Development of a Real-time, Variable Rate Herbicide Applicator Using Machine Vision for Between-row Weeding of Sugarcane Fields

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ABSTRACT

A tractor mounted site-specific, real time herbicide applicator was developed for variable rate herbicide application between sugarcane rows. Using the software based machine vision system, the picture frames captured by the web camera were processed and the quantified greenness level due to weeds was used to actuate the controllers of a sprayer pump system. The pulse width modulation (PWM) drive motor speed control was correlated with the percentage of greenness to vary the application flow rate by adjusting the duty level of PWM motor. The software developed could be reprogrammed and the threshold levels could be adjusted according to the user preference. At five operation speeds tested, the prototype could spray on green targets correctly. The error of green color output from image processing was about 0.31% at SD ±0.25. The application flow rate accuracy was about 91.7%. The laboratory performance evolution revealed that this variable rate method could be used to decrease the herbicide quantity by 20.6%.

Keywords: Variable rate applicator, herbicides, machine vision, pulse width modulation, greenness, threshold level

1. INTRODUCTION

Sugarcane is one of the major cash crops in many countries around the world, including Thailand. Thailand has the suitable climate for cane cultivation but suffers some limitations, such as high production costs, lack of soil management, scarcity of good seed varieties, poorly controlled spread of pests, weeds, and lack of suitable technology at each step of production (Department of Agriculture, 2003). At present, Thai cane growers are facing problems of high production costs and low yields, one of the main causes of which is inefficient weed control.

Precision agriculture offers the promise of increasing productivity, decreasing production cost with optimum use of resources and minimizing the environmental impact (National Research Council, 1997). This technology mainly benefits from the emergence and convergence of several technologies, including the Global Positioning System (GPS), and incorporating the computer software interface component of database, mapping and interpretation with Geographic Information System (GIS) (Gibbon, 2001). Different stages of variability can be achieved by two approaches; the map-based approach and the sensor-based approach. Sensor-based approach, which is used in this research, allows less dependency on positioning devices, an advantage over map-based approach with higher position accuracy and real-time application (Zhang et al., 2002).

With the advancement of computer technology, machine-vision systems have become a possible solution for weed and seed identification (Graniatto et al., 2002). The machine vision system color capability requires four data elements, one each at the red (R), green (G), and blue (B) wavelengths with the corresponding luminous level (L). The production of color on a monitor is achieved by energizing the three components in a manner to produce the resultant color. In color image processing algorithm, the L has an important role as it helps deciding the edge of different segments. In indoor applications, such as automated inspection systems the use of artificial light with constant intensity can solve the problem (Gunasekaran, 1996; Brosnan and Sun, 2004). However, under natural light condition, mathematical segmentation and edge enhancement technique such as averaging, digital filtering, Laplacian edge enhancement, Robert's gradient, Sobel edge detector operator etc. with set threshold operator need to be employed (Galbiati, 1990; Sonka et al., 1999).

Further in image acquisition under natural light condition, and with moving objects a video sequencing and frame grabbing steps needed to be added in the algorithm. The shadow created needs to be recognized (Nicolas and Pinel, 2006). Zhang et al. (2002) used a black skirt surrounding the weed sensor to cover the sensing area with three 50 W light bulbs in each sector for illumination. This system was tested during night. Bulanon et al. (2003) developed a machine vision algorithm for an apple-harvesting robot by using a color CCD camera under natural light condition. Two color models; Luminance Color Difference Model (LCD) and Hue Saturation Intensity (HIS), were used to analyze the sampled pixels (Gonzalez, 1992). As the red is the dominant color of apples, the luminance was compared with the color difference of red, to determine the color properties differential of red.

In the context of machine-vision application in variable rate herbicide application Carrara et al. (2004) designed a system which consisted of a differential global positioning system (DGPS), a portable computer, specifically developed software and an actuation device for applying rate proportionally related to the machine forward speed.

