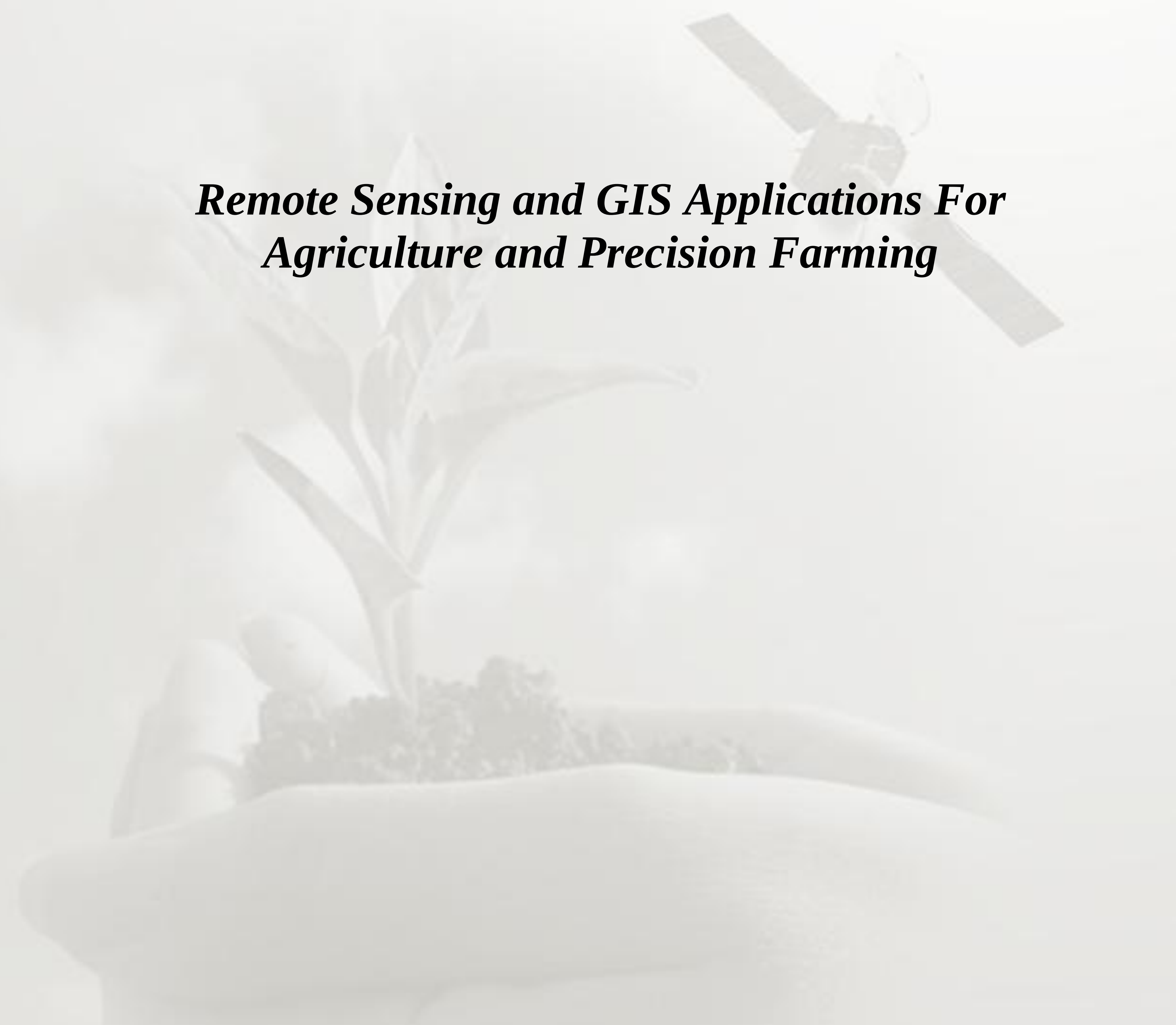
Remote Sensing and GIS Applications For Agriculture and Precision Farming



Development of Variable Rate Fertilizer Applicator Module Based on 8-bit Embedded System

