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Ag Sprayer Boom Control Using Fuzzy Controller

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Abstract. A fuzzy logic boom leveling control algorithm was developed and implemented to agricultural sprayers. Due to limited access, the controller was only tested on two different sprayers, a Case 4410 and a Ro-gator 874C. The Case has a solid boom mount while the boom on the Ro-gator rides on a suspension. The purpose of this paper is to provide detailed methodology of the system and the controller as well as to make available some of the results obtained. The results were compared with conventional controller and the fuzzy controller developed. Even though the improvement was not huge, the authors felt that it is significant.

Keywords: Fuzzy Controller, Boom Controller, Ag Sprayer, &Matlab

1. Introduction

Agricultural sprayers are widely used in the modern farms for pesticides and fertilizer application. Proper application of pesticides and fertilizers is possible only with a sprayer or spreader that is accurately calibrated. When equipment is not correctly calibrated or the sprayer is not controlled, it is easy to apply too little or too much pesticide and fertilizer [1]. That may result in a lack of pest control, damaged turf, excess cost, and contamination of the environment. Sprayer boom stability is important in achieving uniform spray application and increase efficiency.

Modern agriculture depends on the use of pesticides and fertilizer in order to maximize crop yields per area. Agricultural sprayers play an important role for applying pesticides and liquid fertilizer to large fields of crop. These sprayers are agricultural vehicles with a large solution tank to hold pesticide, herbicides or liquid fertilizer and a hydraulically actuated boom mounted at the rear of the vehicle. The boom is a steel or aluminum construction holding the spray nozzles to apply the chemicals to the plants. In order to maximize productivity of agriculture sprayers, high vehicle speed and a large boom are desirable. Today's state-of-the-art boom height control systems are based on ultrasonic sensors which are mounted to the boom [2]. The sensors are generally mounted on the boom, measuring the vertical distance between boom and ground. The dynamics of the boom hydraulics is significantly slower than the time given between sensor reading and required boom actuation. The current boom control system thus can handle slow and continuous change in crop or ground height only.

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2. The System

An analog voltage from an ultrasonic sensor is used for the height feedback. The output of the controller is a PWM signal that modulates a hydraulic valve. As the duty cycle increases the hydraulic pressure increases and raises the boom. There are two booms on every system thus there are two independent control loops. A very simplified system diagram is shown in Fig. 1 where,D(z) is the controller transfer function and G(s) and H(s) are the sprayer and sensor transfer functions, respectively.

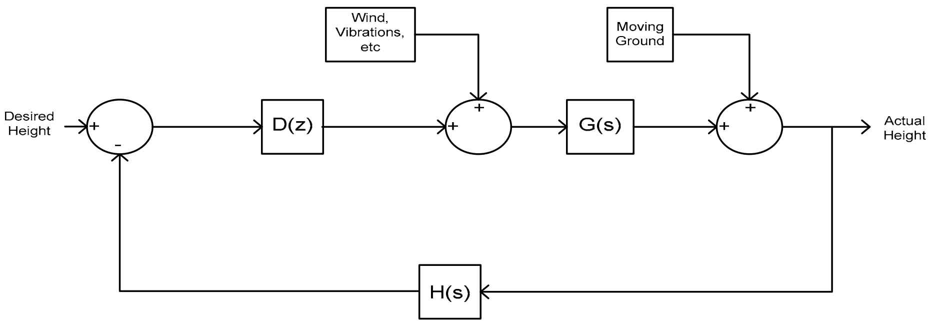

Fig. 1: General system block diagram.

The moving ground can be viewed as a disturbance that is present after the sprayer transfer function. This makes sense since the actual height of the boom can change without changing any inputs to the sprayer. The disturbance to the system can come from mechanical vibrations because of the unevenness of the ground and because of wind.

The controller currently used is a simple proportional controller with dead band. When the system is calibrated, the user has to turn a potentiometer to control the duty cycle until the booms are perfectly level and this is the duty cycle the processor will output to hold the booms still. The user then has to turn another potentiometer to adjust the up speed of the boom. Once the proper raising rate is found the processor uses the duty cycle whenever the booms need to be raised. The user does this once more for the lowering portion of the controller. While this sounds easy it often takes the user a long time to actually get everything set up.

One of the major problems with this type of control and setup occurs when the temperature changes. As the temperature of the hydraulic oil increases, the booms will begin to sag because the pressure starts to drop. The booms can start to bounce because the hold duty cycle allows the booms to slowly drop (with warm oil) and when they are at the bottom of the dead band the raise duty cycle is output. This cycle continues to repeat causing the booms to oscillate.The dead band is needed in this controller to reduce oscillations. Since the duty cycle output is not infinitely adjustable based on the error, the booms will start oscillating when the dead band is reduced too much. Unfortunately, this dead band can introduce problems at higher speeds.