A spraying system for spatially differentiated herbicide application requires a novel hydraulic arrangement controlled by a sophisticated electronic control system (Paice et al., 1995; Stafford and Miller, 1993). The classic technique for controlling the nozzle discharge rate is to regulate the pressure drop across the nozzle. However, this type of pressure-based flow control system has at least three undesirable effects, i.e., slow system response, limited flow control range, and poor nozzle performance (Giles et al., 1996). To overcome these problems, a new technique, called pulse-width modulation (PWM) flow control, was developed for flow rate control with conventional agricultural spray nozzles (Giles and Comino, 1989; 1990). Hans et al. (2000) used the correlations; to estimate the calculated flow rate, and the relative error to conduct flow rate calibration for solenoid operated sprayer nozzles. They developed characteristics curves of PWM settings for nozzle operations.

This paper presents the application of machine vision for the development of a variable rate applicator mounted on a small 4-wheeled tractor for weed control in sugarcane fields of Thailand. No prior research evidences were found on such applications considered in this research.

2. MATERIALS AND METHODS

2.1 General Concept

Practically, sugarcane is grown in rows in Thailand with spacing of 150 cm. A small tractor mounted sprayer of track width 1.10 m can easily be used to apply herbicide between sugarcane rows (Fig. 1).

In this study, all vegetation which grows between sugarcane rows were regarded as weeds. The captured image frames during sprayer passes were processed in order to estimate the percentage of greenness and were correlated with the quantity of weeds. As shown in Fig. 2, the intensity of green color was classified into 4 levels which were used to control the flow rate of spray nozzles. .

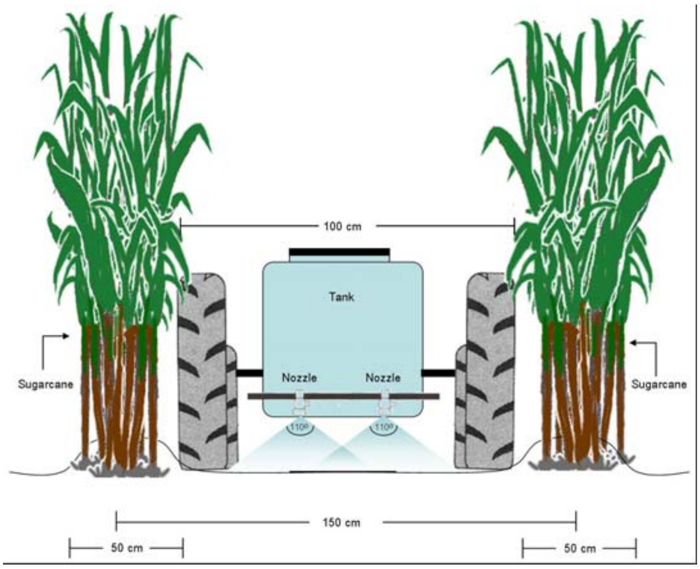

Figure 1. The site-specific real-time herbicide applicator developed for use between rows of sugarcane

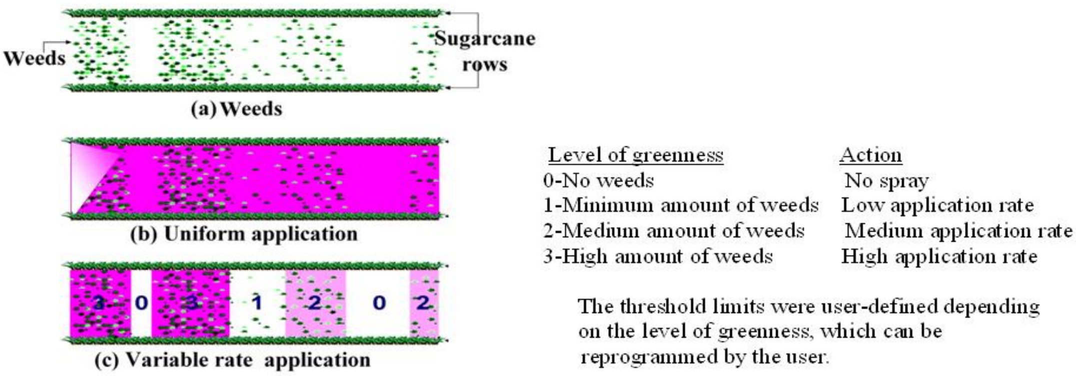

Figure 2. a) Weed pattern in a field, and comparison of (b) uniform spraying as per the conventional method and (c) variable rate application as per the weed density

