242	1.566	97.13
29	1.127	1.705	97.16
30	1.032	1.855	97.14
35	0.662	2.619	96.85

Table 1 shows the result after perform the OEG with the set of images. This test performs on images from our database taken from the field on the dull and bright sunny days. From our experiments, the best threshold value for our database appears to be 29. However, this value may not provide best accuracy in each picture. There is no one constant value that can give the best classification result for every picture. It depends on environment of the captured image.

System performance of the NGS algorithm

We perform test on the outcome of the NGS using equation 3. The non-green pixels are labeled using an adaptive threshold value. The threshold value is adjusted based on difference values between chromatic intensity and its average value. In this thesis, the adaptive threshold is denoted as follows.

$$NGS_{th} = 9*|M-G| - 0.8*|M-B| - 0.8*|M-R|, \quad (4)$$

where R, G and B are red, blue and green intensity level of an image, respectively. M is an average value of the R, G and B values.

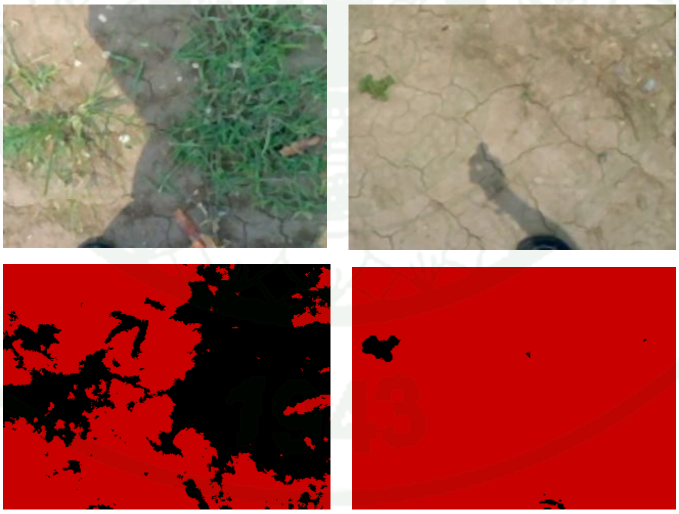


Figure 17 Results of applying the NGS to the images.

After putting this threshold to the NGS algorithm, the method gives outcomes as shown in Fig17. The two-top pictures are input images. Red region are the pixels that give outcome of the NGS higher than the adaptive threshold value (NGS_{th}).

The NGS algorithm is introduced to handle effects of natural light conditions. The bright pixel is considered as white or gray color via human's eyes. So we form the equation that can detect those kinds of color. We found that the balance of color information; red, blue and green, are our important keys. After building and testing the NGS algorithm, the results show that non-color information is mostly removed from the image. These also include the black color of soils too as shown in Fig16.

Table 2 System performance of the NGS×OEG

Threshold value	OEG algorithm		
	FAR (%)	FRR (%)	CSR (%)
20	0.894	1.567	97.5
25	0.869	1.684	97.44
28	0.822	1.855	97.35
29	0.799	1.933	97.31
30	0.774	2.029	97.26
35	0.598	2.658	96.86

Table 2 shows the result after perform NGS×OEG with the set of images. This test performs on images from our database. In this experiment, the best threshold value for our database appears to be 20. However, the FAR is dropped in every threshold value while the FRR is increased. Combining the NGS with OEG causes the CSR less sensitive to changes of the threshold value. Fig 5d and Fig6d, shown in method part, are good examples of the NGS×OEG performance.

Comparison between the proposed algorithm, the NGS with OEG and the OEG

At last, to compare efficiency between the NGS×OEG and the OEG algorithm, the result is the list of corrective classification shown in table3.

Table 3 System performance of the OEG and NGS×OEG with various threshold Values.

