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Development of a PWM Precision Spraying Controller for Unmanned Aerial Vehicles

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Abstract

This paper presents a new Pulse Width Modulation (PWM) controller for Unmanned Aerial Vehicle (UAV) precision sprayer for agriculture using a TL494 fixed-frequency pulse width modulator together with a data acquisition board and developed software. An UAV can be remotely controlled or flown autonomously by pre-programmed flight plans. The PWM controller was implemented through the guidance system on the UAV with control commands sent between the UAV helicopter and the ground control station via a wireless telemetry system. The PWM controller was tested and validated using LabVIEW 8.2. Several analyses were performed in a laboratory to test different control signals. The results show that the PWM controller has promise as a higher precision technique for spray applications, which will improve efficiency of pesticide application, especially in crop production areas.

Keywords: PWM controller, TL494, precision spraying, UAV

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1 Introduction

Unmanned Aerial Vehicles (UAVs) are an inevitable trend of modern aerial equipment based on developments in the direction of intelligence[1]. They can be controlled autonomously via preprogrammed flight paths in many situations where human intervention is considered difficult or dangerous. UAVs have found diverse applications for both military missions and civil aspects[2,3]. Within the past decade, UAVs have been used in precision agriculture for monitoring yield of coffee crops and wheat crops, rangeland management, agricultural management[4–9], examining the relative abundance of viable spores of a plant pathogen and studying the long-distance movement and migratory behavior of the potato leafhopper insect[10–12].

Prevention of insects and diseases of crop is a crucial factor of pest management in agriculture. Basically, agricultural application of fertilizers and chemicals is frequently needed for specific conditions, such as specific time, location and site-specific management of crop pests. These applications are typically made through the use of ground sprayers, chemigation, or aerial application equipment. While these methods are well suited to large acreage cropping systems, they may become inefficient when applications must be made over small plot production systems.

With the advent of microprocessor and switching device technologies, Pulse Width Modulation (PWM) has been used for precision agriculture. Improvements of PWM methods and suitable converter configurations have been made[13]. PWM can be used to control flow by varying valve duty cycle on a fixed frequency[14]. Use of PWM to control the flow of ammonia in precision application has potential to improve lateral application uniformity and ammonia application accuracy and control. Huang *et al*. adopted servo motor control circuit and reported applications of fully autonomous UAVs in ag-

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ricultural or vector control spray applications[15].

The results have shown that a spray system was successfully developed for a UAV to perform aerial pesticide delivery and was also very promising for vector control in the areas that are not easily accessible by personnel or equipment. Literature reviews did not reveal any published PWM precision spray controller for fully autonomous UAV in agricultural applications.

The objective of this research was to develop a PWM controller for a UAV precision sprayer for agriculture.

2 Materials and methods

2.1 UAV

The UAVs used in the research were Vertical Take-Off and Landing (VTOL) unmanned autonomous helicopters. The two UAVs used in this work were the SR20 and SR200 (Rotomotion, LLC, Charleston, South Carolina). The SR20 is an electric VTOL unmanned autonomous helicopter with a main rotor diameter of 1.75 m and a maximum payload of 4.5 kg. The SR200 is a gas VTOL unmanned autonomous helicopter with a main rotor diameter of 3 m and a maximum payload of 22.7 kg. The SR20 carries a light-weight video camera to produce aerial imagery in real time sent back to the ground control station, and the SR200 was developed to carry a low-volume spray system to apply crop production and protection materials. Each of the UAVs can be controlled from a ground communication unit via a wireless telemetry system or a flight plan can be uploaded to the UAV so that it can operate autonomously.

2.2 Design of PWM controller

We have developed a PWM controller based on the TL494 (Texas Instruments, Dallas, TX), which is a fixed-frequency pulse width modulation control circuit[16]. The main characteristics of TL494 are:

- Complete pulse width modulation control circuitry;
- On-chip oscillator with master or slave operation;
- On-chip error amplifiers;
- On-chip 5 volt reference;
- Adjustable dead-time control;
- Uncommitted output transistors rated to 500 mA source or sink;
- Output control for push-pull or single-ended operation;
- Under voltage lockout.

