Closed-Loop Temperature Control using MSP430F5229

Jan Garcia and Anwar Hussein
Rowan University

December 3, 2018

1 Design Overview

The MSP430F5229 microcontroller is designed as an closed-loop system control to interface based on a temperature control system. The control temperature is measured, processed and compared to a desired temperature. A fan speed control algorithm similar to a "Bang-Bang" controller is used continuously as a closed loop temperature controller for a brush-less DC fan. The application uses analog-to-digital conversion, UART communication and performs hardware PWM to address the speed of the fan.

1.1 Design Features

The MSP430F5529 microcontroller was chosen to be used for this application note. These are several of the design features demonstrated using the MSP430:

- ADC for Temperature Control
- UART Communication
- Hardware PWM
- USCIA0 ISR

1.2 Featured Applications

- Control Cooling Fan Applications
- Smart Air Conditioner (AC)
- Closed Loop Control PC Fan

1.3 Design Resources

For more information about this product or code used in this AN click on the following link:
introtoembedded-f18-milestone2-convertoboxers/Closed Loop Systems/main.c/

1.4 Block Diagram

Figure 1 shows a block diagram how the closed loop system was built using a MSP430, a fan, a voltage regulator, and a thermistor. The MSP430 controls the fan with a 3.3 V using a low side switch. A voltage divider was used with the NTC thermistor to collect the voltage read from the thermistor. The ADC collects the analog voltage from the voltage divider and converts it to digital. Finally, the MSP430 is in charge of calculating and adjusting speed of the fan from the feedback loop, thus creating the closed loop system.