Threshold value	NGSxOEG			OEG		
	FAR (%)	FRR (%)	CSR (%)	FAR (%)	FRR (%)	CSR (%)
20	0.894	1.567	97.5	2.692	0.611	94.71
25	0.869	1.684	97.44	1.66	1.163	96.83
28	0.822	1.855	97.35	1.242	1.566	97.13
29	0.799	1.933	97.31	1.127	1.705	97.16
30	0.774	2.029	97.26	1.032	1.855	97.14
35	0.598	2.658	96.86	0.662	2.619	96.85

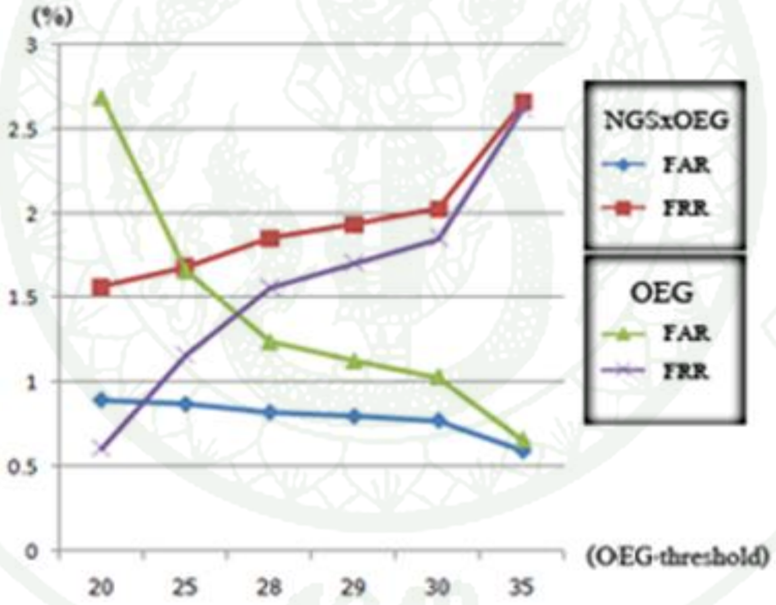


Figure 18 Error distribution curve of the OEG and the proposed NGS×OEG method.

After plotting the obtained FAR and FRR, Fig18 is created. This fig shows the relationship between errors corresponding to the given threshold. From our experiments, Table3, threshold value of 29 yields the best overall correct segmentation rate for the OEG. Each thresholds affect both FAR and FRR. Those two values run in opposite direction; increasing FRR decreasing FAR and vice versa.

From the obtained graph shown in Fig18, it is clearly seen that our purposed system is less sensitive to changes of the chosen threshold value.

System performance of the OEG and the proposed method, NGS×OEG, are equivalent for high distributed weed images. Because most of bright pixels tend to came from weed pixels in our experiment. With this, an effect from considering bright pixels as green becomes less effect. Sometime this analysis even gives a correct detection to some whites, very bright pixels, over weeds. However, in the low distributed weed images, the proposed method is outperformed the OEG in terms of FAR and correct segmentation rate. Especially at threshold 20, the FAR is reduced from 2.692% to 0.894%, as shown in Table 3. Additionally, our proposed method has less over-segmentation problem with the after raining images comparing to the result obtained using the OEG. Therefore, the proposed method is more effective in handling large ranges of soil intensity.

Our major errors occur nearby boundary pixels of weeds. These boundary pixels are hardly classified even when doing it manually as shown in Fig19. Human eyes can distinguish weeds from the background better since both color and shape information are used. The shape analysis is excluded from our proposed method due to limitations of computational resources of embedded device and real-time processing requirement.

Figure 19 Resolution and boundary**.**

2. Controller Part

After finish experiment for weed detection part, the prototype of our proposed system, as describe in method section, is built and tested. In this part, we shall describe the experiment that we conducted to measure accuracy and limitations of the proposed system.

The result from the detection part is submitted to controller part. This part is decided whether the controller is spray or not. If the weed is detected over specific threshold value, the controller will send the ON-command to spray the herbicide substances. Thus, the command is created by analyzing an input image as shown in Figure 20.