2.2 System Components

The major components of the application system include (Fig. 3)

A. Image acquisition and processing system: Picture frames captured by the web camera (Pixel; VGA format 640x480, Resolution; 640x480 (VGA), 30fps@352x288 and image format; RGB24) were sent to the data acquisition system through USB port, processed by Borland C++ builder program. The algorithm was to read a BMP format and to analyze all pixels, pixel by pixel starting from the first to the last. Each pixel was evaluated whether it is green or not. The decision was made by comparing R, G, and B with R^{th}, G^{th}, and B^{th} so the result to recognize greenness. After the analysis of all the pixels, the overall Green Pixel threshold level could be estimated based on the calibration. The processed output was in terms of percentage of greenness of weed in the capture frame area (84 cm x 62 cm) and it appeared on the active window. This processed information then activated the mechatronic system.

B. Mechatronic system: PWM circuit and output signal; an 8-bit signal passed through parallel port is acquired and processed for the percentage of greenness, and sending signals to control the speed of 12-volt DC electric motor of the pump to apply set level of herbicide application.

C. Ground speed monitoring system: As shown in Fig. 4, 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 per revolution) and feed to the application software. The application software incorporated the speed changes and compensates the position and rate inaccuracies in the system.

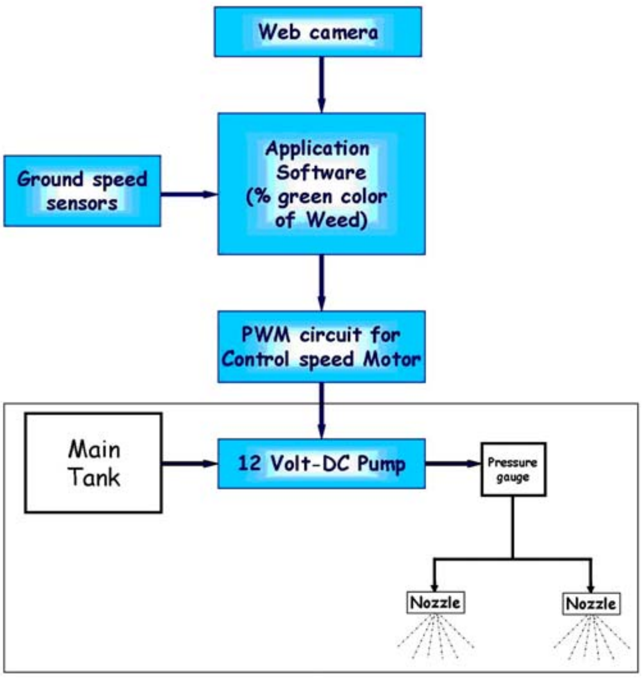

Figure 3. System block diagram of the site-specific herbicide applicator

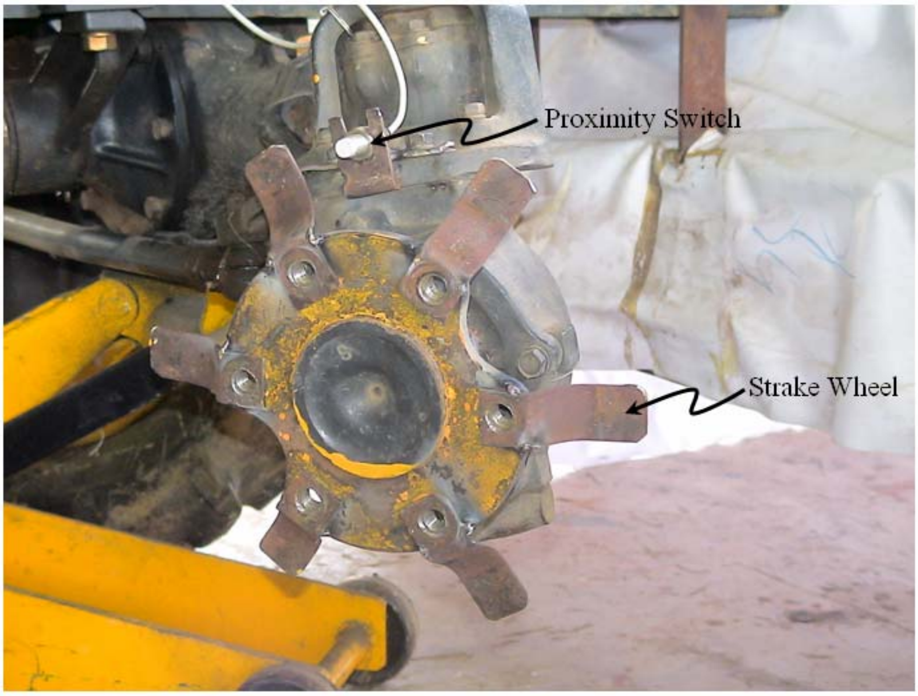

Figure 4. Strake wheel and proximity pick-up used for ground speed compensation

D. Mounting frames and accessories, and the tractor: A 21 kW 4-wheel, 2-wheel-drive tractor of 1.10-meter track-width was used to mount the variable rate sprayer designed for herbicide application in sugarcane fields.

2.3 Application Software

Figure 5 shows the front-end window of the developed software using Borland C^{++} builder program. The application software could be programmed and set to perform following functions:

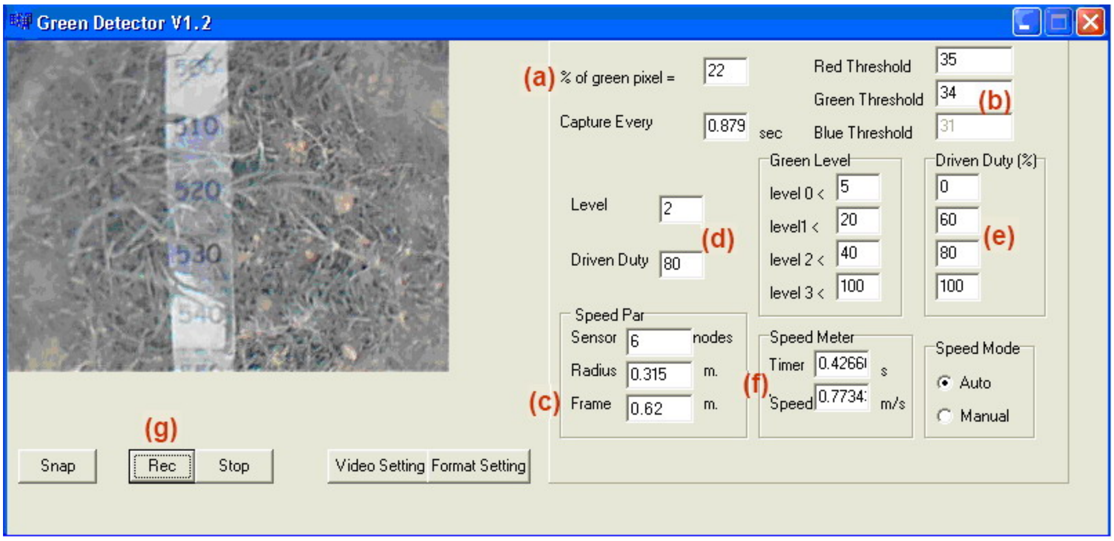

Figure 5. Front-end window of the variable rate application software

To sort green color pixels from web camera images and process output in terms of percentage of green color (Fig. 5a) in which the user can adjust red-green-blue threshold levels suitably for controlled natural light at the time (Fig. 5b). The shadow effect, the natural light luminance control and the uniform distribution of light luminance over the shading area was done by using a white plastic cover structure mounted over the inspection area in front of the tractor as shown in Fig. 6. Size of the capture frame (width X length) was measured and set up in the software program before the operation (Fig. 5c).

The user has an option to adjust the four green color percentage levels for operation (Fig. 5d). Changing percentage level of green color and PWM duty cycle (%) can maneuver the threshold (Fig. 5e), e.g.