Fig. 1 presents the block diagram of the TL494[16]. Different control signal voltages generate different pulse width signals. Output pulse width modulation is obtained by comparing the positive sawtooth voltage of the capacitor, C_T, with the other two control signal voltages. The NOR gate could drive transistors, $Q1$ and $Q2$, only when the clock input signal of the flip-flop is at low-level. Thereby, the increase in the control signal voltage will correspondingly make the output pulse width linearly decrease. The oscillator frequency is decided by two external components, resistor R_τ and capacitor C_τ. The approximate oscillator frequency, f_{osc} is determined by:

$$f_{\text{osc}} = \frac{1.1}{R_\tau \cdot C_\tau}. \quad (1)$$

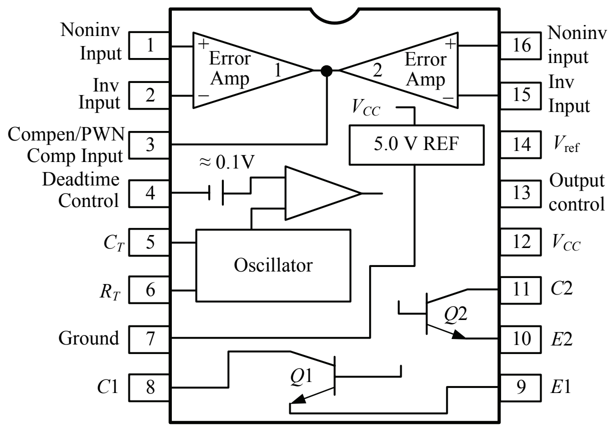


Fig. 1 Block diagram of TL494.

The required timing chart for the TL494 circuit is presented in Fig. 2 and Fig. 3 shows the peripheral circuit of TL494.

In order to have a sustainable operation of the spraying system on the UAV, a modular PWM controller was developed (Fig. 4).

2.3 Performance of spraying system

Based on NI USB 6008/6009 DAQ® and LabVIEW™ (National Instruments, Inc., Austin, TX, USA) the test system basically consists of the following components: A Micronair Ultra-Low-Volume (UAL) –A+ nozzle (Micron Sprayers Ltd, Bromyard, Herefordshire, UK) to evaluate the flow rate; a chemical tank

(9.5 cm×12 cm×15.8 cm) to hold the liquid for spraying; a compact DC pump (UGP-2000 Model, 12VDC, Pumps Inc., Tucson, AZ) to pump the liquid from the tank to the nozzle; a pressure gauge to check the valves for nozzles to prevent them from dripping; a PWM controller to control the speed of the DC pump and hence the spraying rate of the nozzles; a data acquisition card with a 12-bit ADC (NI 6008, National Instruments Inc., Austin, TX) to control the PWM controller. The complete testing system is shown in Fig. 5.

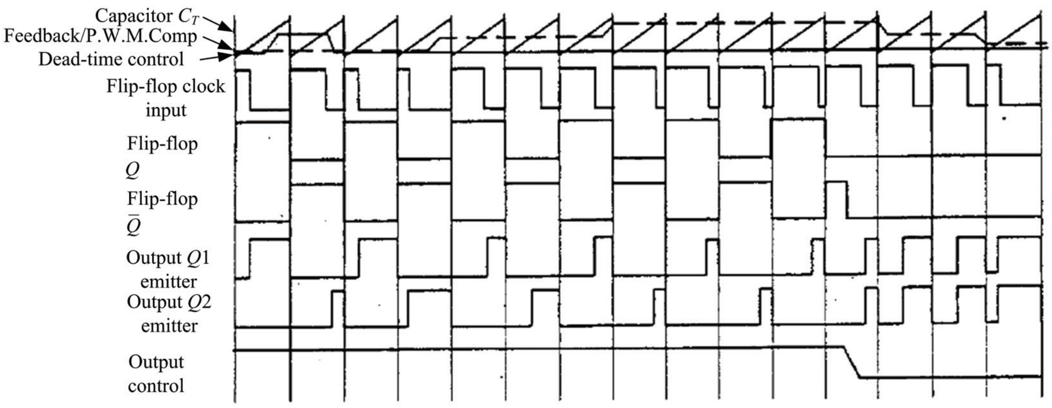


Fig. 2 Timing chart of TL494.

