Application Note Template

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1 Design Overview

This application note demonstrates the operation of a fan controller using a PID controller. This controller has the ability to read from a thermistor and set a fan to a given temperature based off of that read temperature. This temperature has the ability to be transmitted over uart. The fan turns off when the temperature is less than the given threshold. Additionally, all of this was done in less than 1 kb.

1.1 Design Features

- standard 9600b operation
- sleep mode utilization for lowest power consumption possible
- PID controller to maximize efficiency
- Thermistor use and calculation for low cost

1.2 Featured Applications

A few featured applications of this fan controller are:

- CPU/GPU fans
- heaters
- PC case fans

1.3 Design Resources

This project is open-source and available on github.
The project can be found here: Project link.

1.4 Block Diagram

Here is a basic block diagram of the fan controller

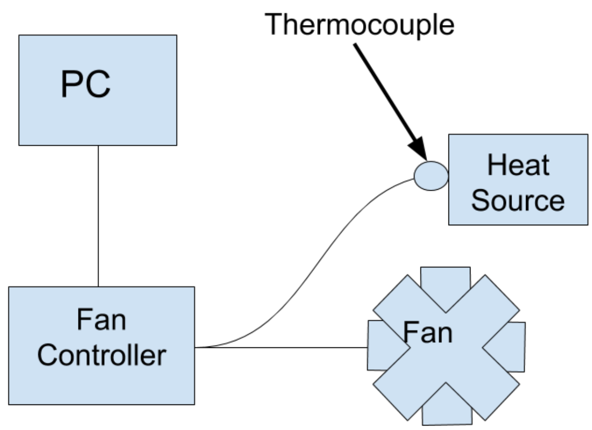

Figure 1: Block diagram of system

1.5 Board Image

Below is a photo of the latest stable design. This includes the microcontroller and surrounding circuitry, thermistor, power regulator, oscilloscope probe, and the fan. Not pictured: power resistor, usb-uart converter, power supply and the microcontroller programmer. However, the connections for these are all visible.

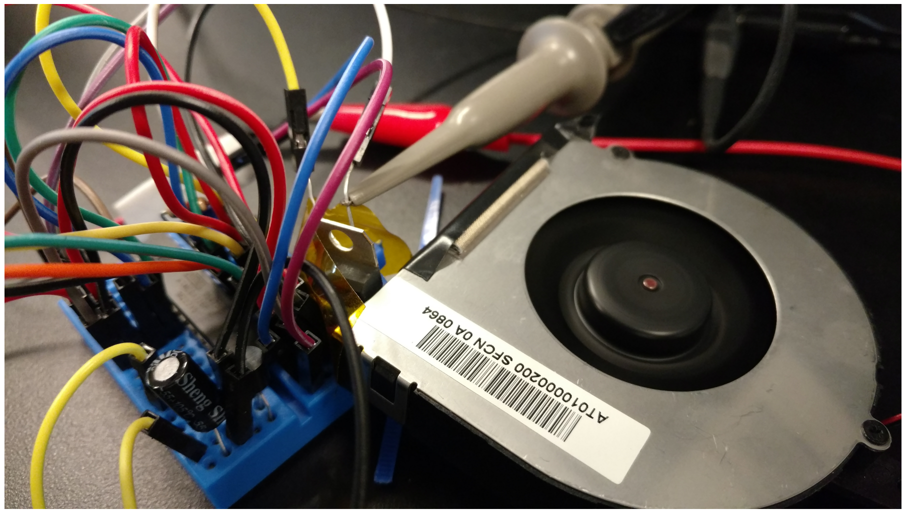

Figure 2: Photo of latest stable design

A further design was made in KiCad, and is visible below:

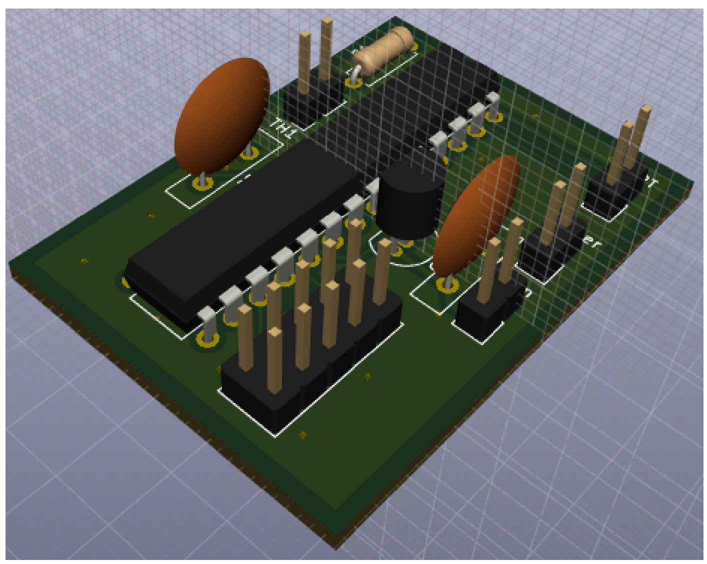

Figure 3: KiCad board visualization

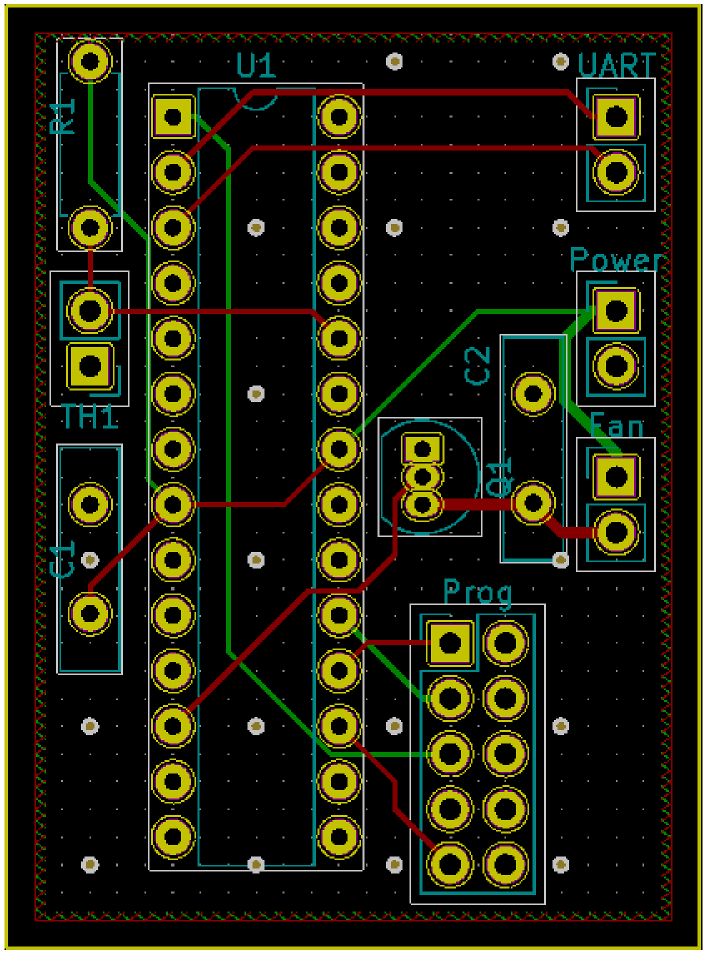

Figure 4: KiCad board design

2 Key System Specifications

This design operates off a single 5v supply. The fan, thermistor, and microcontroller all operate on 5v logic. A 5v linear voltage regulator was used off of the same 12v supply.
The specifications are as follows:

Microcontroller	AtMEGA328p
Baud Rate	9600 baud 8N1
voltage	3.3v-5v
File size	872 Bytes
lowest usable temp	-10 C
Highest temp usable	110 C

Note that the temperature range is given so that there is no more than 5% error in the read temperature. It can operate outside of this range, but performance is not guaranteed.

