Efficient HVAC System

Group 6

Sponsored by AC3 Development Group LLC

Derick Holzmacher

Cory Glass

Andrew Mertens

Joshua New

Motivation

- HVAC systems are one of the leading energy consuming appliances in use in any building.
- With the recent push toward green technology, there is a new demand for a more efficient, and affordable HVAC control system.
- There has also become a need for an HVAC system that introduces filtered outside air into the building in order to provide the occupants enhanced air quality.

Project Overview

- A more efficient HVAC control system to save the user money on a monthly basis through reduced power consumption
- A user friendly interface through a wall mount touch screen thermostat with web connectivity that allows settings to be viewed and changed from a mobile device

Objectives

- Accurately read temperature and relative humidity both inside and outside building.
- Wirelessly transmit outside data to the main control unit
- User interface must be a thermostat replacement in the form of a touch screen that is easy to view and intuitive to operate.
- Communicate with the internet so that the user can view and manipulate system settings from a remote location via mobile device.
- Must be expandable to incorporate additional HVAC components and sensors.

Objectives

- Allow the user to input desired temperature and relative humidity set points
- Determine the most efficient components to use to heat or cool the building based on settings ranging from “max comfort” to “max savings”
- Display the current percentage of the total system energy being used via an “energy usage” bar
- Allow the user to view current power consumption
- Allow the user to input a specific tolerance level for each comfort setting
- Expandable coding to incorporate HVAC systems consisting of more than 2 AC units
- System must be able to be installed without the need for the running of any new wires