0 - 5%	→ no weed	→ no spray
5.1 - 20%	→ minimum amount of weed	→ low application rate
20.1 - 40%	→ medium amount of weed	→ medium application rate
40.1 -100%	→ high amount of weed	→ high application rate

To record the working speed automatically through the ground speed sensor (Fig. 5f), software can be programmed for manual or automatic recording (Fig. 5g) the capture frame when the prototype is on calibration or actual operation in the field.

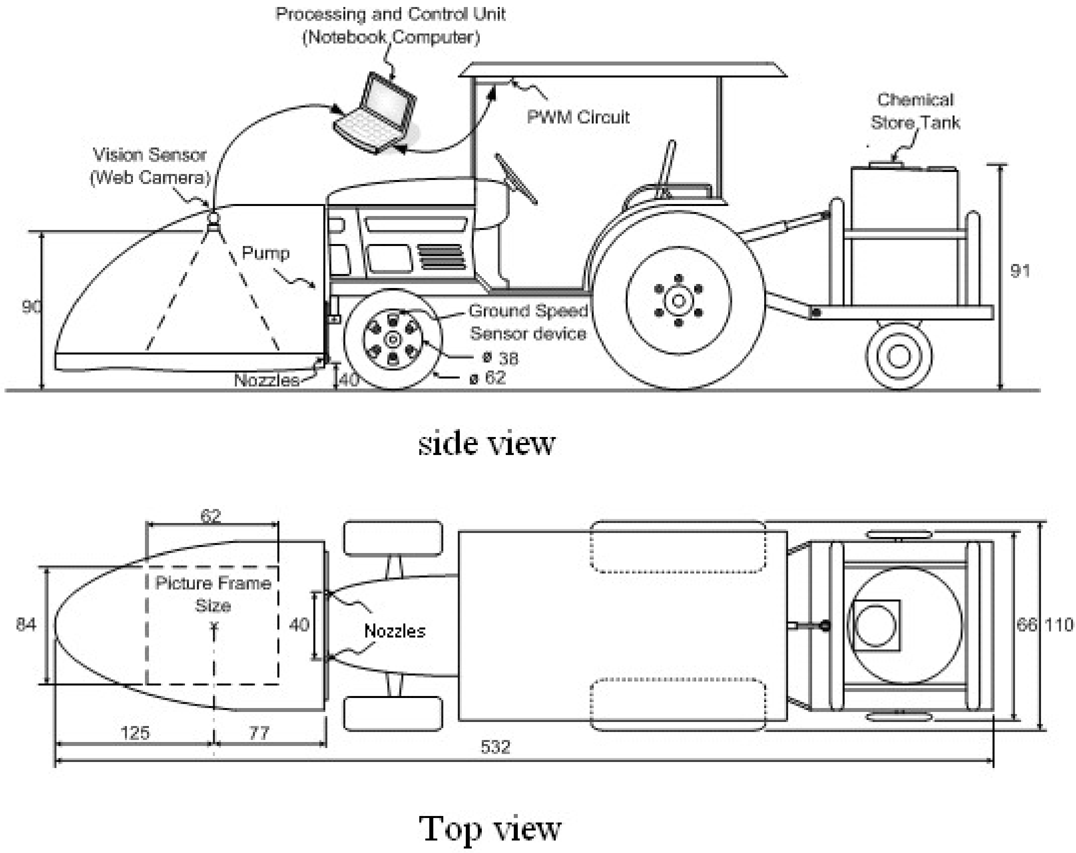

Figure 6. Schematic of a variable rate applicator system (all dimensions in cm)

2.4 Test Procedure and Calibrations for the Software Settings

Figure 7 illustrates the performance evaluation tests conducted for obtaining standard indicators; relative error of percentage greenness from the software, correlation between percentage PWM duty cycle and application flow rate, accuracy of position and flow rate during the test runs with selected forward speed settings.