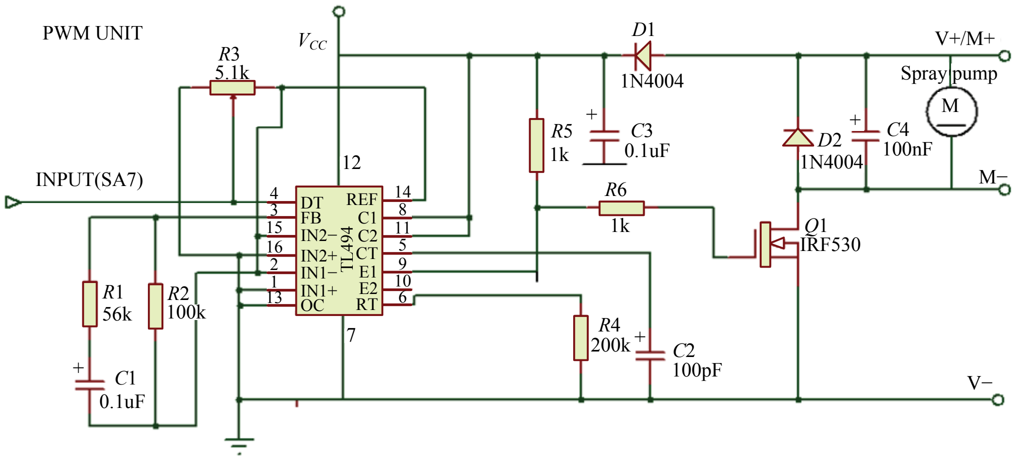


Fig. 3 The peripheral circuit of TL494.

Fig. 4 PWM controller.

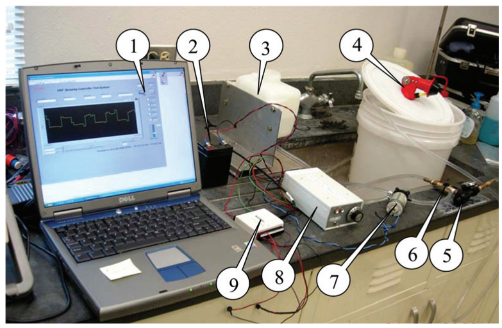


Fig. 5 The diagram of PWM controller test system where: 1) PC with LabVIEW; 2) 12 DC battery; 3) a chemical tank; 4) ULA nozzle; 5) pressure gauge; 6) valve; 7) DC power pump; 8) spraying PWM controller; 9) data acquisition device (USB 6008).

By manually adjusting the control voltage (Pin AO0) through the interfacing software, the pulse width modulated voltage (Pin AI0) and the switching output voltage (Pin AI1) generated by the TL494, as well as, the duty cycle were measured via the data acquisition unit. Data analysis and graphical displays were performed using LabVIEW 8.2 (National Instruments, Austin, TX). PWM controller connection with data acquisition card is shown in Fig. 6.

The data acquisition block diagram for PWM controller spraying system is shown in Fig. 7.