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ABSTRACT

Variable rate technology (VRT) is one of crucial component in precision farming implementation, and is now gaining popularity and widely accepted as one of smart solutions to sustain agriculture production without ignoring environmental impact. With VRT machines, the dose and the position of application could be given precisely as required by crops. Machinery with variable rate capabilities impressed as technologically sophisticated and expensive. In Indonesia, implementation of VRT in crop production is also still questioned, because fear of the complicated and expensive prices of the machines. Therefore, the objective of this research was to develop a prototype smart applicator to perform variable rate fertilizer application suitable for rice cultivation in Indonesia. Simple mechanism which result an affordable price of the machine will be considered in prototype. Therefore, to control the desired dose of application a rotor type metering device was chosen because it has simple mechanism since it could be directly powered by DC geared motor. In this study, the range of speed control is about 30 to 90 % of motor performance. Digital control with PID compensator was used in this system. Embedded system base on 8-bit micro- processor was adopted since it was cheap and available in the local market. The control module is developed based on this embedded system, where I2C (inter integrated circuit) communication protocol was used for hardware-software interfacing using C language programming. This paper will discussed bench test results of motor control. For field operation in the future, the developed VRT applicator will be mounted on multi-purpose vehicle which was modified from riding type rice transplanter. Position of the vehicle in the field will be acquired using agriculture type RTK DGPS.

Keywords : *embedded system, precision farming, smart applicator, 8-bit VRT module, VRT applicator*

I. INTRODUCTION

Preserving environment in farming is now becoming main concern especially in developed countries where high yielding varieties together with high intensive use of inputs including fertilizers and pesticides has been widely employed. It is the fact that since the introduction of synthetic ammonia as nitrogenous fertilizer after World War I, food production has been dramatically increased all over the world. According to FAO database, within 37 years since 1961 world food production in term of paddy equivalent has increased by 2.7 times and rice yield per hectare has been double, but total nutrients (N, P2O5, K2O equivalent) input per agricultural land has also increased by 4.0 times[1].

Of course, beside of maintaining high yield performance, trend is now relying on preserving environment through the concept of site specific crop management or popular as precision farming. In fertilizer application, for instance, how to make effective use of chemical fertilizer became important point, as it is more realized that foot to foot of soil has different fertility and so productive potential. With this in mind, fertilizer management should, therefore, make advantages of soil and crop information.

The uniform conventional fertilizer application practice disregards the productive potentials of the various areas within the field. Thus, some area is less-fertilized and the other is over-fertilized. An increase of fertilizer generally increases the crop yield up to optimum level, but more fertilizer will be less utilized or mobilized. It is also an important issue recently that nitrogen from fertilizers may be lost into the atmosphere or enter streams through surface or subsurface drainage (leaching). Thus, over-fertilization is a potential source of pollution in the form of ammonia (NH_3), nitrite (NO_2), and nitrate (NO_3) which may pose a hazard to human health. Therefore, a contemporary issue is how to give an effective dose at the accurate position and right time for optimum growth of crops while preserving the environment without causing economic losses.

In the USA and Western Europe, precision farming practices have gained its popularity among farmers, and therefore many companies involved by providing new technology for those purposes, such as AgChem, AgriTrak, Mid-Tech, Linco and many others. Precision farming technology by mean of using such as Global Positioning System (GPS), camera vision sensing, yield monitor, variable rate application, etc. is deeply researched and examined since 1997 at several places in Japan, followed by Korea, Taiwan and China.

Application of variable rate technology reported success to reduce fertilizer uses in rice paddy cultivation while production was maintained high in Japan. At topdressing operation, field with variable rate application consumed 12.8% less of NK fertilizer than that of the field with uniform rate application. It was reported that grain yield in dry basis for both treatment showed similar average value of 7.29 t/ha. Field with variable rate topdressing application showed less yield variability (CV was 4.2% and grain yield at 7.3±0.3 t/ha was 72%) than field with uniform rate topdressing application (CV was 8.0% and grain yield at 7.3±0.3 t/ha was 44.9%)[4],[5]. The results mentioned enhance the possibility of applying variable rate fertilization or maintaining high yield with minimum variability.