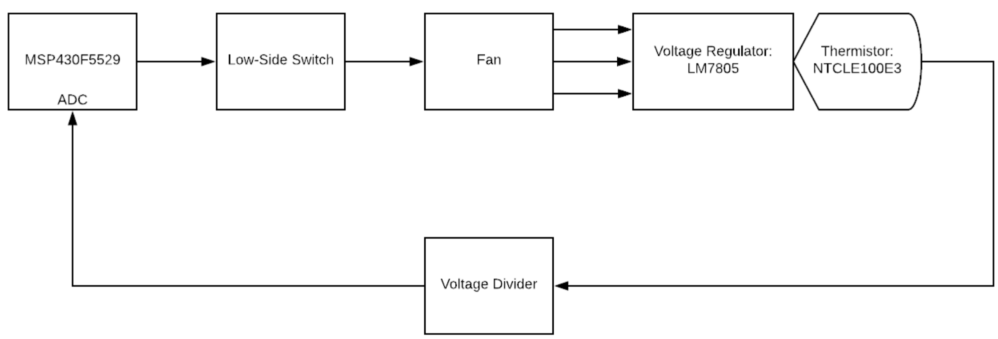

Figure 1: Block Diagram of Closed Loop System

1.5 Board Image

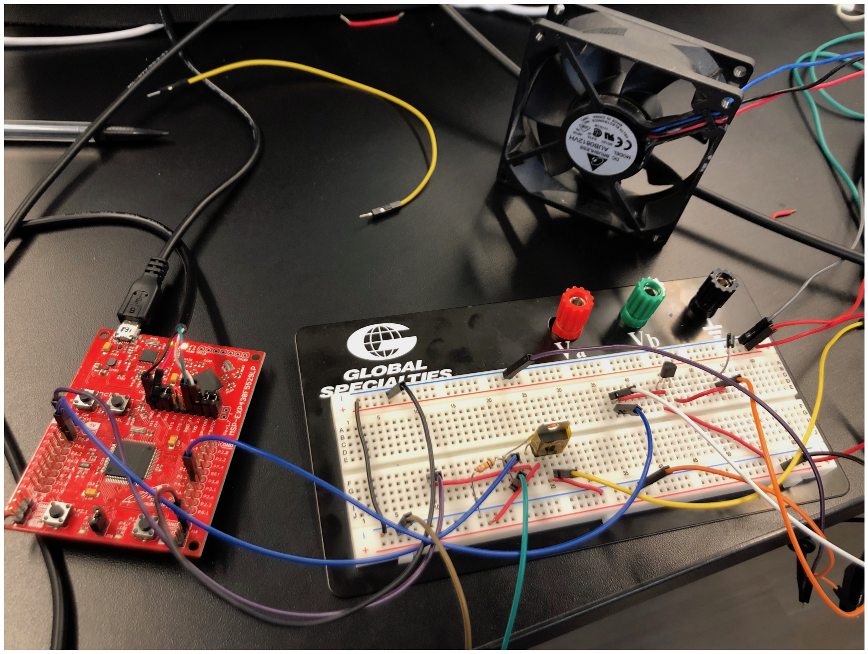

Figure 2: Breadboard Image of Circuit

Figure 2 shows the setup of the MSP430F5529 wired to a breadboard with the fan, voltage regulator, and the thermistor that is physical touching the voltage regulator for accurate temperature reading. In addition, the fan was rated at 12 volts and was fed with a +12VDC on one end and connected to the collector pin of a NMOS on the other. Initially, this fan was directly pointed at the voltage regulator approximately three inches away. The position of the fan was changed throughout the procedure to test system performance. This is explained later in the system performance section of this AN.

2 Key System Specifications

The table below shows some of the specifications the system is able to perform and is required for the application. The microcontroller accesses its ADC12 and Timer A peripherals to perform these calculations, and then outputs to a select set of pins. The signals generated from these pins are then used to drive the hardware, which in turn, affects the environment of the system itself.

PARAMETER	SPECIFICATIONS	DETAILS
Microcontroller	MSP430F5529	Used for ADC peripheral, and timer peripheral.
NTC Thermistor	NTCLE100E3	Used for reading the temperature.
Fan	NMB 3610RL-04W-S66	For cooling the system.

3 System Description

When the temperature of a room changes, the actual temperature is fed back into the closed-loop system and compared to the set point temperature, and the controller then controls the mechanisms and processes that manage the output (hot or cold air generation and flow). Closed-loop systems help address this problem by adding some type of feedback that allows the control system to make changes to its processes. The input, feedback, and output are constantly monitored and compared. The output is updated, often at defined a periodic rate. The amplification phase essentially runs over and over again to produce a constantly changing output.

3.1 Detailed Block Diagram

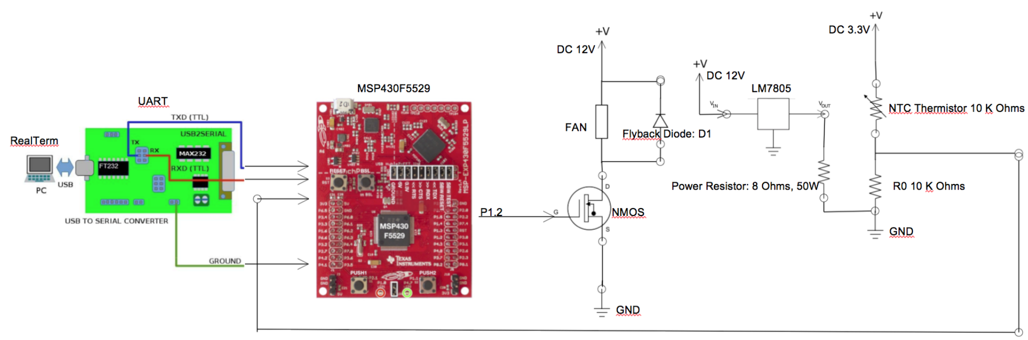

Figure 3: Closed-Loop System Diagram

3.2 Highlighted Devices

- MSP430F5529 - Microcontroller

3.3 MSP430F5529

The MSP430F5529 processor was chosen to be used for this application note. The F5529 has enough hardware addressable pins from the timer modules for hardware

PWM applications. Additionally, the F5529 is one of the easier of the family of processors for PWM and UART applications. The MSP430 family of ultra-low power microcontrollers consists of several devices featuring peripheral sets targeted for a variety of applications. The architecture, combined with extensive low-power modes, is optimized to achieve extended battery life in portable measurement applications. The microcontroller features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency.

4 SYSTEM DESIGN THEORY

Our project implements a system that controls the temperature of an object to maintain a desired temperature. In our implementation the temperature is controlled by a fan that is run by a pulse width modulation (PWM) output of a micro controller. A low-side switch is implemented by using NPN BJT to control the fan speed. The fan runs on a 12V DC input and the PWM output of the micro-controller.