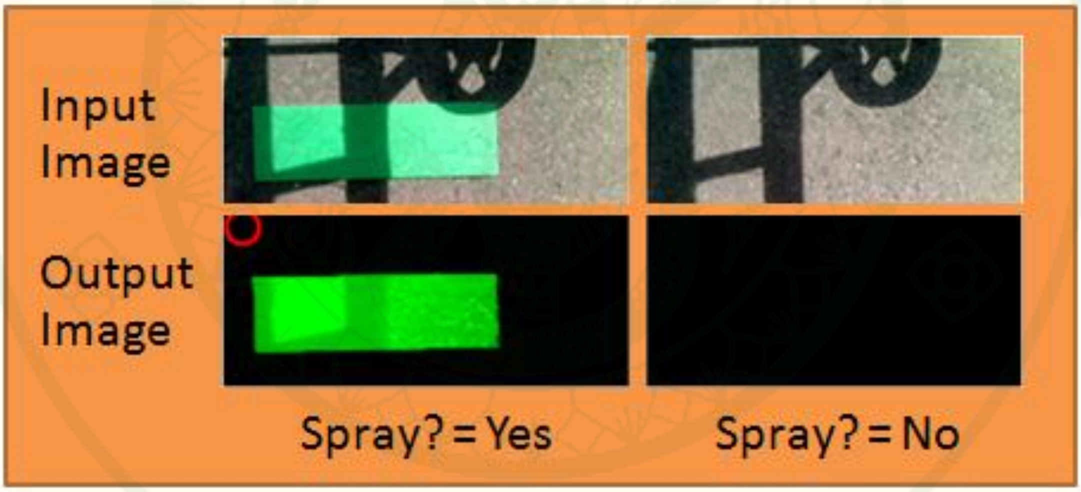


Figure 20 Vision of the proposed system.

The output image came from applying NGS×OEG to the input image. From the detected image, you can basically decide which is to spray or not by counting amount of detected green pixels. In this project, the nozzle is spray with a constant amount of herbicides whenever the greens are detected by the system. This system was attached on a moving tractor. To conduct a conceptual test before moving to a real field, rectangle green plastic plates are used to represent weeds in a field. Placing positions of the patches are shown in the left side of Fig21. During the test, the tractor moves at constant speed of 0.7 m/s. Examples of the obtained sprayed areas are shown in right side of Figure 21.

Figure 21 Before and after testing the system.

The system hit accuracy is visually evaluated by comparing captured input images with its corresponding results. Fig 20 shows examples of the captured input images and its corresponding output images. From our experiments, all green patches are detected correctly. However, the sprayed area can be twice larger than typical sprayed area as shown in Fig 21. The extended area usually happens when the camera captures a single green patch partially. In Figure 22, the system considers this small green block as a found weed and spays the entire block.

Figure 22 Reason for large area of sprayer, 2 blocks with 70 centimeter.

The control technique used in the proposed system is the key to do precision spraying. The normal technique, "1 pulse 1 capture 1 command", has resolution equal to 35 cm per command. This means shortest sprayer area is given to 35 cm.

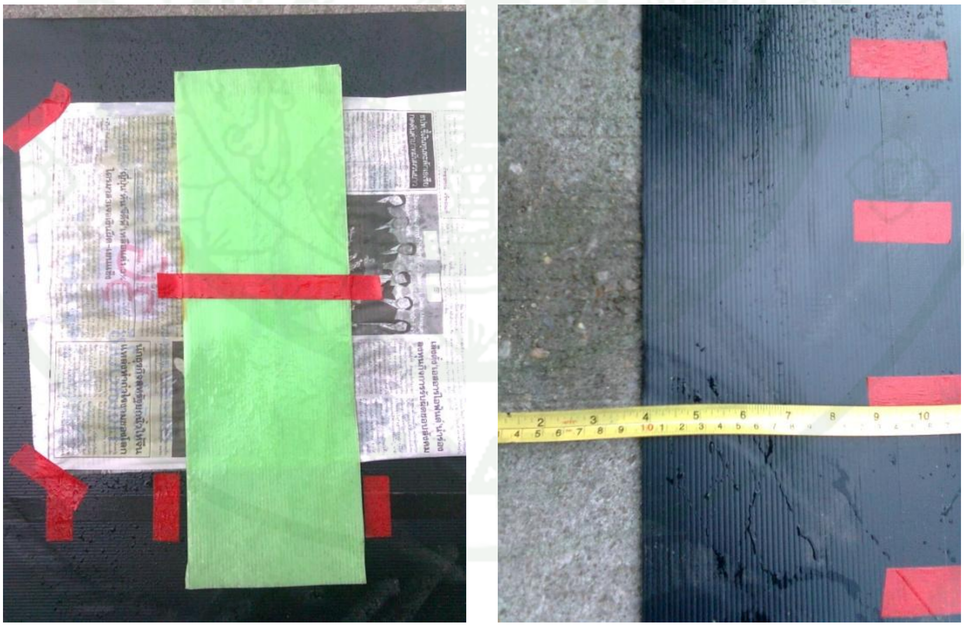


Figure 23 The sprayed area for "3 commands per 1 pulse".