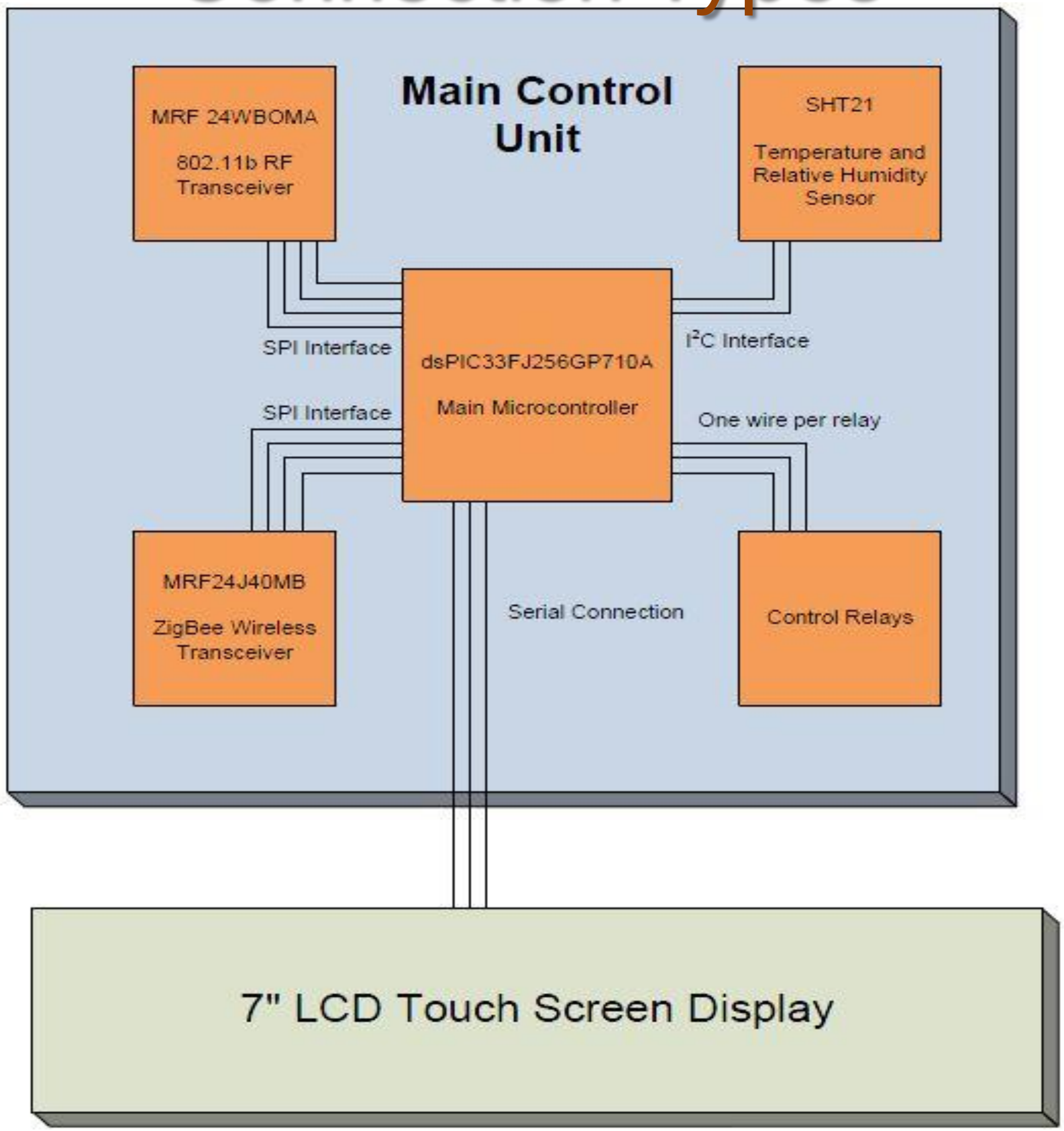
Specifications and Requirements

- Must be able to provide 24V AC to control HVAC components (output)
- Wireless transmission of temperature and relative humidity data over a distance of at least 100 feet
- Measure indoor and outdoor temperature (+- 0.5 ^{o}C) and relative humidity (+- 5%) with specific accuracy
- Measure realistic outdoor temperature (-20 ^{o}F – 110 ^{o}F) and relative humidity (0% - 100%)
- Main Control Unit powered by existing 24V AC wall power (input)
- Total cost of the HVAC system $1500 or less for initial prototyping

Component Overview

- Main Control Unit
  - Main Microcontroller
  - 802.11b Wi-Fi Transceiver
  - 802.15.4 ZigBee Transceiver
  - Temperature / Relative Humidity Sensor
  - Control Relays
- Outside Sensing Unit
  - Secondary Microcontroller
  - 802.15.4 ZigBee Transceiver
  - Temperature / Relative Humidity Sensor
- User Interface
  - Evervision 7” LCD Touch Screen
  - SLCD5 Controller

Main Control Unit Components with Connection Types



Main Control Unit (MCU)

- Houses several components such as the SHT21 sensor, dsPIC33FJ256GP710A main microcontroller, ZigBee MRF24J40MB wireless transceiver, and the MRF24WB0MA 802.11b wireless transceiver
- Powered by a 24V AC common wire that is installed for a thermostat during the initial construction project

Minimum, Maximum, and typical operating voltages for components associated with the MCU

Component	Min Operating Voltage (V)	Typical Operating Voltage (V)	Max Operating Voltage (V)
Main Microcontroller	3	N/A	3.6
Zigbee wireless chip	2.4	3.3	3.6
802.11b wireless chip	2.7	3.3	3.6
Temperature and Relative Humidity sensor	2.1	3	3.6
LCD Touch Screen and Controller	5	N/A	12

Comparison of Main Microcontroller Options

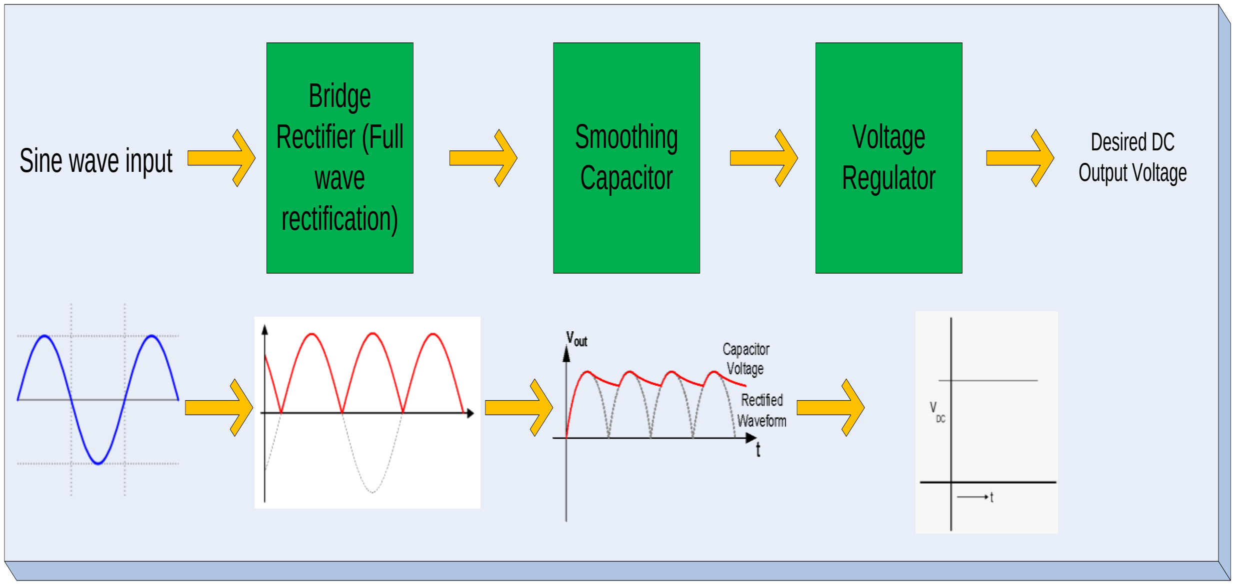
	dsPIC33FJ64GP206A	dsPIC33FJ256GP506A	dsPIC33FJ256GP710A
Pins	64	64	100
Flash Memory	64Kbyte	256kbyte	256Kbyte
ADC	1 ADC, 18 ch.	1 ADC, 18 ch.	2 ADC, 32 ch.
UART	2	2	2
SPI	2	2	2
I^2C	1	2	2
I/O Pins	53	53	85