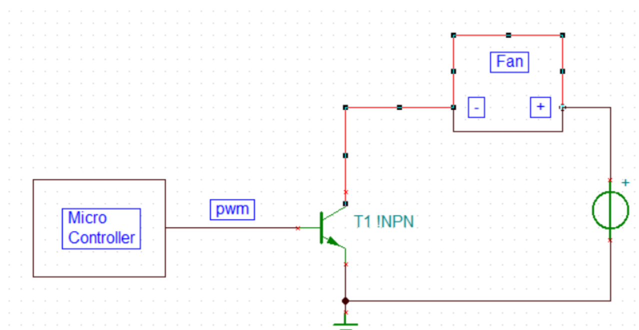

Figure 4: Low Side Switch using NPN BJT

The temperature value of the heating object (the voltage regulator in our case) is detected by using a thermistor and the value is read by the micro controller. The microprocessor's Analog digital converter takes the varying resistance value and calculates the PWM to control the speed of the fan. To determine the the relationship between resistance vs temperature we have used the **Steinhart and Hart Equations**.

$$\frac{1}{T} = A + Bln(R) + C(ln(R))^3 \tag{1}$$

The intended temperature value is set as a parameter and the ADC calculates the temperature difference between the intended temperature and the read from the termistor and will determine the speed of the fan. In addition to that the read of the thermistor will be displayed through a UART communication. The ASIC characters are used to display the characters that are displayed on the UART communication. That way we monitor the varying read of the ADC.

4.1 Hardware PWM

The MSP430F5529 was configure to hardware PWM (Pulse Width Modulation) and had to be used to control the duty cycle of the fan utilizing the Timer A peripheral from the microcontroller. The PWM purpose was to vary the different speed of the fan using a ”Bang Bang” control algorithm by determining the duty cycle percentage. A control variable for speed will essentially be comparing its value against the calculated temperature. The calculated temperature is the difference between the desired temperature and the current temperature. The PWM sets the duty cycle by pulsing the output of the microcontroller for a certain amount of time, hence the name pulse width modulation. Therefore, the microcontroller will be activating the clock peripheral as a hardware element and will let the pulsing be controlled by the clock as hardware PWM.

The microcontroller’s hardware PWM is done by initializing the timer modules to output to a timer output pin directly. In this application, the timer was set in UP mode and OUTPUT MODE 7: RESET/SET. When the timer is in UP mode, the timer will begin to increment until it reaches the values set by the capture compare register. This results in determining the period of the signal by the capture compare register. The capture compare register was set to 255 as this helped to map the values for the RGB to a duty cycle and create a 1kHZ signal. As the capture compare register periodically reaches its values, the output will perform the RESET/SET, then reset the timer and begin to increment again until the capture compare register value is reached. The PWM process can be view down below in Figure 5.

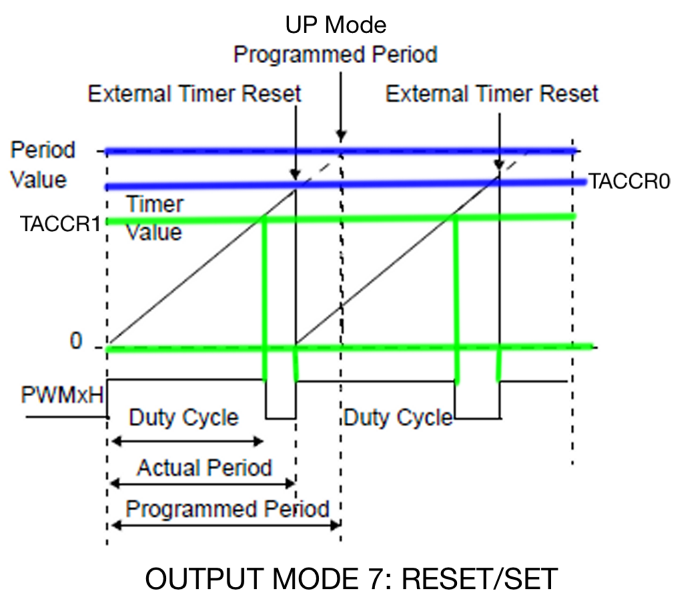

Figure 5: Hardware PWM Diagram

4.2 Temperature Sensing and ADC12 Conversion

The MSP430F5529 includes an analog-to-digital converter (ADC) peripheral. This module is capable of converting a require analog voltage output into a readable digital voltage value from the microcontroller. The module is a 12-bit ADC with a configurable voltage reference, V_{ref}, multiple input channels, and interrupt capabilities.

