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Home Monitoring System v1.00

A ZWorld Rabbit RCM3000 development kit was used to manage a web-enabled home temperature control and alarm monitoring system. One optional feature (web display of current temperature) was implemented. The feature requirements (Listings 1, 2) were met with three exceptions:

1) A single alarm zone was implemented, rather than 8 zones.
2) Activation of the Alarm Relay was separated from activation of the Alarm LED. (See description of Alarm system.)
3) Web user control of the thermostat was not implemented. This feature will be available in Version 1.01, scheduled for December 2006.

In particular, two requirements as listed on the Project specifications document were met:

1) "The system's IP address is to be stored in EEPROM."
2) "The high and low temperature set-points are to be stored in EEPROM."

During the project demonstration it was determined that the intent of these stated requirements had been misunderstood. Version 1.01 will be updated to meet clarified requirements:

1) "The system, on boot, will use a static IP address from a stored value in EEPROM."
2) "The system, on boot, will use high and low temperature set-points from stored values in EEPROM."

Hardware

A prototype circuit board was built up with a Dallas Semiconductor DS18B20 temperature sensor, a Microchip 24LC01B serial 8-bit-by-128 word EEPROM, and a Texas Instruments ULN2003A Darlington transistor array; together with various switches, relays, and LEDs (Figs. 1, 2). The prototype board was connected to the Rabbit by a pair of standard 34-pin ribbon cables, using Rabbit connectors J2 and J4 (Fig. 3). The Rabbit was connected to a LAN jack with Category 5 network cable. Power lines at +5.0 and +3.3 vdc, and signal ground are provided to the board through the ribbon cable. A single capacitor filters the +3.3 volt line. A small section of ribbon cable connector provides test points for the load circuits of the 4 relays.

The design for the LED circuits included a series resistor, whose value was determined by:

$$R = (V_{CC} - V_{LED} - V_{SINK}) / I_{LED} = (5\text{ V} - 2.2\text{ V} - 1\text{ V}) / 20\text{ mA} = 90\ \Omega$$

Since the LED can operate with under 20 mA, a readily-available value of 110 Ω was substituted for the series resistor.

The quiescent state of the system is: no relays energized and no LEDs emitting light.