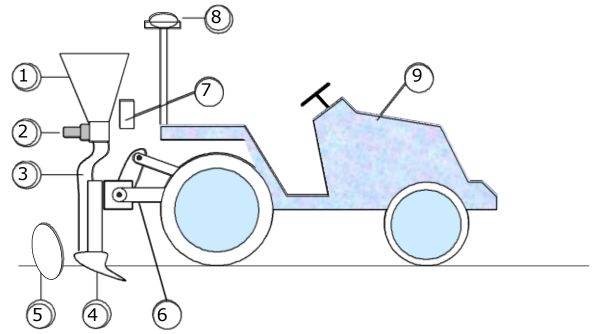
With all explained, it is undoubtedly that precision farming could offer better solution for agriculture sustainable production in the future. Technology to implement precision farming relies on variable rate technology (VRT). Therefore, VRT is one of crucial component in precision practice, and is now gaining popularity and widely accepted as one of smart solutions to sustain agriculture production without ignoring environmental impact. With VRT machines, the dose and the position of application could be given precisely as required by crops. Machinery with variable rate capabilities impressed as technologically sophisticated and expensive. In Indonesia, implementation of VRT in crop production is also still questioned, because fear of the complicated and expensive price of the machines. Therefore, the objective of this research was to develop a prototype smart applicator to perform variable rate fertilizer application suitable for rice cultivation in Indonesia. Simple mechanism which result an affordable price of the machine will be considered.

II. VARIABLE RATE APPLICATOR DESIGN

2.1. Vehicle

Concept design of developed VRT granular fertilizer applicator is shown in Figure 1. In this concept, the applicator is mounted on a multipurpose vehicle or light tractor using three-point hitch. The concept of VRT applicator has four mains components, electric parts (motor and controller), fertilizer bins with total capacity 120 l, 2-4 metering devices and 4- 8 nozzle spreaders.

The applicator works as follow; first the fertilizer was metered by a roller feeder, the grains are then released gravitationally or transported pneumatically by pressured air stream, through delivery hoses and finally put in the soil. The fertilizer is put into the soil to dept of 5-10 cm, in order to avoid vapor losses in dry season or losses due to water runoff during rainy season.



1. Fertilizer hopper	2. Servo motor	3. Delivery hose
4. Furrow opener	5. Cover	6. Hitch frame
7. Controller module	8. GPS Antenna	9. Tractor

Figure 1. Concept of variable rate applicator

As shown in Figure 2, computer or controller module was utilized to organize the system. This machine performed variable rate application based on fertilization mapped. The map contained desired rates of application (kg/ha) as well as their position in the field will be used to guide the operation of the machine in the field. Change of the desired application rate was implemented by precisely control the rotor speed of metering device while monitoring the ground speed of the vehicle An agriculture purpose RTK-DGPS with accuracy of 5 to 10 cm is used to perform accurate positioning during fertilization, and the data were sent to the PC computer through serial port (RS232) at 5 Hz. While the speed of the vehicle was monitored, through the vane disc and a magnetic proximity sensor

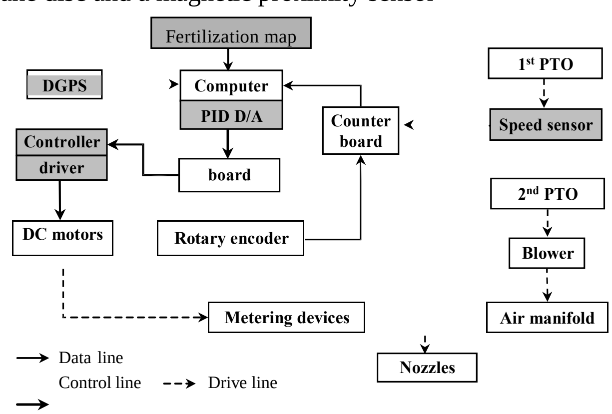


Figure 2. System control of variable metering.

2.2. Metering device

The accuracy of metering device is the heart of fertilizer performance. Positive volumetric displacement type of metering rotor is used. The fertilizer feeders were star-types with 6 fins, while the pesticide feeders were solid rollers with cylindrical notched chambers. The fins of the two feeders were shifted about 30° to reduce the peak of rotor's torque and the fluctuation of fertilizer output when the applicator was operated in double feeder mode. The fertilizer feeders had theoretically volume of 22.8 cm^3. per rotation. Figure 3 shown a schematic of the metering mechanism. No agitator is needed inside the hoppers and the rotors are only the moving parts in the mechanism. Tests of metering devices of this type showed that their output rates (g/s) were proportional to rotor speed when they were operated up to 85 rpm[5]. Therefore, range of controlled operation of the metering device in this research is set below 85 rpm.

