Control System for Lamp Luminosity

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Abstract

This paper details a project in which a PID system controls the brightness of a DC light bulb by varying the duty cycle of the voltage through the bulb. Practical applications of this idea include an automatic dimmer that responds to a desired light level. Possible areas that would require constant light are a green house, a library, or in a house to conserve power. In addition, the system could be adapted to measure temperature instead of luminescence, allowing for a temperature control system. Future work on this project could include motorizing the bulb socket to relocate the bulb to lower light areas and using offset values to account for ambient light levels.

Introduction

This project implements a PID controller with the HCS12 micro-controller in order to control the brightness of a light bulb by varying its input voltage. The system will judge the brightness of the light bulb by obtaining voltage readings from an array of three photo-sensors that vary their voltage based on their detected luminescence. In order to achieve a desired brightness, the system utilizes a micro-controller that takes the voltages from the sensors, discretizes them, and compares the input with a user defined level. Before the controller begins to adjust the output, the micro-controller averages the values from the sensors together. The PID controller then attempts to compensate for any differences between the input and the desired value by adjusting the duty cycle of the voltage to the bulb making the lamp glow brighter or dimmer. This voltage will remain constant until the next sample is taken and the controller varies the voltage again based on the PID algorithm. This process is repeated until the desired brightness is achieved.

Procedure

Our sample data is obtained from an array of three photo-sensor circuits whose outputs will be averaged together on the micro-controller. Each of the three photo-sensors consists of a photo-transistor connected to the inverting terminal of a trans-impedance amplifier. These photo-transistors are a special type of a photodetector that work by varying their output current based on the level of luminescence detected by the diode. Because the ADCs require a voltage input, we must use the trans-impedance amplifier to convert the current from the photo-transistor into a usable voltage. In addition, the project also required that the photo-sensors be characterized; that process will be discussed later on in the results section.

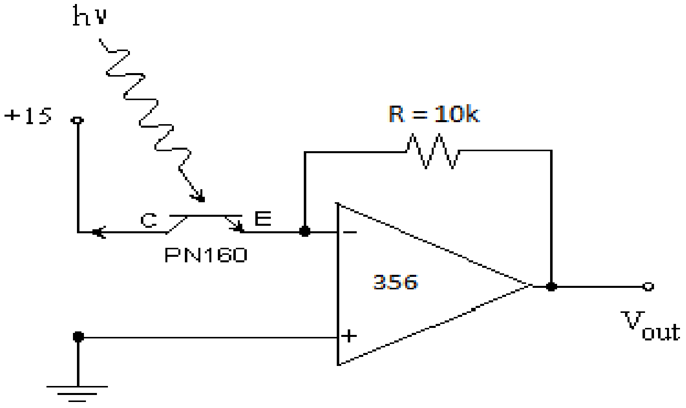

Figure 1: Optical Sensor

The above circuit produces a voltage value, $V_{OUT} = -R*I_{IN}$, where R is 10kΩ. Because the trans-impedance amplifiers are in an inverting configuration, the signal is conditioned by connecting each sensor's output to a separate inverting amplifier. These inverters use equal input and feedback resistors, resulting in a gain of -1.

Each of the outputs from the inverting amplifiers are then attached to an ADC pin of the micro-controller. Within the micro-controller, the digitized values from the three sensors are averaged together for simplicity before being subtracted from the reference value set by the user. This error is then fed to the PID controller algorithm.

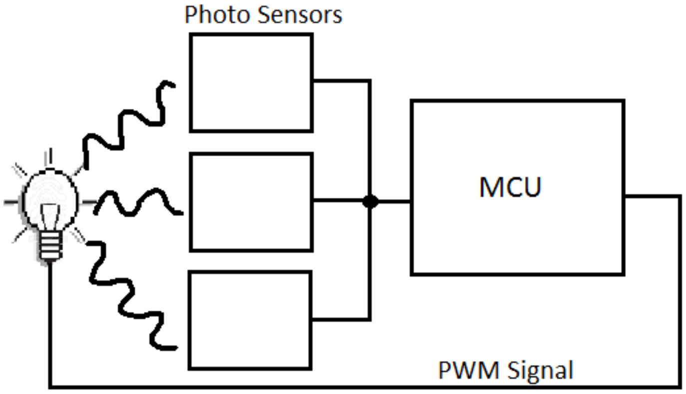

Figure 2: System block diagram

The PID controller uses a feedback loop to control the PWM output of the MCU. Within this loop, the controller uses a combination of the previous output, the current error, and the previous two errors to estimate what adjustments must be made to reach or maintain the desired output. If the controller is reading a smaller luminescence than the desired value, the duty cycle of the output signal will be increased, if it is lower, it will be decreased.