To provide better sprayed area resolution, we developed new sprayer system. We focus on how to reduce resolution of the applicator so that we can maximize precision to the system. By increasing a number of commands from one command per pulse to three commands per pulse, the result is shown in Fig23. Processed area reduces three times compared to the normal technique. The sprayed area reduced from 35 to 11.67 centimeters. If give one pulse to this technique, It provides a reduced area as shown in the right side of Figure 23. The left side image of Figure 23 indicates sprayed area of the 3 commands per 1 pulse technique over the green patch. The result indicates that the over-sprayed area is less comparing to the over-sprayed area in Figure 22.This is done by increasing commands to three commands per pulse, instead one command per pulse. With this technique, the shortest sprayed area is reduced to 11.67 cm. Anyway, this technique requires a constant speed to create a sync command.

From our experimental results, the weed detection algorithm takes the longest processing time. The whole processing time, excluding the spraying time, is about 106 milliseconds or less as shown in Figure 11. The results indicate that our weed detection algorithm is fast. The system is feasible for developing a real-time herbicide applicator system.

We tested limitations of the system's sprayer by sending high frequency commands as high as possible to the nozzles. We conducted this test two times with difference conditions. In first experiment, we tested by giving a short pulse for OFF-command among the long pulse for ON-command to the system as shown in left side of Figure 24. Then, we gave a short pulse for ON-command among the long pulse for OFF-command to the system as shown in right side of Figure 24.

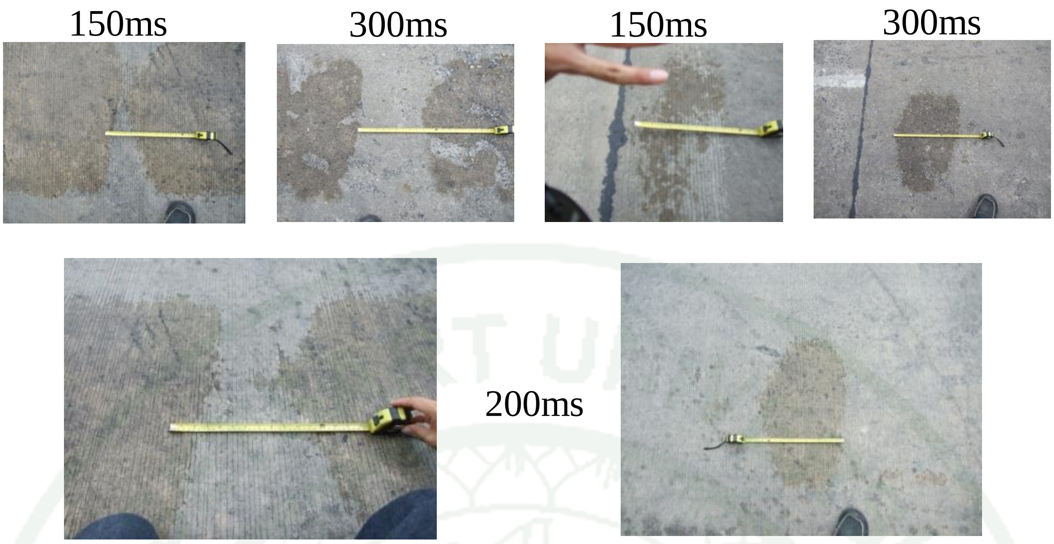


Figure 24 The sprayed area at different pulse width duty cycles.

The goal of this test is to find the shortest time that the system can still provide the acceptable spraying result. The key's parameter of these experiments is how much time we provide to short pulse. Starting with 300 milliseconds, the system can provide the experiment to the clear OFF and ON command. The system also works correctly with the ON and OFF command sequence. Then, we lower the time duration given to the short pulse. The results indicate that the feasible shortest pulse width command is at 200 milliseconds. Otherwise, if the pulse width is lower than that, the result will be ruined instead as shown at 150 milliseconds in Figure 24.

2. Practical Field

This section presents results of testing our proposed systems on a practical field. Our practical field is a pavement shown in Figure 25. The field compounds soil and weeds, represent by small living greens shown in the right side of Figure 25.

Figure 25 Our practical field.

This part is the hardest part in our thesis. Capturing images of living plants under natural light condition while moving around the field are tough. Our web camera work very hard to process light balance and focus every moving frame. Due to this, quality of the capture images drop down and unstable. We have to re-do the experiment setup before running on the field. Initialize the constant threshold to cover overall environment is merely impossible.