The 12-bit ADC is used to read the current temperature from the NTC thermistor through the LM35 voltage regulator. To read the voltage output from the thermistor, a voltage divider was used with the thermistor resistance (R_t) of $10K\Omega$ in series with another resistor (R_0) of $10K\Omega$. The thermistor resistance is found by the ratio of the ADC full range value (ADCmax) to the value returned by the ADC (ADCval). In this case, the ADC max used was 12-bits or 4095. Therefore, the ratio of the voltage divider with the ratio of the ADC values in the equation can be used to solve for R_t:

$$R_t = R_0((ADCmax/ADCval) - 1) \tag{2}$$

Once the value for R_t has been calculated, the Steinhart-Hart equation can be used to determine the thermistors temperature response curve.

4.3 System Performance

The performance of the system was designed to operate at a stable state within $\pm 3^oC$. The system is fully-operational in the range of 25^oC to 65^oC. Using UART and the oscilloscope reading, the system's operation was verified. The oscilloscope readings was able to read the voltage oscillations about the system's input temperature.

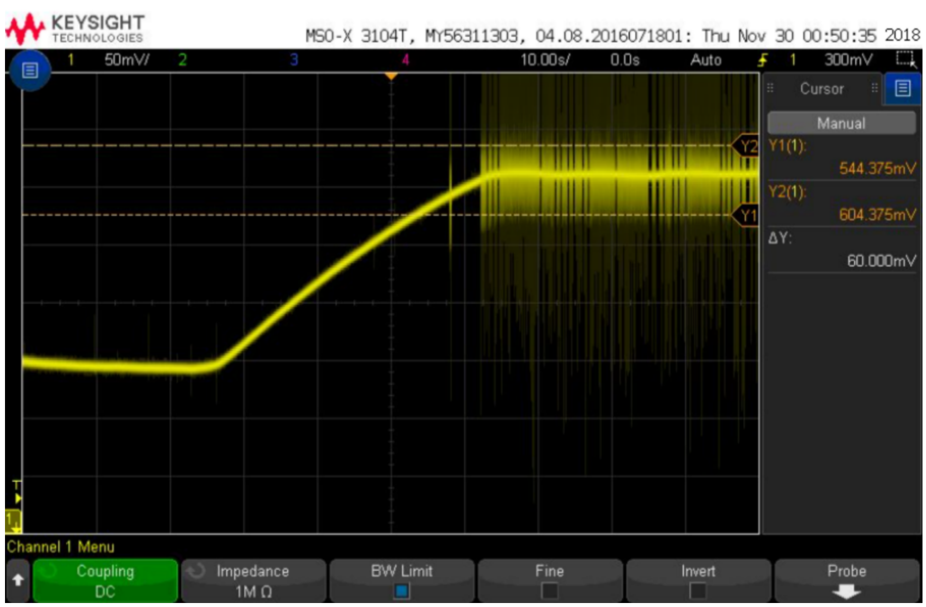

Figure 6: Steady-state Temperature read from the LM35 when heating

Figure 6 shows the temperature of the voltage regulator is at a steady-state temperature. The voltage regulator successfully heats up the system that maintains the regulator at that desired temperature.

4.4 Algorithm of the System

The overall system can be understood better by observing below the following diagram of how the algorithm works.