$$u(t_k) = u(t_{k-1}) + K_p \left[\left(1 + \frac{\Delta t}{T_i} + \frac{T_d}{\Delta t} \right) e(t_k) + \left(-1 - \frac{2T_d}{\Delta t} \right) e(t_{k-1}) + \frac{T_d}{\Delta t} e(t_{k-2}) \right]$$

Figure 3: Discretized implementation of a PID controller

K_p for this project was defined as 2*Zeta*W_n*K_d, where K_d is varied by the user (a value of 0.7 was eventually selected). In addition, values of Zeta = 0.7 and $W_n = 1/(\tau * \text{Zeta})$ were used. The value of τ was determined by analyzing the response time of our ADCs and was found to be 0.035s. T_d is defined as K_d/K_p and T_i is defined as K_p/K_i, where $K_i = K_d * W_n^2$. Once a value for $u(t_k)$ is determined, it is converted to a duty cycle by dividing it by 756.4425 and then multiplying it by 0.0733. This signal is then output to the base of a 3904 NPN transistor whose collector and emitter pins are connected to +15v and the light bulb respectively. This configuration allows the transistor to be used as a sort of switch, only allowing current to flow from the collector to the emitter when the base voltage received from the PWM pin of the MCU is high.

Results/Discussion

The characterization of the photo-transistors was performed by plotting the average of the photo-transistors versus the resulting duty cycle of the system. The graph was then used to produce a best fit line whose slope could be used in the code.

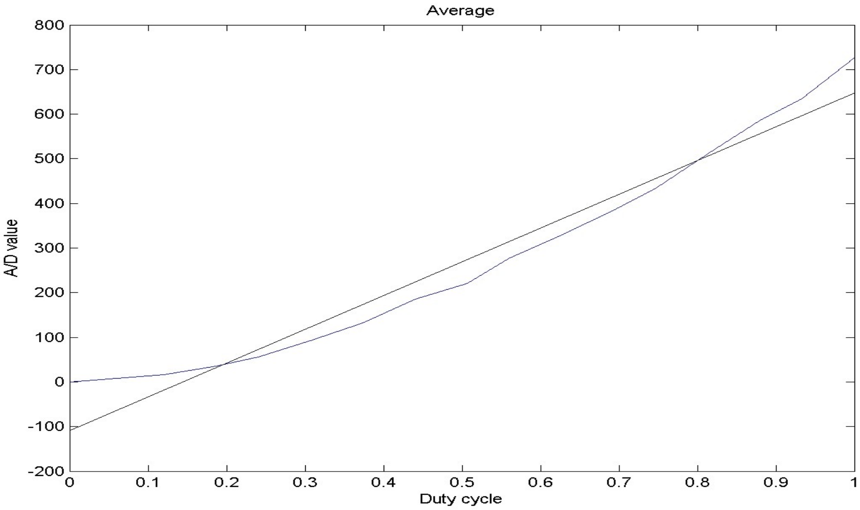

Figure 4: Photo-transistor characterization

Once the system was complete, several tests were run to observe the response of the system to a changing reference level. The following graphs show two tests run with the complete system at K_d values of 0.3 and 0.7.