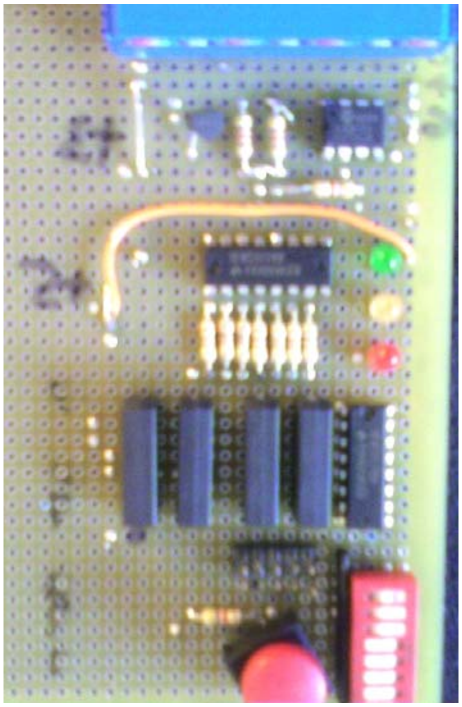

Fig. 2: Prototype board

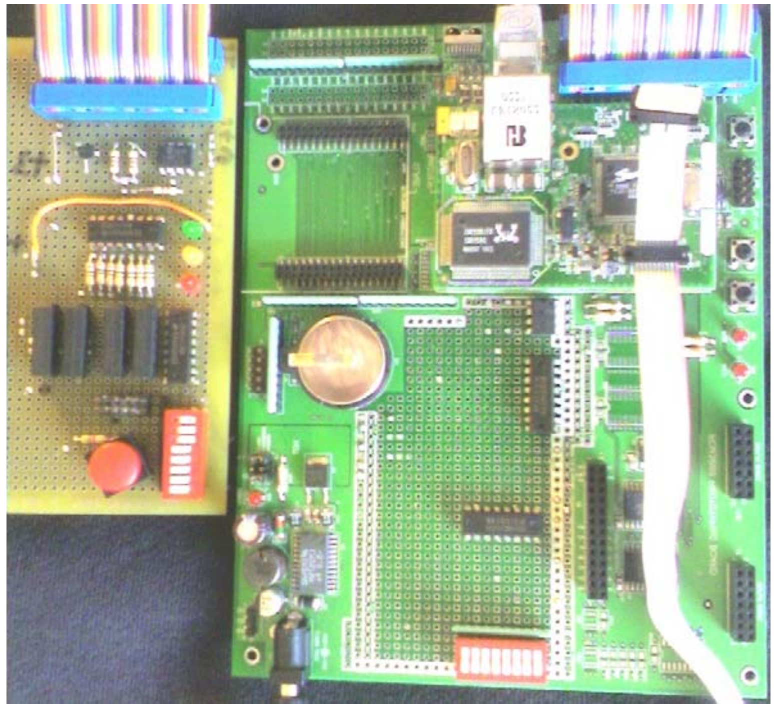

Fig. 3: Prototype with Rabbit controller

Communication between the Rabbit and the prototype board is done via the Rabbit's parallel ports. Closure of any switch places an active signal (logic 0) on a corresponding Rabbit line. Active signals from the Rabbit to the relays and LEDs are buffered through the Darlington array, which sinks current from the devices. Logic signaling between the Rabbit and the temperature sensor is accomplished by the Dallas One-Wire bus interface. Logic signaling between the Rabbit and the EEPROM is accomplished by the I2C-compatible 2-wire Microchip interface.

Software

A Dynamic C program PROJECT.C (Listing 3) controls the system operation. It invokes Dynamic C libraries to manage the alarm, LED, relay, thermometer, EEPROM, and web interface systems (Listing 4). The EEPROM library is used "as-is" from the ZWorld distribution. Other libraries are modified or adapted from sample code provided by ZWorld.

The main routine initializes the systems and a set of variables representing the current time, current alarm status, current temperature, desired temperature, and allowed temperature range. It tests the EEPROM by writing and reading back the static IP address and the temperature range limits (Fig. 3). The program then enters an endless loop.

0xEF	(unassigned)	
0x30		
0x28	high temperature threshold	numeric
0x20	low temperature threshold	numeric
0x10	static IP address (home)	string
0x00	static IP address (SSU)	string

Fig. 4: EEPROM memory map

For each loop iteration, the program does the following:

- Obtains the current system time, the current value from the temperature sensor, and the status of the Alarm and Reset-Alarm switches.
- Decides whether the alarm has been tripped, has not been tripped, has been tripped and reset, or has been deactivated; and sends appropriate signals to the Alarm Relay and Alarm LED.
- Determines the relationship of current temperature to the allowed range, and sends appropriate signals to the Cool Relay, Cool LED, Heat Relay, Heat LED, and Fan Relay.
- Builds an HTML page containing the current time, temperature, and alarm status.
- Invokes a library function that sends the HTML page to any connected TCP socket.

System Operation

Alarm system

If the Alarm switch is closed, an active logic signal appears on the Alarm signal line. If the Reset Alarm (momentary push-button) switch is closed, an active logic signal appears on the Reset Alarm signal line. The program detects the state of each line and stores it. If the Reset Alarm signal is active, the program deactivates the Alarm relay. If the Alarm signal is active and the Reset Alarm signal is inactive, the program activates the Alarm relay and the Alarm LED. If the Alarm signal is inactive and the Reset Alarm signal is active, the program deactivates the Alarm relay and the Alarm LED.

Note that if the Reset Alarm button is pressed while the Alarm switch remains closed, the Alarm relay immediately disengages, but the Alarm LED indicator remains active, alerting the operator to the continued existence of the alarm fault; moreover, upon releasing the push button the Alarm relay will re-engage. In order for the Alarm relay to stay disengaged and the Alarm indicator LED to deactivate, the Alarm switch must be open at the time the Reset Alarm button is pressed.

Temperature Control system

Static Celsius values are set for desired temperature, the temperature tolerance, and a time delay for leaving the fan on after the heat turns off. From these values an allowed range is calculated and stored in EEPROM. The program also maintains a set of variables describing the current state of the temperature system.