Reasons for choosing dsPIC33FJ256GP710A

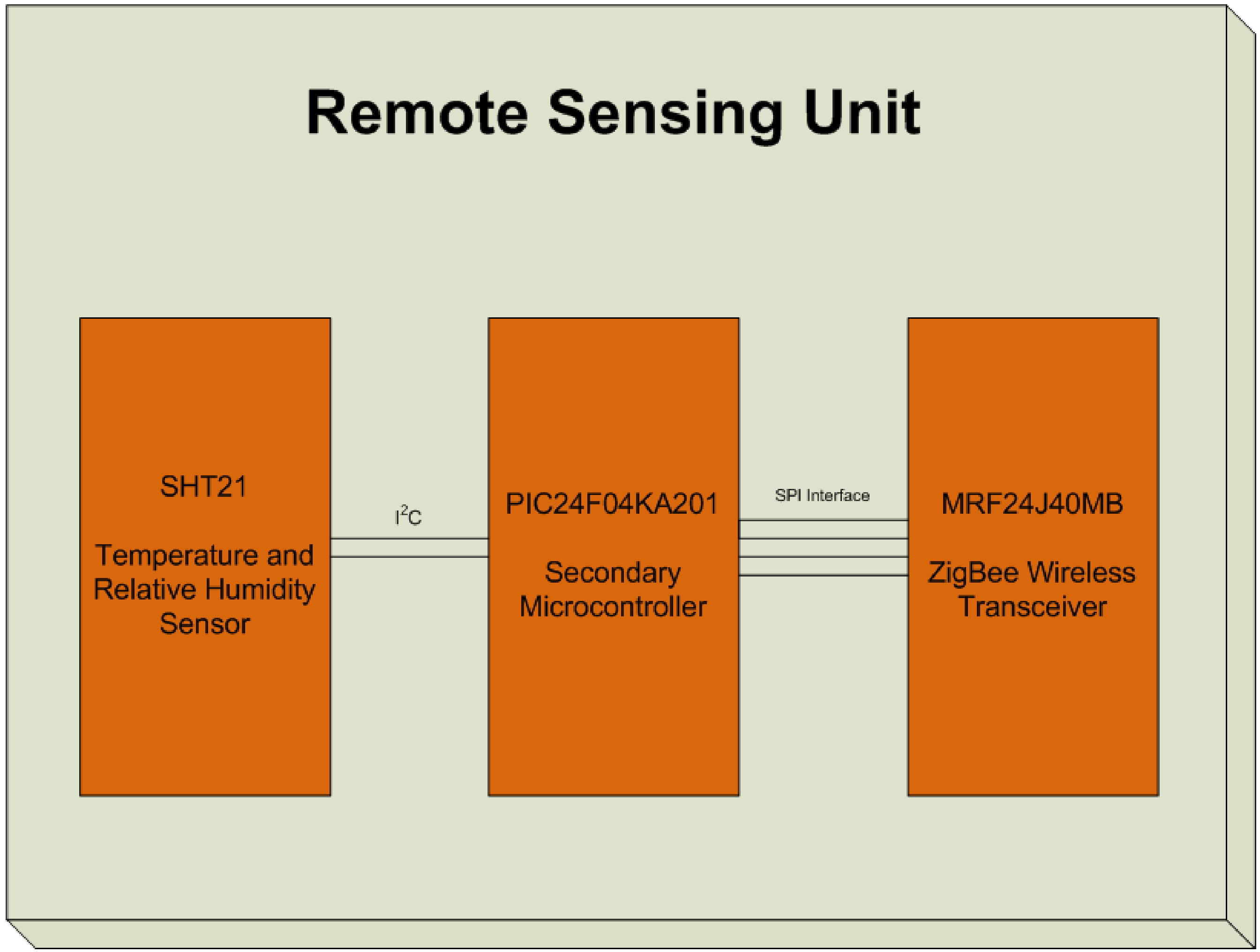
- C compiler optimized instruction set
- 256K bytes Flash memory
- 30K bytes RAM
- 85 Programmable I/O pins
- Supports 2 I^2C modules
- Supports 2 UART modules
- The sponsors have stressed their desire to expand the capabilities of the system