A fuzzy controller algorithm was developed for this system. This will be discussed in detail in the next sections.

3. Fuzzy Controller Details

A simple fuzzy logic PD controller [3] was used but the new output of the controller was added to the previous output. This essentially made it a type of PID controller with a very fast integral. The block diagram for this controller is shown in Figure 2.

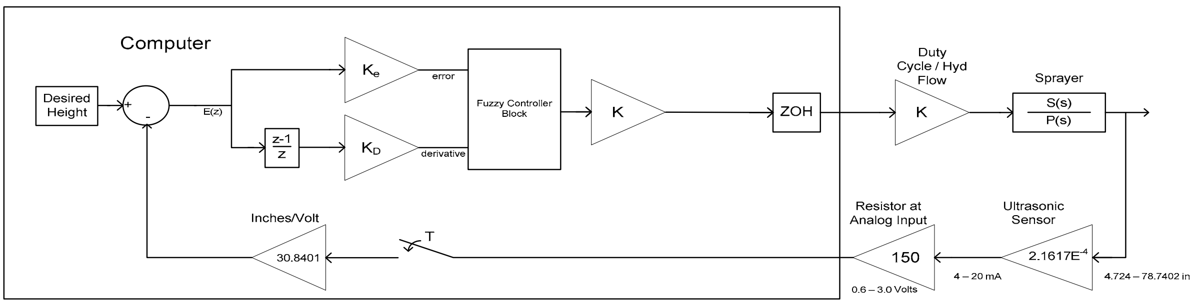

Fig. 2: Block diagram of system with control effort feedback.

Seven membership functions were used for the proportional input and the output while only five membership functions were used for the derivative input [4]. Seven membership functions were used to give the controller more non-linearity at the extremes. The error (proportional) input membership functions are shown in Fig. 3. The units shown in all figures are inches for distance and seconds for time. All functions are increased or decreased by the tolerance so the slopes of the functions are independent of the tolerance.

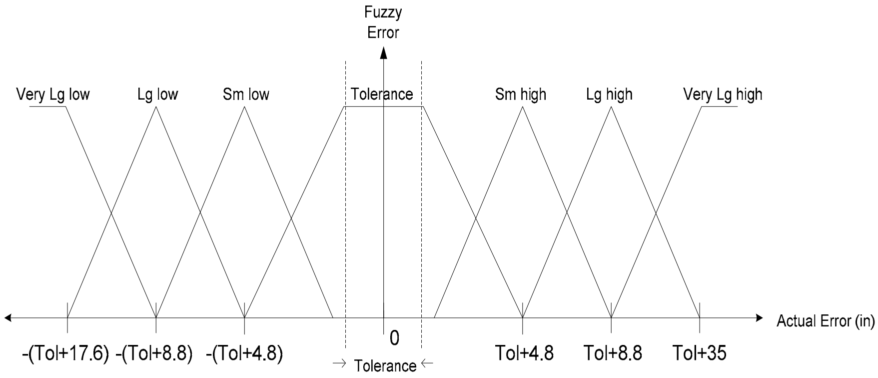

Fig. 3: Membership functions of error.

The delta error (derivative) input membership functions are shown in Figure 4. A tolerance was also used in the delta error. This was necessary in order for the machine to find the static output needed to hold the boom steady. If the tolerance was set to zero the output would keep changing minimally due to high frequency in the delta error. The delta error tolerance in the first control algorithm was set to zero.

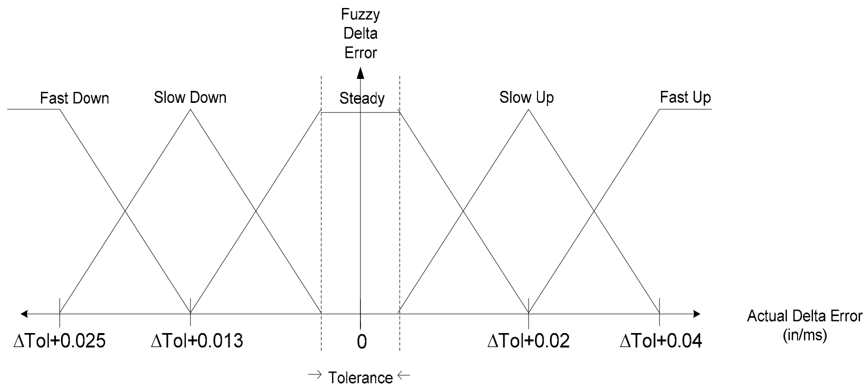

Fig. 4: Membership functions of delta error.