The program invokes library functions first to cause the sensor to perform temperature reading, then to read the converted temperature. The program converts the binary reading to Celsius and compares this with the allowed range values.

If the current temperature is higher than the high range value, then the system is placed in “Cool” status, and the Cool relay, Fan relay, and Cool LED are activated. Otherwise, if the system is currently in “Cool” status, then the “Cool” status is revoked; the Cool relay, Fan relay, and Cool LED are deactivated.

If the current temperature is lower than the low range value, then the system is placed in “Heat” status, and the Heat relay, Fan relay, and Heat LED are activated. Otherwise, if the system is currently in “Heat” status, then the “Heat” status is revoked; the Heat relay and Heat LED are deactivated; after the preset time delay, the Fan relay is deactivated.

Web Interface system

The workhorses of this system are the library function my_handler() and its argument, a library struct MyState (Listing nn, nn). my_handler() implements a state machine. It uses the variable my_response built by the main program, which contains the HTML layout for the web page.

Listing 1: **Requirements**

- The system's IP address is to be stored in EEPROM.

- <u>Heating/Cooling System:</u>
  - Three relays are used to operate the furnace and air-conditioning system. The FAN relay is to be energized whenever the HEAT or COOL relays are energized. A HEAT or COOL LED is to be activated whenever the HEAT or COOL relay is energized.
  - The current temperature is obtained by reading from a temperature sensor.
  - When the current temperature rises above the high temperature set-point, the COOL relay is to be energized until the temperature is reduced a sufficient amount.
  - When the COOL relay is energized, the FAN relay is also to be energized.
  - When the current temperature falls below the low temperature set-point, the HEAT relay is to be energized until the temperature is raised a sufficient amount.
  - When the HEAT relay is de-energized, the FAN relay is to to turn on and remain energized for a specified amount of time in order to dissipate the hot air still within the furnace.
  - The high and low temperature set-points are to be stored in EEPROM. The user must be able to set the desired temperature, and the system will set the high and low temperature set-points based on the desired temperature.

- <u>Alarm System:</u>
  - The alarm system is to monitor eight zones that are simulated by dip-switches. When a dip-switch is open, the zone has been violated.
  - An ALARM relay is to be energized whenever one of zones is violated.
  - An ALARM LED is to be activated whenever the ALARM relay is energized.
  - A pushbutton switch is used to de-activate the alarm.

- <u>Web Interface:</u>
  - A web interface will allow the user to set the desired temperature.
  - When the web-page is refreshed, the current temperature will be displayed as well as an indication of the status of each of the zones monitored by the alarm system.

Listing 2: **Test Plan**

Introduction

The features to be tested are:

- Temperature Control system
- Alarm system
- Web Interface system
- Relay system
- LED system

The items to be tested are:

- Temperature Sensor
- EEPROM
- Cool relay + Cool LED + Fan relay as a unit
- Heat relay + Heat LED + Fan relay as a unit
- Alarm relay + Alarm LED + Alarm switch + Reset Alarm switch as a unit
- Cool LED + Test Cool LED switch as a unit
- Heat LED + Test Heat LED switch as a unit
- Alarm LED + Test Alarm LED switch as a unit
- Web server
- Web server + client as a unit

Features

Temperature Control system

The Temperature Sensor must return an accurate reading when properly addressed.
Reason: The Temperature Sensor must function correctly in order for the product to meet spec.

When the desired temperature setting is changed, the high and low set points must change accordingly.
Reason: The high and low set points must be calculated correctly in order for the product to meet spec.

The Cool relay, Cool LED, and Fan relay must activate together when the current temperature is higher than the high range set point.
Reason: Specified behavior.

The Cool relay, Cool LED, and Fan relay must de-activate together when the current temperature is not higher than the high range set point.
Reason: Specified behavior.

The Heat relay, Heat LED, and Fan relay must activate together when the current temperature is lower than the low range set point.
Reason: Specified behavior.

The Heat relay and Heat LED must de-activate together when the current temperature is not lower than the low range set point. At a specified time afterward, the Fan relay must de-activate.
Reason: Specified behavior.