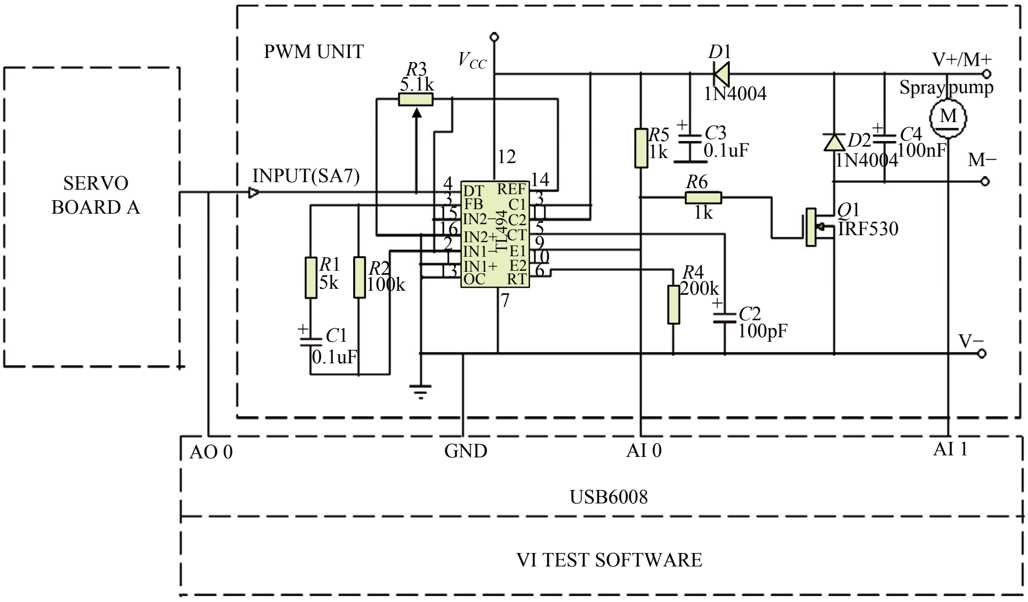


Fig. 6 PWM controller connection with data acquisition card.

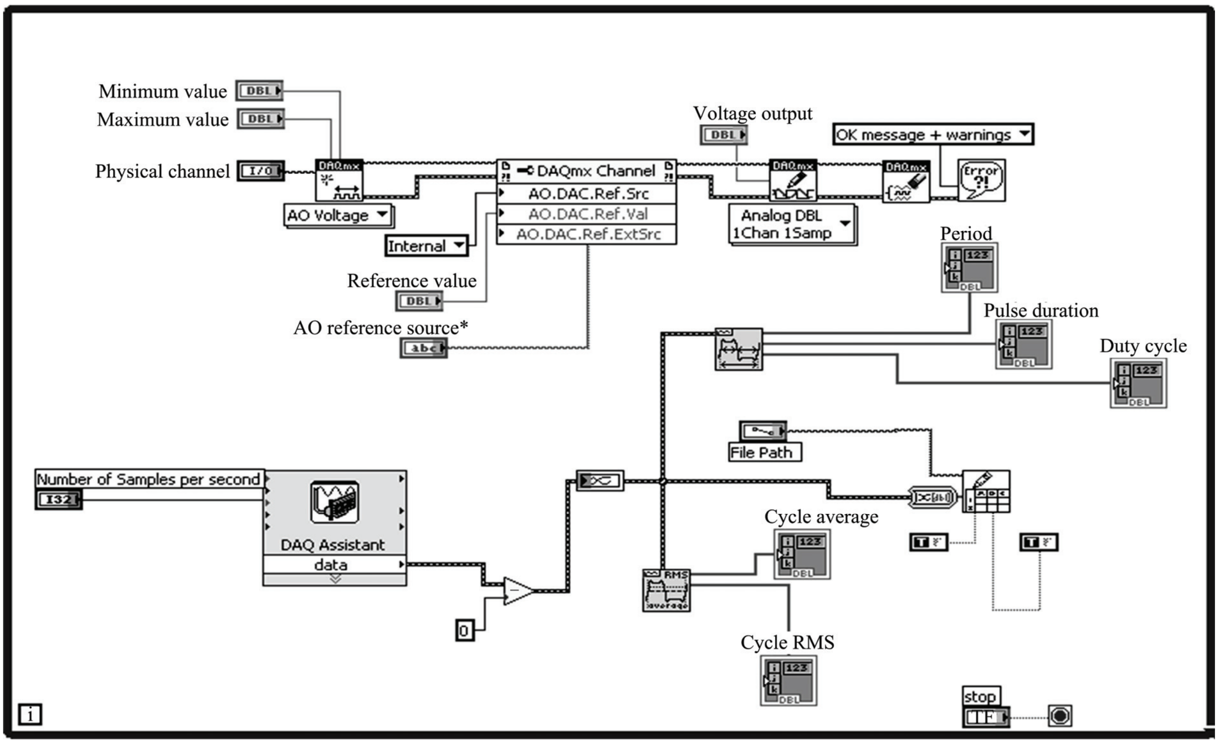


Fig. 7 The data acquisition block diagram for PWM controller spraying system.