The prototype variable rate sprayer system was mounted on a tractor (Fig. 6). The various components of this sprayer were a wheel speed sensor, PWM circuit, web camera and controller (notebook computer), white plastic cover structure for light control, spray-boom with height adjustable two fan type nozzles arranged on an adjustable 75 cm spacing, a 100-liter capacity tank, 2-support wheels for the rear frame, and a 12-volt DC electrical pump having maximum flow rate 3.785 l/min at an operating pressure of 275.8 kPa.

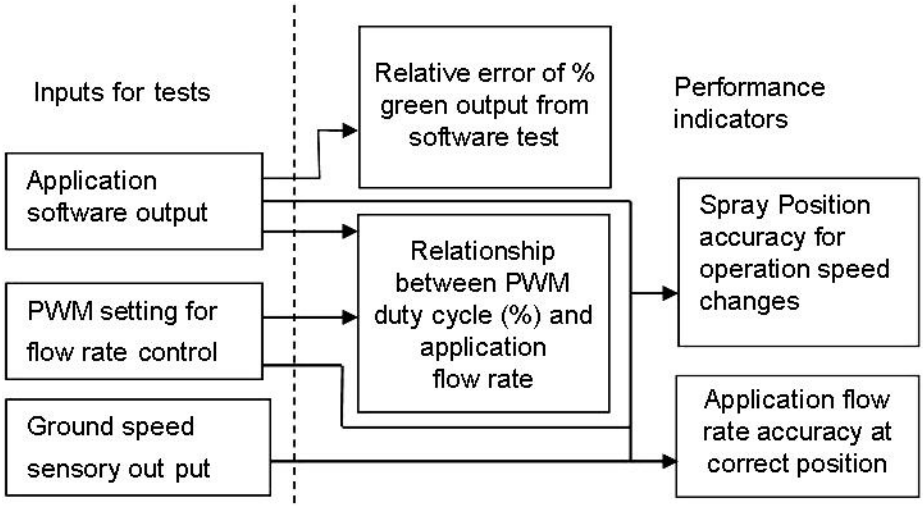

Figure 7. Tests considered for the performance evaluation

The performance evaluation of the prototype was conducted to find the relationship between application rate and percentage PWM duty cycle, the results were used for setting up the software program. At PWM duty cycle of 50, 70 and 90%, the application rates were 1.78, 2.32 and 2.6 lit/min. This was corresponding to minimum, medium and maximum application flow rates respectively. Both the spraying height and the nozzle spacing were found to be 40 cm. The captured picture size from web camera was of 62 cm X 84 cm and used as the picture frame size setting in the program.

The position and flow rate accuracies were evaluated at laboratory premises as shown in Figs. 8-10. Position accuracy was tested for five speeds i.e. 0.46, 0.61, 0.77, 0.92 and 1.08 m/s. The flow rate accuracy was estimated by collecting the spray output on specially arranged corrugated plastic containers with distance marks on it, laid along the side of the tractor for 9.60 m operation distance. In this particular test, spray boom output was directed to the container and liquid was collected using absorbing tissues and from the change in of these tissues the flow rate was estimated. The position marks shown in the captured picture corresponding to application flow rate from spraying nozzles were analyzed to estimate the flow rate accuracy.

Figure 8. An application position accuracy test

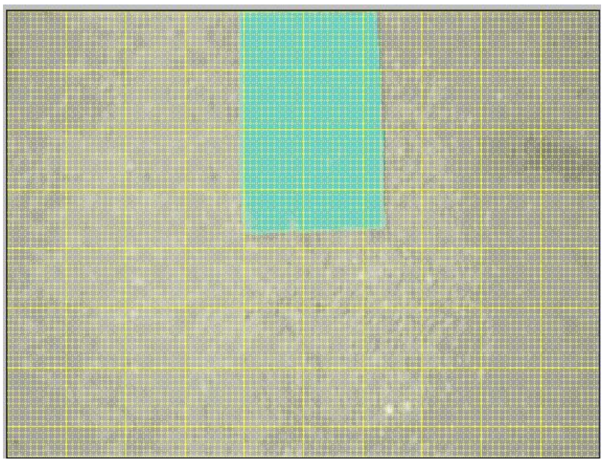

Figure 9. Calibration of accuracy of percent green color level; comparison between software processed and calculated

Figure 10. Test conducted for flow rate accuracy measurement with specially arranged corrugated plastic container with distance marks and nozzles on extended boom

3. RESULTS AND DISCUSSION

The test conducted to evaluate the application accuracy; to find out the distance between web camera and spray nozzles showed that one second of programming time delayed for the actuation, therefore, a 0.77 m distance lag occurred when the machine was operating at a speed of 0.77 m/s. The spraying position was found accurate enough for five operation speeds of 0.46, 0.61, 0.77, 0.92 and 1.08 m/s. In all test runs, the green patches were found fully overlapping with the rectangular application area, which corresponded to the capture frame size (Fig. 8).