3 System Description

3.1 Detailed Block Diagram

Below is a more detailed image of the basic structure of the microcontroller and what it's interfacing with.

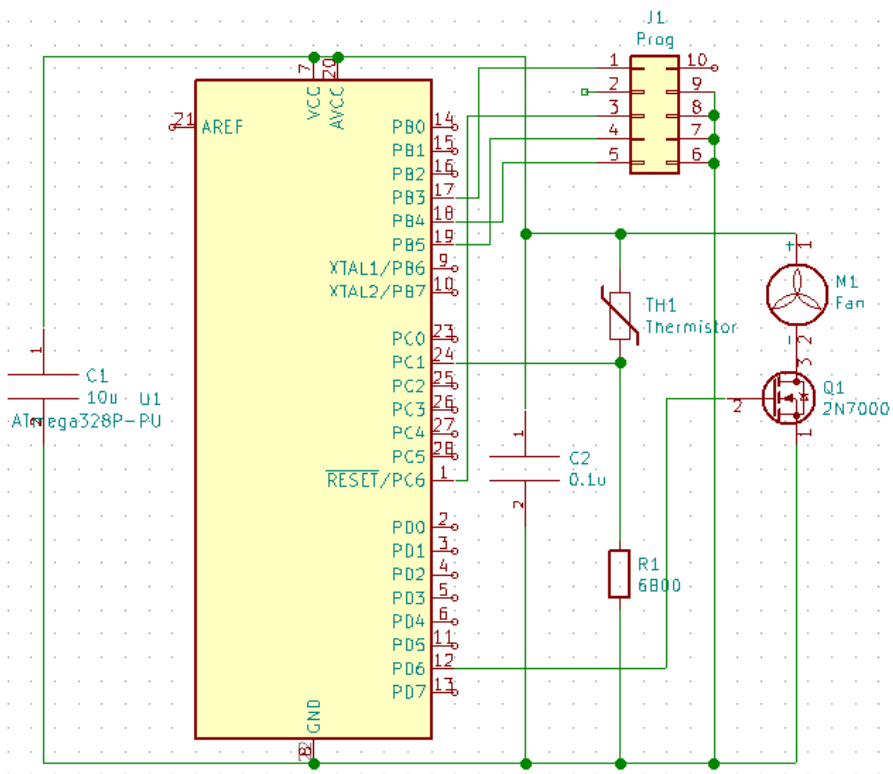

Figure 5: KiCad Schematic

3.2 Highlighted Devices

- ATMEGA328p-pu -Microcontroller used for the fan controller.
- Thermistor -Temperature sensing device
- 2N7000 -Fan driving transistor

3.3 ATMEGA328p-pu

This device is a low power 8-bit microcontroller offered by Atmel with 2 8-bit timers and 1 16-bit timer. In this project, an 8-bit timer was used in fast PWM mode, and a 16-bit timer was used in fast CTC mode, and the USI is used as a UART transceiver. The 8-bit timer is used for PWM driving the transistor, and ultimately the fan. 872 bytes of the 32 KB flash were used. 48 bytes of the ram were used. The absolute maximum current consumption, sourcing or sinking, is 20 mA with a maximum of 200 mA for the entire package.

3.4 Thermistor

This device is a through-hole two pin thermistor. This device has a temperature characteristic visible below:

$$\frac{1}{3.354016 * 10^{-3} + 2.569850^{-4} * ln(R)} \tag{1}$$

where R is resistance. This is the first two terms of the Steinhart and Hart Equation. Below the input voltage Vs. The temperature calculated is visible. Instead of making the microcontroller do several logarithms and float divisions, the equation was simplified to two equations.