Metering devices showed that its output rate (g/s) was proportional to rotor speed, when it was operated up to 85 rpm. For single roller feeder, if the rate of application is decided, the rotor speed (Nm, in rps) can be simply calculated as follows:

$$N_m = (10\, S\, W\, D_s)/Q \qquad (1)$$

where,
S = Ground speed of the applicator [m/s]
W = Effective width covered by one metering device [m]
Ds = Rate of application [kg/ha]

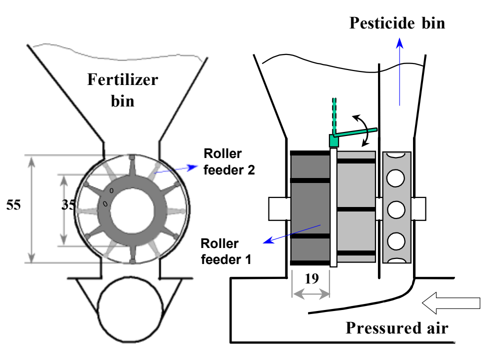


Figure 3. Schematic of metering device

2.3. Motor and Controller

DC geared motor was use in this design because it is tough and reliable for field application, beside it is also cheap and availability in local market. Through a careful design a DC motor can be directly coupled to the shaft of fertilizer metering device for simple construction. A 30 W dc motor has specification of 22 V/ 2600 rpm equipped with 1/20 reduction gear box. The whole system is knock-down, thus easy for maintenance. To measure speed of the motor for feedback control system, an optical rotary encoder was used. The encoder gives output of 30 pulses per rotation.

The controller module for metering system controller consists of microcontroller module (DT-51 Minsys), Smart Peripheral Motor Controller (SPC Motor Controller, and motor driver (EMS Hybrid 30A) made in Innovative Electronics. For flexibility, a 3 x4 keypad was functioned as input device, while a 2 x 20 line LCD display was used as output of the controller. With input and output devices, the controller parameters could easily be adjusted and the result could be easily monitored.

The specification microcontroller used was 8 bit micro-processor base on AT89C51, 8kb EEPROM expandable to 64k, 4 I/O ports (PPI portA, portB and portC, port1), LCD port, and serial port interface for communication with PC computer, laptop or netbook.

A pulse width modulation (PWM) driver (EMS Driver from Innovative Electronics) with hybrid transistors was used. The motor driver has ranges output up to 36 V at maximum current up to 30 A. This driver was interfaced to micro-controller through Smart Peripheral Controller (SPC). SPC motor controller has 2 channel input driver, equipped with four 16 bit counters. Communication between SPC, EMS driver and micro-controller could utilize i2c protocol, UART or parallel port.

III. MATERIAL AND METHOD

3.1. Materials of experiment

Design of granular fertilizer applicator with volumetric metering system is adopted and modified to become variable output. Variable dose is performed by controlling the rotation of metering device rotor by meant of controlling the rotation of a dc gear motor. With digital control it is possible to set the desired speed of the rotor very precise and accurate.

For this purposed, material of experiment will be consists of metering device, dc geared motor, rotary encoder, counter, interface controller, motor driver, usb to serial port and laptop computer. Computer was use to program the micro-controller, and also to monitor and record the data during process development. C programming language was use to developed the system control and data acquisition. Data acquisition was done through serial communication by using usb to RS-232 cable. Data were displayed in the laptop monitor and recorded in computer's hard drives. Microsoft excel was used to do further data processing.

In this technique, the map-based application method was adopted. In this method, soil and plant were sampled and laboratory analyzed prior to fertilizer application. After further calculations, a fertilization map was constructed. The fertilization map contained information of the required application rates (kg/ha) on each plot in the field. The work of soil and plant analysis was conducted by another team of precision farming research, and there is not discuss further.