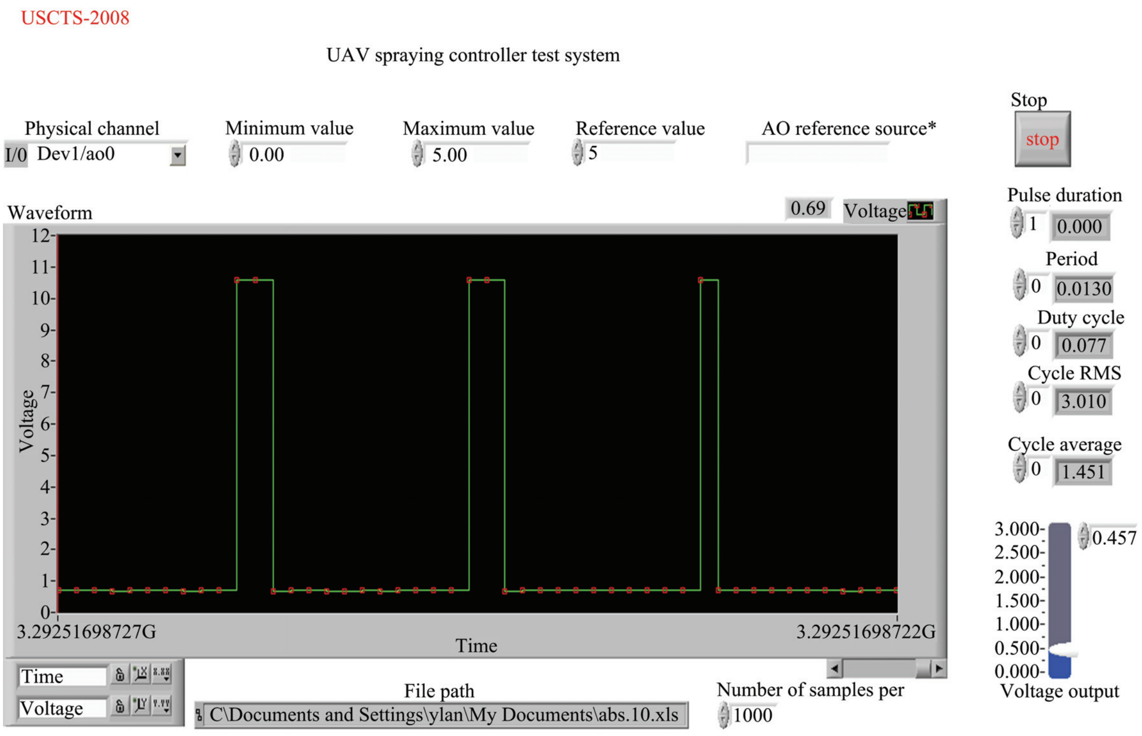


Fig. 8 The virtual instrument test software for spraying controller.

For the PWM controller, a fixed frequency of 55 kHz was used. The number of samples per minute is 1000. The acquired signal was displayed when new samples are available. Controls were designed to allow the user to choose the sampling frequency, to display the number of points, and to select the channel to which the input signal is routed. The interfaces of the PWM controller test system are shown in Fig. 8.

3 Results and discussion

3.1 PWM controller

Fig. 9 shows the relationship between the control voltage and the duty cycle. The duty cycle exhibited different values at switching control voltage values ranging from 0 V to 3.0 V. They were highly correlated with a strong linear relationship ($R^2 = 0.9965$). By controlling the duty cycle via the input voltage, the output voltage could be controlled due to the linear response between duty cycle and output voltage (Fig. 10).

Flow pressures plots for the DC powered pump (UGP-2000) shows a nonlinear ($R^2 = 0.996$) dependence on control voltage (Fig. 11). The pressures will exhibit different values at any particular switching control and duty cycle.

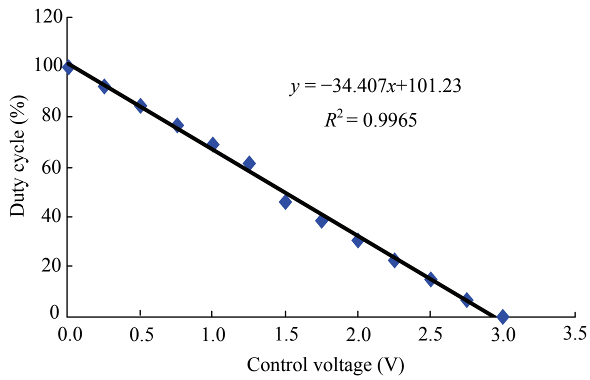


Fig. 9 Relationship between control voltage and duty cycle of PWM controller.