The output consists of seven membership functions, shown in Figure 5. The membership functions did not change between the controllers but the controller output gain, K in Figures 2 and 4 changed significantly. K was set to 0.35.

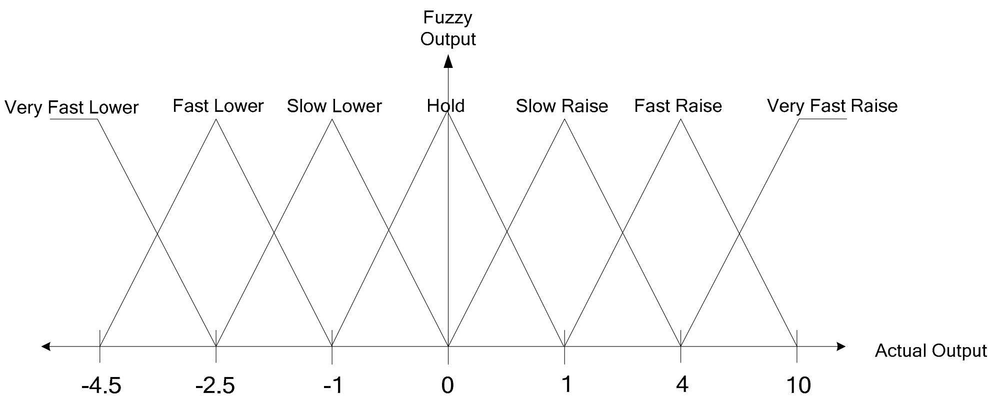

Fig. 5: Membership functions of output.

Due to the non-linearties of the system and the controller, some multipliers were needed to make the controller work properly. Once these values were set and the system was working nicely, a surface plot of the output was created with Matlab. The remaining multipliers in the system were set to make the surface plot smooth and eliminate sudden changes in the output. The output Rule Matrix is shown in Table 1 below.

Table 1: Rule Matrix for Fuzzy Logic Controller

	Fast Down	Slow Down	Steady	Slow Up	Fast Up
V Large Low	1.5 * FR	1.0 * FR	2.0 * SR	1.0 * SR	1.0 * SL
Large Low	1.5 * FR	1.0 * FR	2.0 * SR	1.0 * SR	1.0 * SL
Small Low	1.0 * FR	1.5 * SR	1.0 * SR	1.0 * Hold	1.0 * SL
Tolerance	1.2 * SR	1.0 * SR	1.0 * Hold	1.0 * SL	2.3 * SL
Small High	1.7 * SL	1.0 * Hold	1.0 * SL	1.5 * SL	1.0 * FL
Large High	1.0 * SR	1.0 * SL	2.0 * SL	1.0 * FL	1.5 * FL
V Large Hi	1.0 * SR	1.0 * SL	2.0 * SL	1.0 * FL	1.5 * FL

The weighted average method was used to calculate the output and the minimum of the inputs was used for the weight

4. Results and Conclusions

The controller works flawlessly when the machine isn't moving but it slowly oscillates when driving through the field. The oscillations really can't be seen well in the figure but they were quite apparent when driving the machine. Since the hydraulic system responds slowly, the output of the controller will quickly saturate. Once the boom starts moving the controller saturates the other way. By selecting the proper sampling time this issue was overcome but it is still a very serious problem that needs to be dealt with. Data was collected for two different sprayers with the original controller and with fuzzy controller. The tractor was driven at 20 miles per hours and speed and route was kept same for all the test runs.

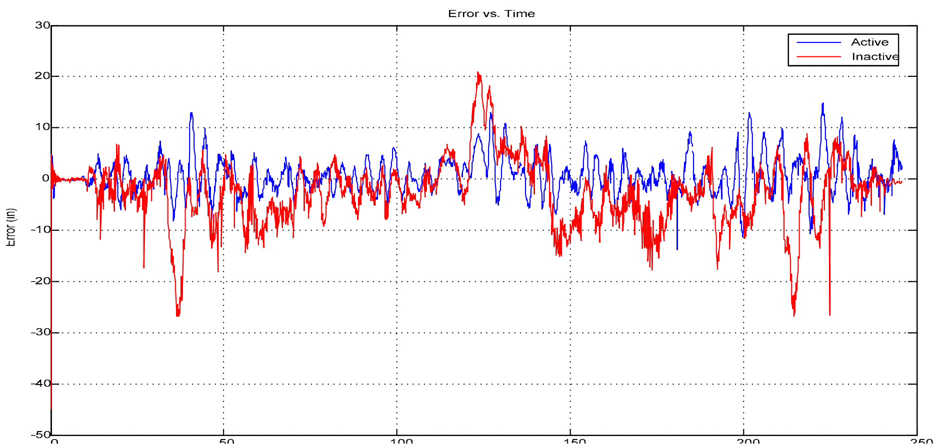

Fig. 6: Height error on Ro-gator sprayer at 20 mph with fuzzy and original controller.