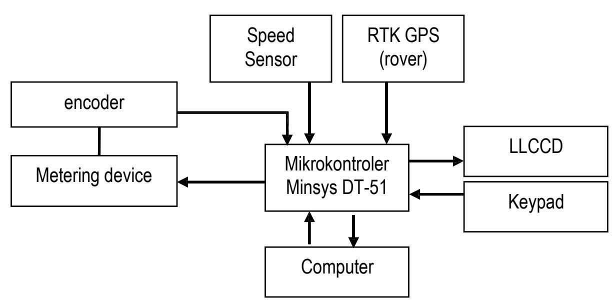


Figure 4. Block diagram of control system

Block diagram of the system is presented in Figure 4. To performed variable rate application in the field, micro-controller should manage information of vehicle accurate dose of application. The change of rate of application is done by precisely control the metering rotor while monitoring the vehicle's ground speed. The ground speed was measured by a segmented vane disc and a proximity sensor will be sampling at 1Hz. While an agriculture purposes RTK-DGPS having accuracy 5 to 10 cm will be used to perform accurate positioning in real time (5Hz) during field operation.

3.2. Method of controling the metering device

System identification

The metering system approximated with linear model of first order system with delay, as represented in Laplace transform as follows;

$$G(s) = \frac{R(s)}{C(s)} = \frac{Ke^{-ds}}{1 + T\ s} \qquad (2)$$

Where,

R = speed of rotor or output of control
C = set point or input control
K = gain of system (rps)
T_s= time constant (s)
d = delay time (s)

The value of K, T and d was determined by using step response model. Curve fitting using Least Square Method was adopted to fit data of response and model as stated in equation (2). Procedure of system identification is presented in figure 5.

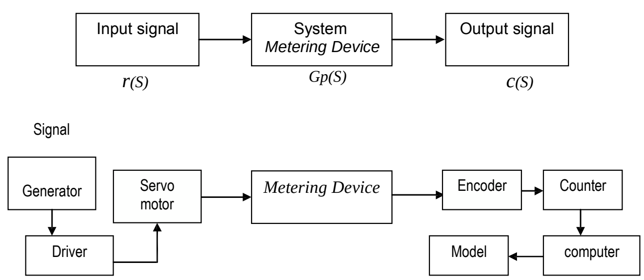


Figure 5. Schematic of system identification

To find the value of K, T_s and d, curve fitting was done in time domain using time difference model where Laplace variable s was approximated by z transform as follows:

$$s = \frac{1}{2T_s}\left(\frac{1 - z^{-1}}{1 + z^{-1}}\right) \qquad (3)$$

so that,

$$c_n = \frac{K\left(r_{n-d/T_s} + r_{n-1-d/T_s}\right) - c_{n-1}\left((1 - \frac{2T}{T_s})\right)}{\left(1 + \frac{2T}{T_s}\right)} \qquad (4)$$

Where,

r_n : discrete values of a unit step at n[th] time
T_s : is period of sampling (s)
c_n : discrete output at n[th] time, rotor speed of the metering device (rps)

Digital PID Control

Digital control based on embedded system will be used in this research. A feedback control with a digital PID compensator, therefore, was adopted to improve the robustness of control. For this purpose, the rotor speed was monitored using an optical rotary encoder with resolution 30 pulses per rotation. A 16 bit counter was used to count the pulses every 20 ms.

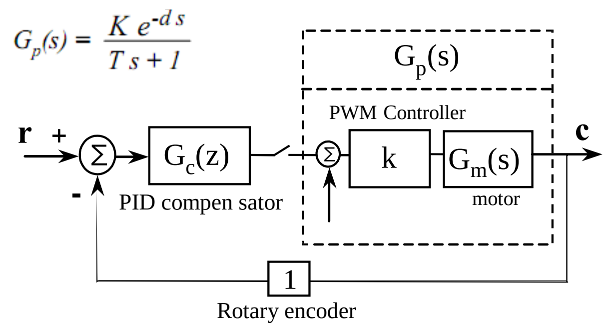


Figure 6. Schematic diagram of digital control

A feedback control is designed to generate an output that causes some corrective effort to be applied to a process so as to drive a measurable process variable(**r**) towards a desired value(**c**) known as the set-point, as shown in Figure 5. PID digital is implemented as follows:

$$C_n = C_{n-1} + K_p\left[(e_n - e_{n-1}) + K_I T e_n - K_D\left(\frac{e_n - 2e_{n-1} - e_{n-2}}{T}\right)\right] \qquad (3)$$

Where,

C_n = next value of control
e_n = error of process
Kp, K_i, K_D is PID constant for proportional, integral and differential component.