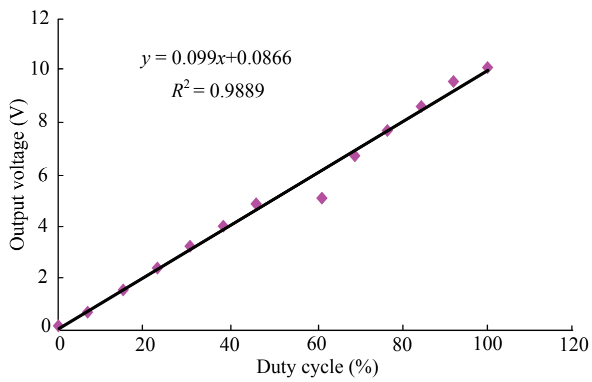


Fig. 10 Relationship between duty cycle and output voltage of PWM controller.

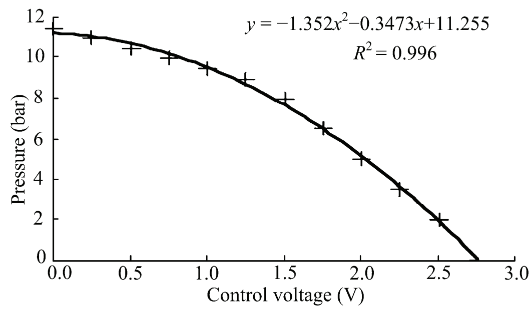


Fig. 11 Relationship between control voltage and flow pressures of PWM controller.

To confirm the functionality of the PWM unit, the relationship between flow rate and duty cycle was tested (Table 1). The flow rate from the PWM controller test was found to have a strong linear relationship (R^2 = 0.9836) with duty cycle (Fig. 12). The tests were very repeatable as indicated by the low coefficient of variations (CV). It took a duty cycle of at least 15.3%, which corresponded to an output voltage of ~1.6 V, to start the pump. By varying the duty cycle from 15.3% to 100%, the flow rate changed from 2.25 g/30s to 13.61 g/30s.

3.2 Flight control system and PWM controller with UAV

An Autonomous Flight Control System (AFCS) is an integrated package mounted under the fuselage of the RS200 helicopter. The AFCS receives commands from a ground monitoring station via a wireless telemetry system and control the actions of the helicopter. The AFCS consists of the following five modular components (upper part of Fig. 13a):

(1) 3-axis, 6 degrees of freedom IMU (inertial measurement unit);

(2) 3-axis magnetometer;

(3) GPS receiver;

(4) Proprietary radio receiver with servo interface and safety pilot override;

(5) Linux-based flight computer.

Table 1 Experimental data of PWM controller

Trial No.	Duty cycle (%)	Avg. flow ($g \cdot s^{-1}$)	Flow amount ($g \cdot s^{-1}$) 1	2	3	CV (%)
1	0.00					
2	7.00					
3	15.30	0.08	0.08	0.08	0.08	3.30
4	23.00	0.08	0.08	0.08	0.08	0.30
5	30.70	0.17	0.17	0.17	0.17	1.10
6	38.40	0.20	0.21	0.19	0.20	4.10
7	46.10	0.22	0.24	0.21	0.21	8.00
8	61.50	0.23	0.25	0.21	0.22	7.50
9	69.20	0.34	0.34	0.34	0.33	1.10
10	76.90	0.38	0.37	0.38	0.38	0.70
11	84.60	0.39	0.39	0.39	0.39	0.40
12	92.30	0.40	0.40	0.41	0.39	1.00
13	100.00	0.45	0.46	0.44	0.46	1.60