The current temperature and desired temperature settings must not affect the behavior of any component or system in any way not specified in this Test Plan.
Reason: The system must be deterministic and reliable.

Do not test: Basic continuity and component-function checks.

<u>Alarm system</u>

If the Alarm switch is open when the system starts, the Alarm Relay and Alarm LED must be initialized together in the de-activated state.
Reason: The system must be deterministic and reliable.

The Alarm relay and Alarm LED must activate together when the Alarm switch is closed.
Reason: Specified behavior.

The Alarm relay must de-activate for the period of time during which the Reset Alarm switch is closed.
Reason: Specified behavior. This gives the operator an opportunity to shut off the sounding alarm.

If the Reset Alarm button is released while the Alarm switch is closed, the Alarm relay must activate.
Reason: Specified behavior. If the Alarm switch is closed, the security fault has not been cleared.

If the Reset Alarm button is released while the Alarm switch is open, the Alarm relay must remain de-activated and the Alarm LED must de-activate.
Reason: Specified behavior. If the Alarm switch is closed, the security fault has been cleared.

If the Alarm LED is activated, it must remain activated until the Alarm switch and Reset Alarm button switch are both open.
Reason: Specified behavior. If the Alarm switch is closed, the security fault has not been cleared.

Closing and opening the Alarm switch must not affect the behavior of any component or system in any way not specified in this Test Plan. Pressing the Reset Alarm switch must not affect the behavior of any component or system in any way not specified in this Test Plan.
Reason: The system must be deterministic and reliable.

Do not test: Basic continuity and component-function checks.

LED system

(Note: The following three items were non-functional in v1.00, but will be available in v1.01.)

If the Test Cool LED switch is closed, the Cool LED must activate until the Test Cool LED switch is opened, regardless of any other setting.
Reason: The LED test feature should override other conditions.

If the Test Heat LED switch is closed, the Heat LED must activate until the Test Heat LED switch is opened, regardless of any other setting.
Reason: The LED test feature should override other conditions.

If the Test Alarm LED switch is closed, the Alarm LED must activate until the Test Alarm LED switch is opened, regardless of any other setting.
Reason: The LED test feature should override other conditions.

Closing and opening any Test LED switch must not affect the behavior of any component or system in any way not specified in this Test Plan.
Reason: The system must be deterministic and reliable.

Relay system

Activation and de-activation of any one relay must not affect the behavior of any component or system in any way not specified in this Test Plan.
Reason: The system must be deterministic and reliable.

EEPROM

The EEPROM must store and return any single 8-bit unsigned integer or any single 8-character word when properly addressed.
Reason: The EEPROM must function correctly in order for the product to meet spec.

Web Interface system

When the product starts up, its IP address must be displayed on the standard IO port screen.
Reason: The network interface must function correctly in order for the product to meet spec.

When the product has started and is connected to an internet-enabled LAN, and a web client points its browser to the product's IP address, then the web client browser must display the Home Monitoring System web page.
Reason: Specified behavior.

After each refresh, the current time, current temperature, and alarm status must be displayed in the browser window.
Reason: Specified behavior.

Approach to Testing

Temperature Control system

Observe the behavior of relays and LED's as the current temperature is varied. Use fingers, a heat gun, and/or freeze spray to manipulate the current temperature. Use 3 ohmmeters connected to relay load circuit test points, to observe the relay states. Be alert for undesired or incorrect behavior of components or systems. Each test item must display the behavior described in this Test Plan.

Alarm system

Observe the behavior of a relay and an LED as switch settings are varied. Use a paper clip or tiny flat-head screwdriver to operate the switches. Use an ohmmeter connected to relay load circuit test points, to observe the relay state. Be alert for undesired or incorrect behavior of components or systems. Each test item must display the behavior described in this Test Plan.

Web Interface system

Observe the behavior of the web client browser after each refresh, as temperature and switch settings are varied. Use fingers, a heat gun, and/or freeze spray to manipulate the current temperature. Use a paper clip or tiny flat-head screwdriver to operate the switches. Be alert for undesired or incorrect behavior of components or systems. Each test item must display the behavior described in this Test Plan.