1. T(v) = 21v - 17
2. T(v) = 45v - 106

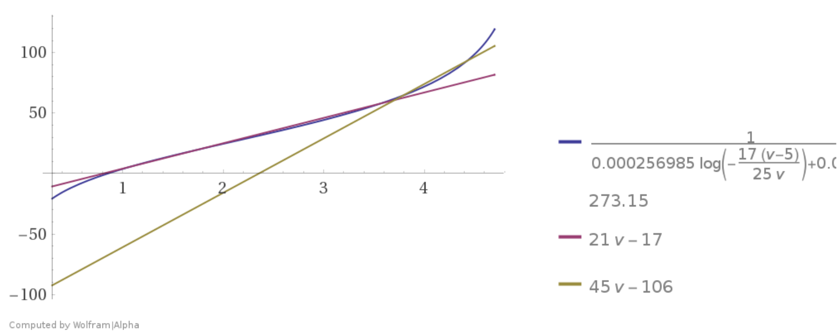

Figure 6: Voltage vs temperature

3.5 2N7000

This device was used as a low side switch to switch the fan. The fan needed 100 mA, and that is well within the 250 mA max current rating. Any MOSFET with an I_{max} higher than 200 mA may be used.

4 SYSTEM DESIGN THEORY

This design required reading an analog voltage from the thermistor using an ADC, calculating the temperature, and set a PWM value for a fan. This occurs until power to the system is removed. The PWM value for the fan is set using a PID controller. The PID controller has a specific equation that is followed. This is visible below:

$$u = K_p e + K_i \int_0^t e dt + K_d \frac{d}{dt} e \qquad (2)$$

This is then modified so the microcontroller can easily compute it.

$$u = K_p e + K_i \Sigma_0^t e + K_d (e - e[t-1]) \qquad (3)$$

This PID controller uses three calculations and sums the result. Initially, it calculates the error from a reference temperature. The error is then multiplied by a constant, and this is the Proportional component of the PID. For the integral, all of the past errors are summed up and multipled by a constant. For the D term, the previous error is subtracted from the current error, and multiplied by a third constant.
Because of the limits of unsigned numbers, the p and i terms had to be kept positive. For example, if we just use the proportional term and if the current temperature is one bit over the reference temperature, an underflow will occur and the fan will be set to max speed.

4.1 Design Requirement 1

This design has one simple requirement: a fan needs to be set at a speed based off a read temperature. This was done successfully with a PID controller. There is some overshoot at lower temperatures (25 deg) and it quickly reaches temperature. Near higher temperatures (65 C), there is some oscillation because something as small as a slight draft can cause a 5 deg temperature change. These oscillations are within $\pm$ 1 degree C.

5 Getting Started/How to use the device

5.1 Connecting power

This is as easy as it sounds. Connect the following pins to Vcc and ground

- VCC - Pin 7,21
- GND - Pin 8,22

Please note that the input voltage needs to be somewhere between 3.3v and 5.5v. The controller can operate below this, but the temperature reading will be skewed.

5.2 Connecting the thermistor

This is just as easy as connecting power. The thermistor needs to be connected to Vcc and ADC1 (pin 24). a 6800Ω resistor needs to be connected from ADC1 (pin 24) and ground.

5.3 Connecting the fan

The fan is driven by a 2N7000 acting as a low side switch. Connect the fan to Vcc and the source of the MOSFET. Connect the gate to OC0A (pin 12), and the drain to ground.

5.4 Connecting UART

If you wish to read the temperature out and set the temperature manually, UART will need to be connected. RXD is pin 2 and TXD is pin 3. The UART is 9600B 8 bits, no parity, 1 stop bit. The default temperature is set to 30 C, but that can be set by entering the temperature in C and hitting enter (¡CR¿).

6 Getting Started Software/Firmware

6.1 Programming the device

Before this tutorial, you need to have avr-gcc, avrdude installed.
First, you connect your favorite In-system-programmer in SPI.