Figure 6 compares the error in maintaining a fix height on the Case sprayer (90 ft boom) when the controller was active and inactive. Here we mean active when the fuzzy controller is engaged and inactive means that fuzzy controller was disengaged and only the original controller is working. The most improvement can be seen where there are the largest errors. The frequency of the "moving ground" disturbance is high enough that it is impossible for the hydraulic system to respond quickly enough to give zero error. However, where the errors get large (like when the boom is close to the ground) the controller does its job by keeping the booms off the ground.

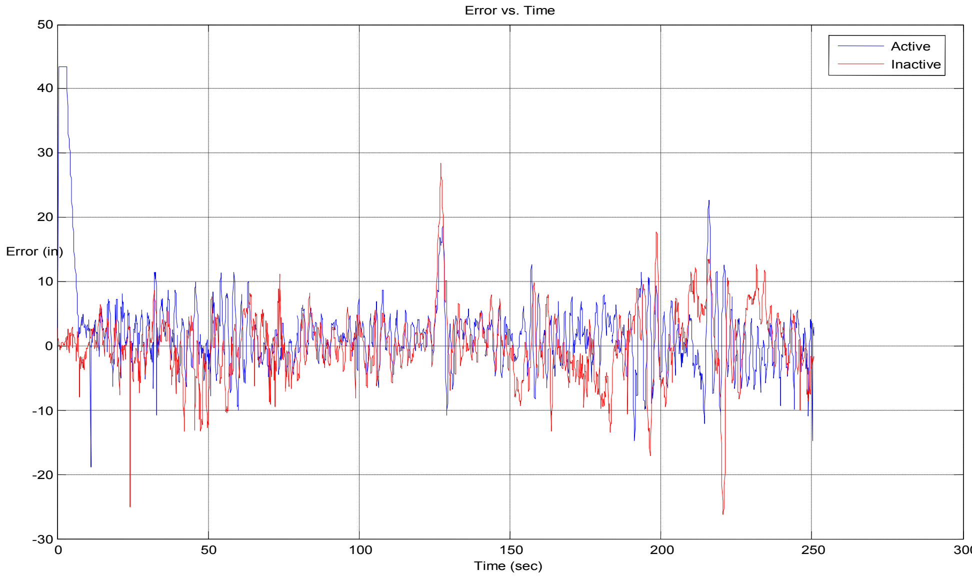

Fig. 7: Height error on Case sprayer at 20 mph with and without fuzzy controller.

Figure 7 compares the errors on an 874C Ro-gator (100 ft boom) when the controller is both active and inactive. Once again the most improvement can be seen when the height is the farthest away from the desired point. One of the most noticeable differences between inactive and active control on the Ro-gator is that the inactive controller tended to consistently ride too low. The active controller seems to be centered very well near zero error.

For the most part, the controller keeps the boom within 10 inches of its set-point. While this may seem poor, it must be pointed out that when traveling at 20 mph with a sampling time of 100 milliseconds there is a gap of 3 ft between samples. Although it is hard to see in these figures, it seems to take up to 0.5 seconds before the boom can respond to a change in the controller output (depending on how substantial the change). This corresponds to 15 ft passing by before a change in height can occur. While this number may be smaller for some booms it seems to be about the same for booms in the 100 ft range.

Unfortunately, if you compare the amount of time the boom spends within 4 inches of the set-point when the controller is active and inactive there is really very little difference. The Ro-gater had about a 15% improvement within 4 inches when the controller was active and for the Case sprayer the was only about 4%. This does not mean the controller is ineffective, it simply means that it doesn't keep the boom in as tight of a band as we would like. The speed of the implement and the response times of the hydraulic are the biggest factors in this. It is quite apparent from the figures that there is significant improvement the further away from the set-point the booms get.

5. References

[1] Vern Hofman and Elton Solseng, "Spray Equipment and Calibration". Report published by Agricultural and Biosystems Engineering. North Dakota State University, 2004.

[2] Feng Chao, "Effects of spray height and spray angle on spray deposition in tobacco plants" Paper presented on 6th IEEE Conference on Industrial Electronics and Applications (ICIEA), June 2011.

[3] Vineet KUMAR, K.P.S. RANA and Vandna GUPTA, "Real-Time Performance Evaluation of a Fuzzy PI + Fuzzy PD Controller for Liquid-Level Process" International Journal of Intelligent Control &Systems VOL. 13, NO. 2, JUNE 2008, 89-96.

[4] K. M. Passino and S. Yurkovich, "Fuzzy Control", Menlo Park, CA: Addison Wesley Longman, 1998.