This experiment is conducted in order to test the accuracy of the proposed system. This experiment is done by moving the herbicide applicator, the vehicle that attached with our systems, to practical field. During process, our systems sprayed a liquid to the suspected green. The accuracy is measured by comparing a spraying distance to the distance of the weed. Before starting the test, the longest length of all green patches along the moving direction in the field is measured as shown in Figure 26. This measure is set as a ground truth for our experiments and it is represent by the red line in Figure 27. The blue, green and brown lines are distance measurement obtained from running the 1 pulse 1 capture 1 command, 1 pulse 3 captures 3 commands and 1 pulse 1 capture 3commands over the same field test, respectively.

Figure 26 Length considered as ground zero.

Figure 27 Sample line of the experimenter's result.

Table 4 Performance of the propose technique on practical field-1.

Control's Technique	DAY1		DAY2	
	CSR (%)	OSR (%)	CSR (%)	OSR (%)
1pulse 1capture 1command	87.12737	42.72536	28.60169	57.52217
1pulse 3capture 3command	84.34959	24.67221	79.13136	39.36513
1pulse 1capture 3command	78.45528	36.09272	66.10169	18.32461

Accuracy is measured in terms of corrected spray rate (CSR) and over spray rate (OSR) rate. CSR is measured by length of wet weed area, plant that had been correctly sprayed by our system, divided by length of all weed area. OSR is measured by length of wet soil area, soil that had been sprayed by our system, divided by length of all sprayed area. We also conduct the same experiment using same threshold values in other days. This test is to check whether one initialization is enough or not. The result is shown in Table 4.

Table 5 Performance of the propose technique on practical field-2.

Control's Technique	GDR (%)	
	Day1	Day2
1pulse 1capture 1command	84.38	37.50
1pulse 3capture 3command	93.75	84.38
1pulse 1capture 3command	87.50	75.00

In our experiment field, we have eight groups of weeds. Group Detected Rate (GDR) is a ratio between a number of weed's group that our system reacts to their existence and a number of all grouped weed. The result is shown in Table 5.

In Day1, we run the experiment and record the data as shown in Table4 and Table 5. "1pluse 1command" provide highest CSR. However, it also provides highest OSR and least in GDR. Both "1pulse 3captures 3commands" and "1pulse 1capture 3commands" give little bit lower in CSR, compared to "1pulse 1 command". But those give half in OSR and better in GDR compared to "1pulse 1 command". In Day2, the environment is different form Day1. This day is much warmer than the first day, lighten light. The results become worst in every measured value. This shows that our system still not good enough in experiment field without initializing threshold parameter for each usage.

Table 6 Performance of the propose technique on practical field-3.

Control's Technique	DAY3	
	CSR (%)	OSR (%)
1pulse 1capture 1command	53.8354	14.8902
1pulse 3capture 3command	78.8006	21.7981
1pulse 1capture 3command	65.3417	15.1919

From the result in Day1 and Day2, we study more about the system environment. Since 3 command's techniques always reach the limit of vehicle speed, we always put adaptive in case they reach the limitation of our system, 300 msec in our previous experiment. Whenever it reach the system limitation, the system automatically go back to 1 pulse 1command technique. In Day3, the adaptive part is removed. To guarantee the performance of the system, we run the experiment with the extra slow speed, around 0.3 meters per second in Day3. The result is shown in Table6. It seems that there are much different to our previous experiments. Performing analysis over the obtained results is very difficult as several parameters are varied during the test. For example, greenness of some weeds are fade naturally after running several tests. This is due to damages caused by running a heavy tractor over them. For better analysis, experiments of the three control techniques should be set with green patches put on the practical soil field. This is to ensure each control technique’s performance.

CONCLUSION AND RECOMMENDATION

Conclusion

In this thesis, a new color-based weed detection using machine vision is developed. The detection scheme is designed to compensate effects of illumination variations. The proposed method is fast and suitable to use in limited resources device such as in embedded system. The proposed method is also feasible for future real-time application.

Background component of an input image is segmented using the proposed Non-Green Subtraction (NGS) technique. The NGS segregates an image into two classes, which are background and non-background. The non-background is further segmented into weed and non-weed pixels using Over Excessive Green (OEG) technique. The experimental results indicate significant improvement on the false accepted rate and overall correct segmentation rate, especially with sparse weed images comparing to the results obtained using only the OEG technique.