IV. RESULT AND DISCUSSION

4.1.Motor performance

The DC gear motor that was tested had good linearity characteristic with respect to control voltage of 4 to 24 volt, as shown in figure 6.

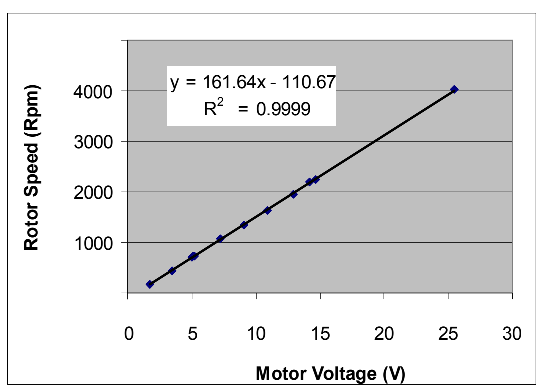


Figure 6. Rotor speed versus input voltage

When the voltage was expressed in term of PWM (pulse width modulation) values (0 to 255) as control input, the relationship was not linear. However, it has polynomial 3rd order, as shown in Figure 7. The calibration curve mentioned is important to give initial setting command to the controller.

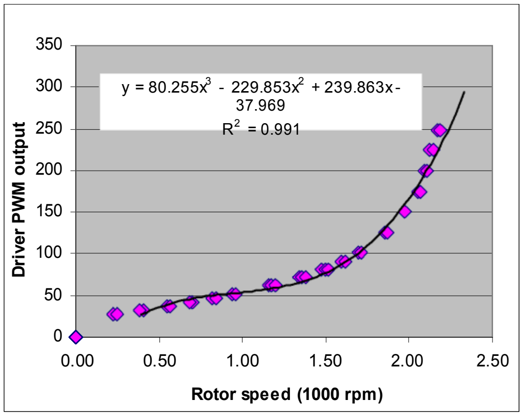


Figure 7. PWM output of motor driver versus rotor speed

4.2. Modeling of motor

Open loop control was done with PWM set point 50, 100, 150, and 250 respectively to run the motor. The speed of the rotor was then monitored and recorded in laptop computer at sampling rate of 30 ms. Rotary encoder was used to sense the rotation speed of the rotor, and output pulse was then counted using 16 bit counter. The data was then plot and curved fitted using model in equation (4), and the result is presented in Figure 8.

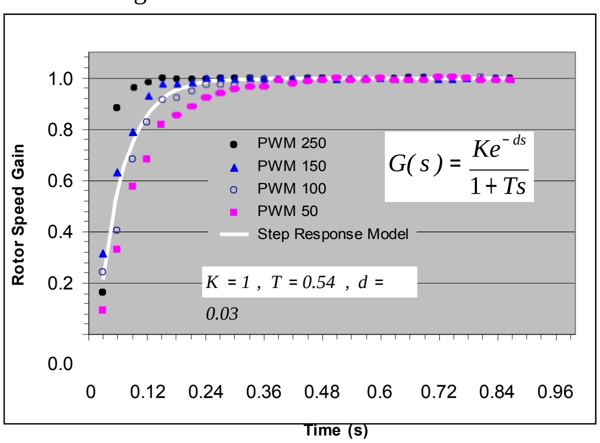


Figure 8. Step response model of system

In order to tune the compensator, the process gain K, the time constant T and the dead time d of the system were determined in the same manner as previously explained.

4.3. PID control

Without properly controlled, motor could not give precise response, for example of stair step set point change as illustrated in Figure 9. Though the value of set point command calculated based on calibration curve as in Figure 7, not all setting speeds of the rotor could be followed precisely. However, this process could be improved as feed back control is applied in the system as it was shown in Figure 9, where all the setting points could be followed very precise in quick response either in low speed as well as high speed rotation of rotor.