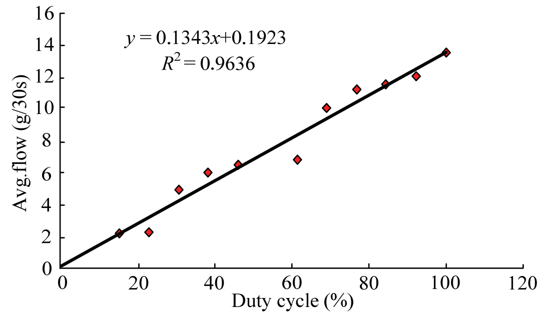
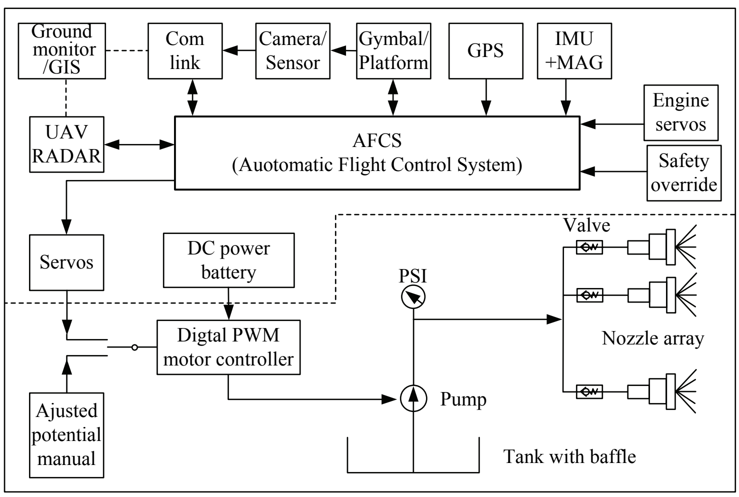
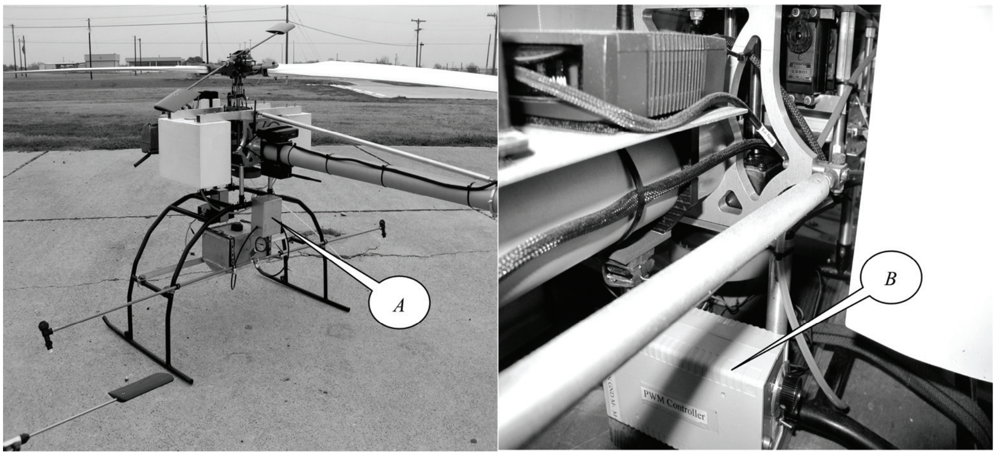


Fig. 12 Relationship between duty cycle and flow amounts of PWM controller..



(a) The AFCS control system

Fig. 13 Diagram of integrated AFCS system with PWM controller spraying system for UAV.



(b) Integrated spraying system with PWM controller, where: (A) pump box; (B) PWM controller box.

Fig. 13 Continued.

An integrated spraying system with PWM controller (Fig. 13b) was designed to be mounted onto the RS200. Spray system actuation and flow rate modifications were accomplished using a servo control to turn on and off the spray system. The PWM controller controls the DC pump motor speed through a D/A output terminal or a servo board analog output. The voltage delivered to the DC pump motor was in pulse with the pump speed determined by the modulated pulse width.

4 Conclusion

Based on the research the PWM controller was developed to apply the UAV precision sprayer. The performance of the PWM controller designed in this study was tested. The controller could adjust the duty cycle in the PWM signal using a TL494 which is a fixed-frequency pulse width modulation control circuit. The relatively strong correlation between control voltage and duty cycle (R^2 = 0.9965), flow amount and duty cycle (R^2 = 0.9636) indicates that the PWM controller has promise for precision spraying. The development of a PWM controller for UAV precision sprayer has a great potential to enhance the efficiency of pesticide applications.

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