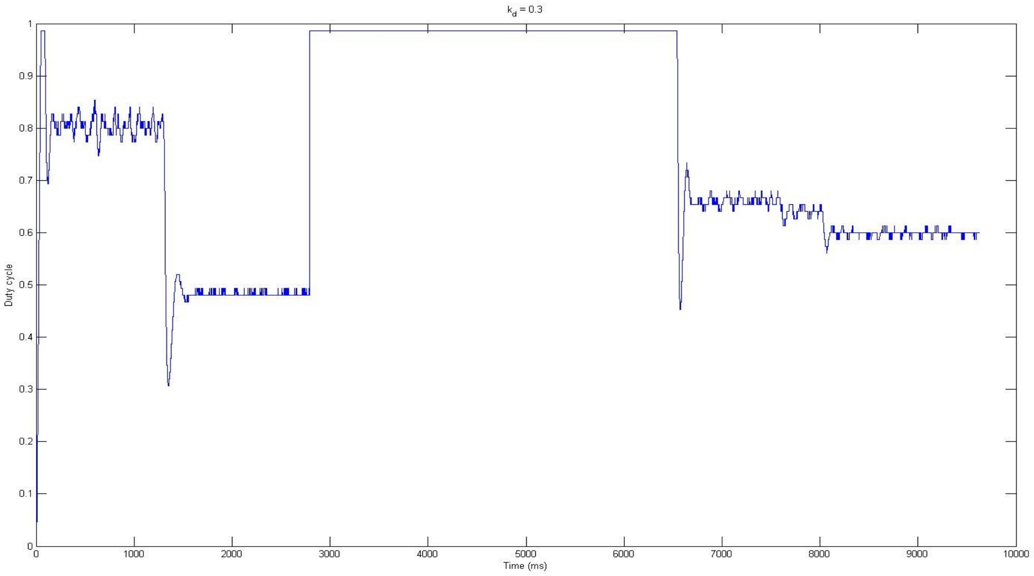

Figure 5: PID controller with K_d of 0.3

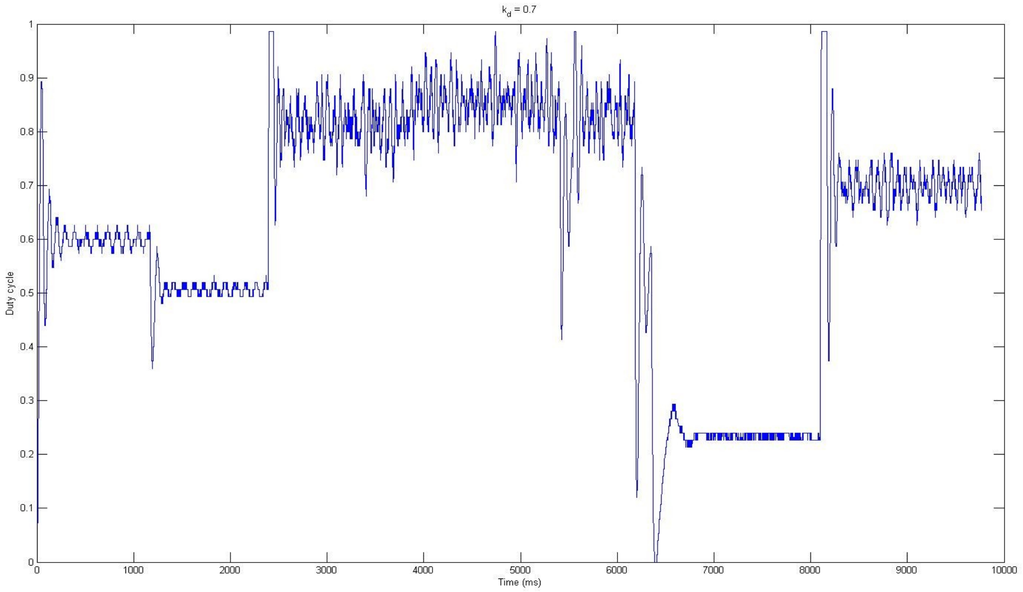

Figure 6: PID controller with K_d of 0.7

As seen in the graphs, a higher K_d value results in a decrease in the overshoot of the system, but increases both rise time and settling time. This is consistent with the established behavior of the PID controller. It was also observed that a higher K_d makes the system more susceptible to noise, as shown in Figure 6 between approximately 250 and 600 ms. In addition, Figure 5 demonstrates how the system responds to too high a PWM value; when the controller requests too high a value, the system will simply rail at a 100% duty cycle.

Conclusion

In conclusion, this project was an interesting experience in working with photo-transistors, trans-impedance amplifiers, and implementing a PID on a micro-controller to successfully control a system to achieve a constant desired result. Some problem areas were learning how the photo-sensors worked, interfacing the sensors with the micro-controller, and the implementation and tuning of the PID controller.

Future work on this project could include individually weighting the ADC values prior to averaging them to account for differences in the behavior and location of the different photo-sensors. It may also be desirable to measure the ambient light levels so that they can be accounted for in the controller's calculations via some sort of offset. In addition, a mechanical portion could be implemented that moves the light bulb in response to changing levels detected by the photo-sensors.