- MISO - Pin 18 (PB4)
- MOSI - Pin 17 (PB3)
- RST - Pin 1 (PC6)
- SCK - Pin 19 (PB5)
- VCC - Pin 7
- GND - Pin 8,22

Following this, you need to make sure the device is connected. Open your favorite terminal and run

```
$ avrdude -c usbasp -p m328p
```

The fuses should be E:FF, H:D9, L:E2. If not, refer to here for writing fuses. following this, in the "atmega328p" folder, fun the following command:

```
$ make install
```

This will program the device and verify the chip to make sure that it's programmed correctly. This program uses 872 bytes. The node should be completely setup and ready for use. If an issue is encountered and a solution cannot be found, please search AVRfreaks. If an issue is still not found, feel free to make a post on that website, as it is one of the largest microcontroller communities on the planet.

7 Test Setup

For setup, please refer to the previous section "Getting Started/How to use the device"

7.1 Test Data

The temperature is outputted over UART at approximately 10 Hz. it gives the current temperature and the reference temperature with a tab dividing the two. This simple format can make a PC interface a breeze.

8 Design Files

8.1 Schematics

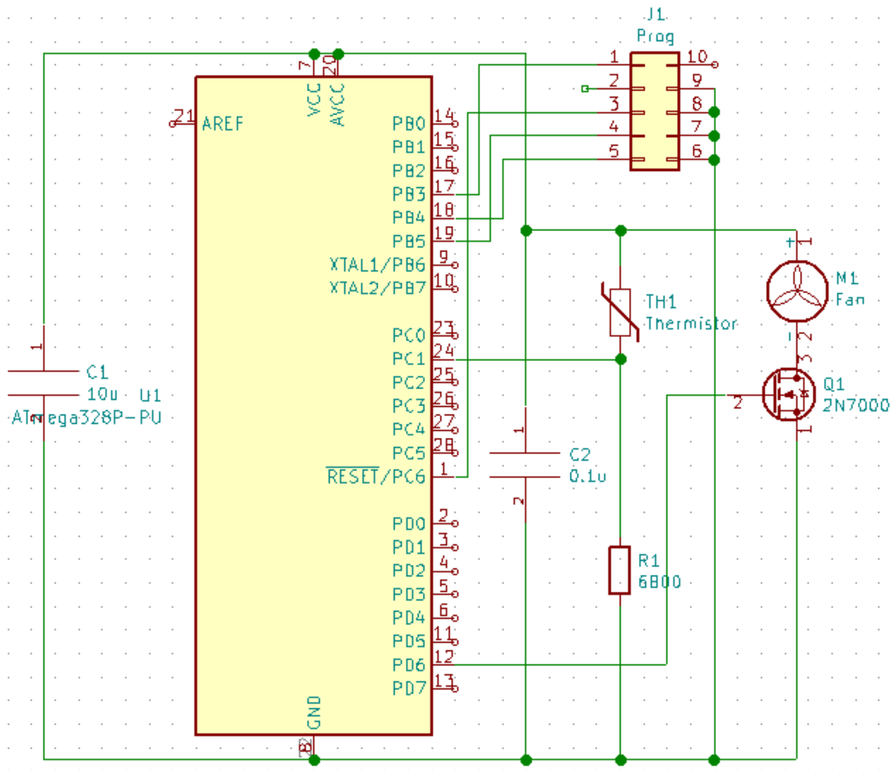

Figure 7: Schematic of system

8.2 Bill of Materials

This bill of materials is priced in quantities of 1000. If surface mount components are used, price can be significantly reduced.

ITEM	QTY	PRICE/EA
ATMEGA328p-pu	1	$1.45
1/4 Carbon Film Res 6800Ω	1	$0.01
0.1 uF capacitor	1	$0.04
220 uF capacitor	1	$0.06
35mm x 47mm breadboard	1	$0.14
TOTAL		$1.70