Furthermore, the prototype system of a real-time precision herbicide applicator aimed to use over between rows in sugarcane field is developed and tested. A notebook interfaces with a web camera to capture an image. A fast color-based weed detection based on Non Green Subtraction and the Over Excessive Green techniques is used to detect weeds in the image. The detected signal is interfaced with a micro-controller MSP430 to control a pulse width modulation for appropriate herbicide spraying.

Our experiments inspect a feasible processing time of our system. The system requires at maximum 106 msec. of processing time including capturing an input image, weed detection and pulse width modulation control. The results indicate real-time processing capability. It is also shown feasibility of adapting our prototype to full embedded system configuration. Furthermore, the NGS weed detection technique is very robust under natural light condition. The system requires no assistant light diffuser. It can be easily attached to any moving vehicle without considering shadow caused from the vehicle.

The control's technique is also important to our systems. Different techniques provide different results. Our experiment showed the best result at "1 pulse 3 captures 3 commands".

Recommendation

1. The quality of the input pictures has a direct effect to the detection system. Therefore appropriate camera is required. Especially the appropriate lens was needed to be considered.

2. The detection system and sprayer system require an adequate location adjustment for their best processing result. Setting a proper distance between the camera and the nozzles is very important issue as it can generate subsequent problems.

3. One way to handle problems caused from mis-setting a proper distant mentioned in 2 is enlarging the captured area of the camera. A ratio of the captured area and the sprayed area should be higher than one. This will help misalignment problem during running a field test. This misalignment is caused from the speed sensor or initial parameter adjustment. The more ratios, the more robustness of the system will be. However, the spayed area will be even larger.

LITERATURE CITED

Baker.L., 1991. A History of the Photographic Lens by Rudolf , Optics and Lasers in Engineering, vol. 14, issue 1, pp. 55-56, doi: 10.1016/0143-8166(91)90038-U.

David R. Shaw, 2005. Remote sensing and site-specific weed management. Frontiers in Ecology and the Environment: Vol. 3, No. 10, pp. 526-532, doi: 10.1890/1540-9295(2005)003[0526:RSASWM]2.0.CO;2 .

D.C. Slaughter, D.K. Giles, D. Downey, 2007. Autonomous robotic weedcontrol systems: A review. computers and electronics in agriculture 6 1 (20 0 8) 63–78. doi:10.1016/j.compag.2007.05.008

Gajendra Singh and K.A.R. Abeygoodwardana, 1982. Computer Simulation of Mechanical Harvesting and Transporting of Sugarcane in Thailand. Agricultural Systems, 8: 105-114. doi:10.1016/0308-521X(82)90059-2.

Meyer, G.E., J.C. Neto, D.D. Jones and T.W. Hindman, 2004. Intensified fuzzy clusters for classifying plant, soil and residue regions of interest from color images. Comput. Elect. Agric., 42: 161-180. doi:10.1016/j.compag.2003.08.002

Naeem, A.M., I. Ahmad, M. Islam and S. Nawaz, 2007. Weed classification using angular cross sectional intensities for real-time selective herbicide applications. Proceedings of the International Conference on Computing: Theory and Applications, (ICCTA'07), Kolkata, India. IEEE Computer Society 2007, 731-736. doi: 10.1109/ICCTA.2007.132.

R. Tangwongkit, V. Salokhe, H. Jayasuriya. ―Development of a Tractor Mounted Real-time, Variable Rate Herbicide Applicator for Sugarcane Planting‖. Agricultural Engineering International: the CIGR Ejournal. Manuscript PM 06 009. Vol. VIII. June, 2006.

Zhang, N., N. Wang, J. Wei and Q.A. Stoll, 2002. Real-time, embedded, weed-detection and spray control system. Comput. Elect. Agric., 36: 113-132. doi:10.1016/S0168-1699(02)00096-0.

CIRRICULUM VITAE

NAME : Mr. Apimuk Muangkasem

BIRTH DATE : February 25, 1987

BIRTH PLACE : Bangkok, Thailand

EDUCATION :

YEAR	INSTITUTE	DEGREE/DIPLOMA
2008	Kasetsart Univ.	B.Eng. (Electrical Engineering)
2010	Kasetsart Univ.	M.Eng. (Information and Communication Technology for Embedded Systems)

POSITION/TITLE : -

WORK PLACE : -

SCHOLARSHIP/AWARDS : TAIST ICTES Master Degree Scholarship