Accuracy in percentage green color output was confirmed by comparing the percentage green level obtained from image processing of the captured image by the software and the value estimated from the graphical analysis (Fig. 9). The output was calibrated using 100 x 75 grids of a 62 cm x 84 cm picture frame size. The error was found to be around 0.31% with standard deviation of ±0.25.

The prototype was further tested for application flow accuracy, in which the flow rate was analyzed from quantity of liquid collected in distance marked grooves of the plastic container. In addition corresponding application positions on captured pictures were recorded during test runs. The results were then compared with the PWM duty cycle settings as shown in Fig. 11. The application flow rate accuracy was found to be 91.7%.

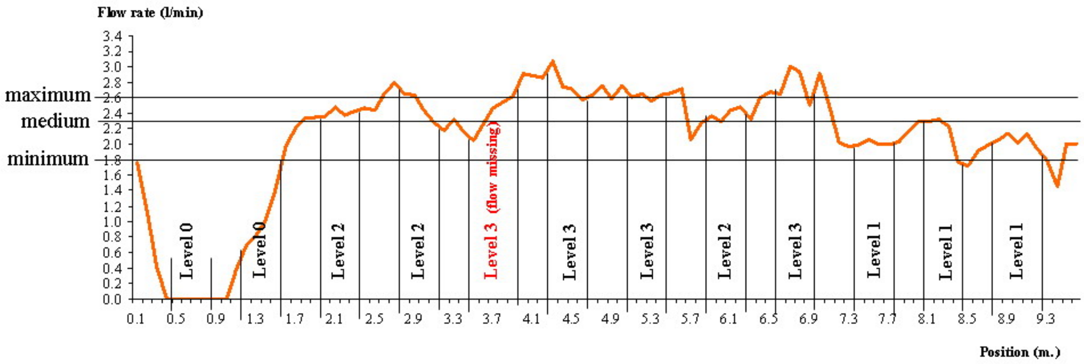

Figure 11. Test result of application flow rate accuracy comparison between measured and PWM set rate with respect to application position

Further analysis conducted focusing at economic and environmental concerns revealed that at typical operating speed of 0.77 m/s and with uniform application rate of 2.62 lit/min, herbicide quantity required for one ha was about 709 lit, while the developed variable rate method in a test field could decrease the quantity by 146 lit. The variable rate application cycle average of 2.08 lit/min (Fig. 11), which was equivalent to 20.6% reduction than normal application rate. This reduction could be stochastic and depending upon the amount of weed density in the field, further tests would be necessary to correlate the quantity reduction with varying weed density levels.

The developed applicator showed promising results, which employed appropriate minimum-cost technology suitable for use in medium and large sugarcane plantations, commonly available in most developing countries in the region. More over, the developed machine with some modifications would be able to use for nutrients application in some crops, i.e. NPK application based on crop color variability.

4. CONCLUSIONS

Basic mechatronic and machine vision principles were applied to develop a variable rate herbicide applicator to optimize the herbicide application rate corresponding to the amount of weeds. The study mainly focused at applying the systematic concepts and by using the low-cost devices locally available in Thailand. The tractor mounted real-time variable rate herbicide applicator performed satisfactorily under actual field conditions. The developed system has the adjustment flexibility for RGB ratio, threshold level of percent green color, threshold level of percent duty of PWM, capture picture size, with forward speed compensation and could be reset by the user before start of the work. Testing of the developed sprayer showed at least 20% reduction in the herbicide amount.

5. ACKNOWLEDGEMENTS

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