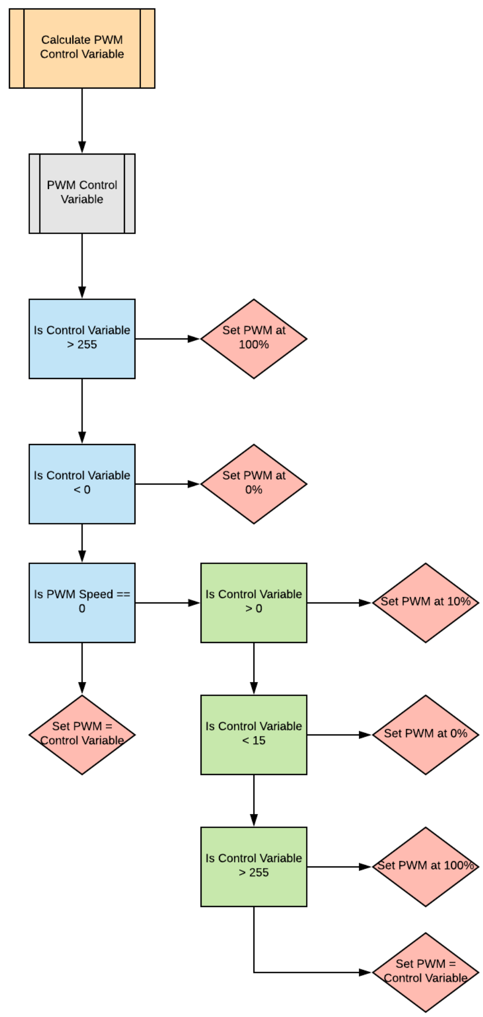

Figure 7: System Diagram

5 Getting Started/How to use the device

In order for our system to work as intended there are certain things that need to be made sure. The first and the most important one is the thermistor need to be setup in such a way that it is in contact with the heating device (voltage regulator). A 12 volt power source is required to run the fan. The negative terminal of the fan should be connected to the collector pin of the LSS (low side switch) and the positive terminal to the positive terminal of the 12 V power source. The base side of the LSS should be connected to the PWM output of the micro controller. its very important that the LSS and the micro-controller to have a common ground.

The second most important thing is the orientation of the fan. The fan should be on a 45 degree angle facing the heat source for intended temperature $> 60^oC$. For temperature value below 60^oC the fan needs to be connected to an air flow channelling device so that the surface area of the air flow can be reduced to only the heat source. Once the above procedures are done, the user can set the desire temperature parameter and our system will successfully maintain that temperature with $\pm 32^oC$ accuracy.

6 Getting Started Software/Firmware

Our project uses an MSP430 F5529 micro-controller made by TI instruments. The software we used to program the micro controller is TI's Code Composer Studio with C programming language.In addition we have used RealTerm serial capture program for the URAT communication. Our program implements three main functionalists PWM, ADC and UART. The PWM users timer A0 Compare/Capture registers to store and output the PWM value.

The analog to digital converter of the micro controller is called ADC12 and is capable of doing a 12 bit conversion. on the ADC implementation of the program we have used SteinHart equation in order to interpret the temperature from the resistance reading of the themistor.

7 Test Setup

The temperature read from the ADC is a transmitted message converted into ASICC that is read from the Realterm terminal. The desired temperature can be specified by changing the desired temperature value through the code. For example, setting the value for the desired temperature at 50^oC will allow the algorithm to determine the correct PWM Duty Cycle for the fan.

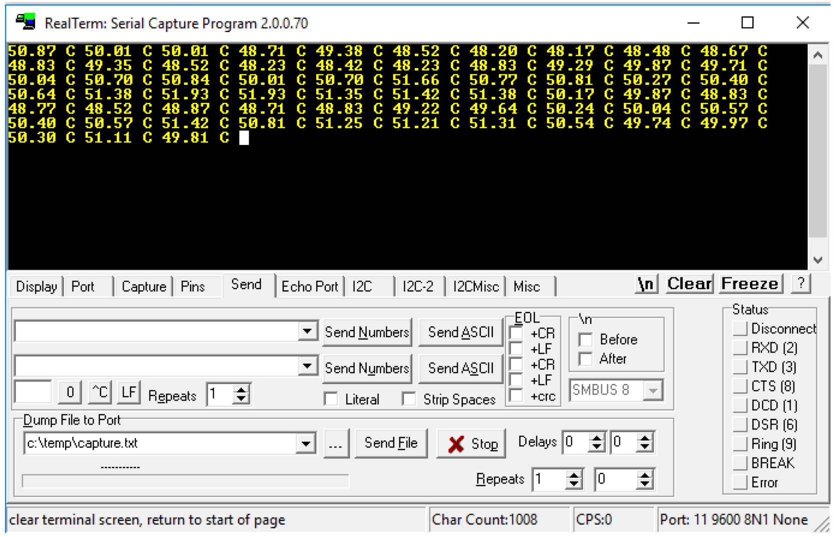

Figure 8: Realterm