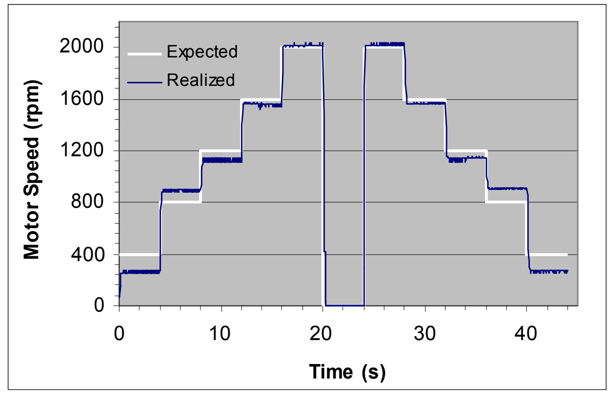


Figure 9. Step response of motor without control

In order for control loop to work properly, the PID compensator must be properly tuned. Process gain was defined as rotor speed per second (rps) output (Hz) per unit of controller input. Least square fitting was used, where the process gain K= 1, time constant T= 0.054s and dead time d= 0.030s Tuning of the controller was done using modified Ziegler-Nichols method, where the PID constants were defined as the following equations, where:

$$K_p = C_p\ 1.2\ T/(K\ d),\quad K_i = C_i\ 0.5/d \text{ and } K_d = C_d\ 0.5\ d. \qquad (5)$$

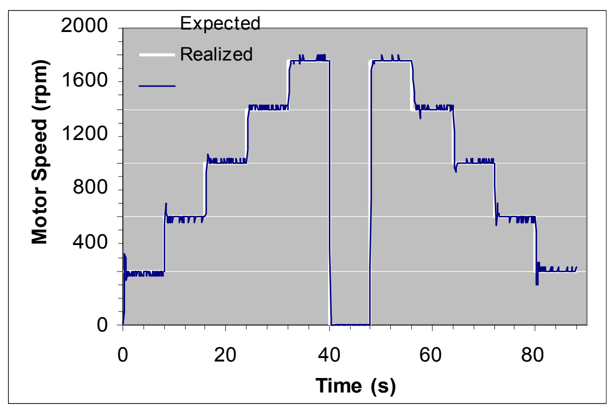


Figure 10. Stair step response of motor with PID control

Tough the torque on the rotor fluctuated because of frictions and other causes, such as cyclic loading as well as various granules sizes, the controller able to maintain the speed of motor in a good accuracy. It is shown in Figure 4.10, digital PID compensator obviously improved the performance of motor compared to the previous one. When control loop was run at 16 Hz or period of sampling 60 ms, the best performance was found when C_p = 3.86; C_i = 0.0002; C_d = 0.1.667. However, the parameters value will be explored further to minimized disturbance due to the variation of fertilizer size in the next experiments.

V. CONCLUSIONS

A prototype of embedded control module for variable rate granular applicator has been constructed and tested. The current module used 8bit micro-controller equipped with LCD display and keypad for user interface input output. Peripheral modules could be used

The necessity of quick and accurate response of rotating rotor which is needed for variable rate metering mechanism could be fulfilled by using cheap dc geared motor equipped with encoder which is digitally controlled. For the purpose, the PID compensator should be properly tuned in order to get precise response to wide various stair step response which simulate the capability of variable rate of the machine.

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REFERENCES

[1] Electronic Publication : FAO Statistical Database, Food and Agriculture Organization of United Nation. 2000 Website: http://apps.fao.org/default.htm

[2] Lee, C. K., M. Umeda, J. Yanai, M. Iida, T. Kosaki, "Grain Yield and Soil Properties in Paddy Field", ASAE/CSAE- SCGR 1999 Annual International Meeting 1999. , Toronto CANADA, Paper No. 991057.

[3] Iida, K., M. Suguri, M. Umeda and T. Matsui, "Estimation of nitrogen content using machine vision in a paddy field", 2000 ASAE Annual International Meeting, Milwaukee, Wisconsin, USA, paper No.003021.

[4] Sinivasan, A., "Precision farming in Asia: Progress and prospects". Proc. of the 4th International Conference on Precision Agriculture, 19-22 July 1998, St. Paul, USA. Available

[5] Radite, P.A.S., M Umeda, M. Iida, M. Khilael, "Variable rate applicator for paddy field". 93rd Intl meeting of ASAE, Milwaukee, Wisconsin, USA., 9-12 July, 2000. ASAE paper No.001156.

[6] Iida, Michihisa, M. Umeda, P. A. S. Radite, "Variable Rate Fertilizer Applicator for Paddy Field". 94rd Intl meeting of ASAE, Sacramento, California, USA, July 29-August 1,2001. ASAE paper No. 011115.