Conversion from 24V AC to 3.3V DC

- First signal needs to be converted from AC to DC using full wave rectification
- The entire signal is the same polarity but the magnitude of the signal is still not constant to be considered DC.
- The signal is rippling in magnitude and in order to solve that problem a smoothing capacitor will be used
- Next step after using a smoothing capacitor is to use a voltage regulator



Remote Sensing Unit Components with Connection Types



Secondary Microcontroller PIC24F04KA201

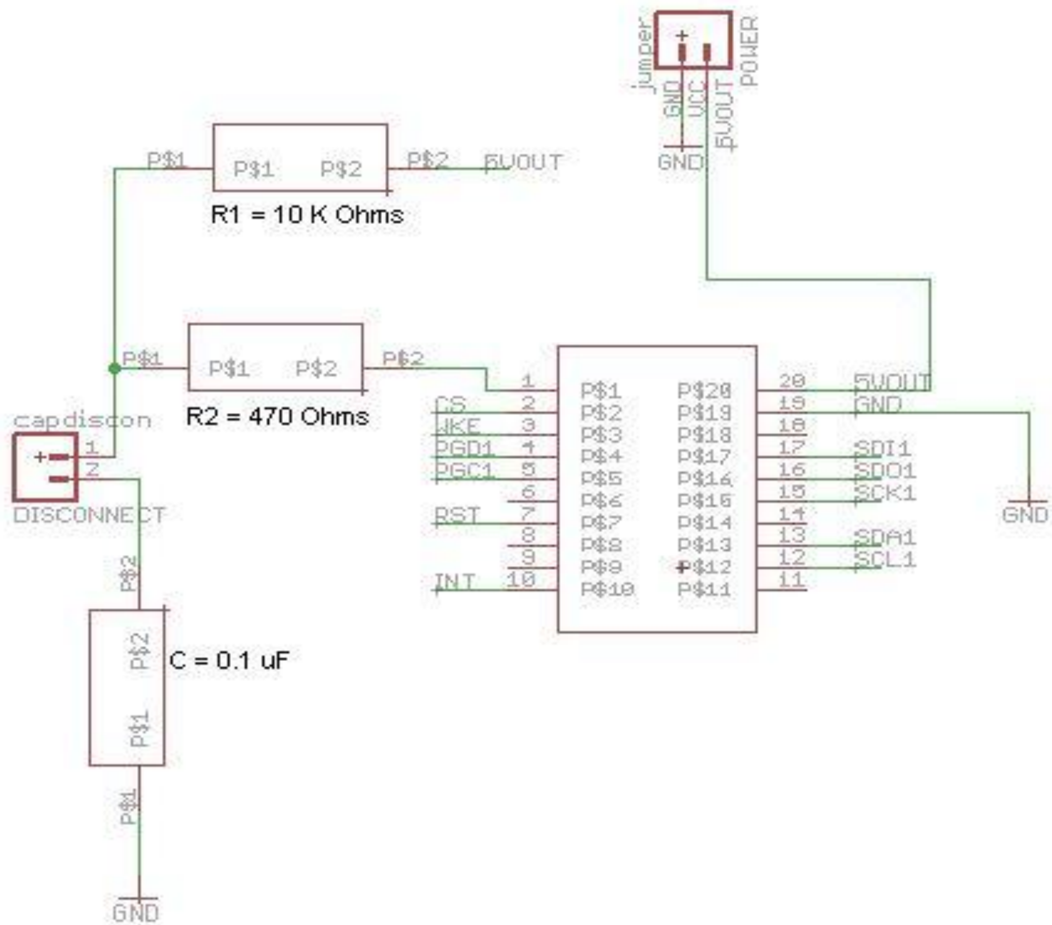
- 20 Pins
- 4K bytes Program Memory
- SRAM 512 bytes
- 3 16-bit timers
- 1 UART
- 1 SPI
- 1 I^2C

Functions of Secondary Microcontroller

- Take input from Temperature and Relative Humidity Sensor (12 or 14 bits)
- Plug number into conversion formula
- Send information to Main Control Unit

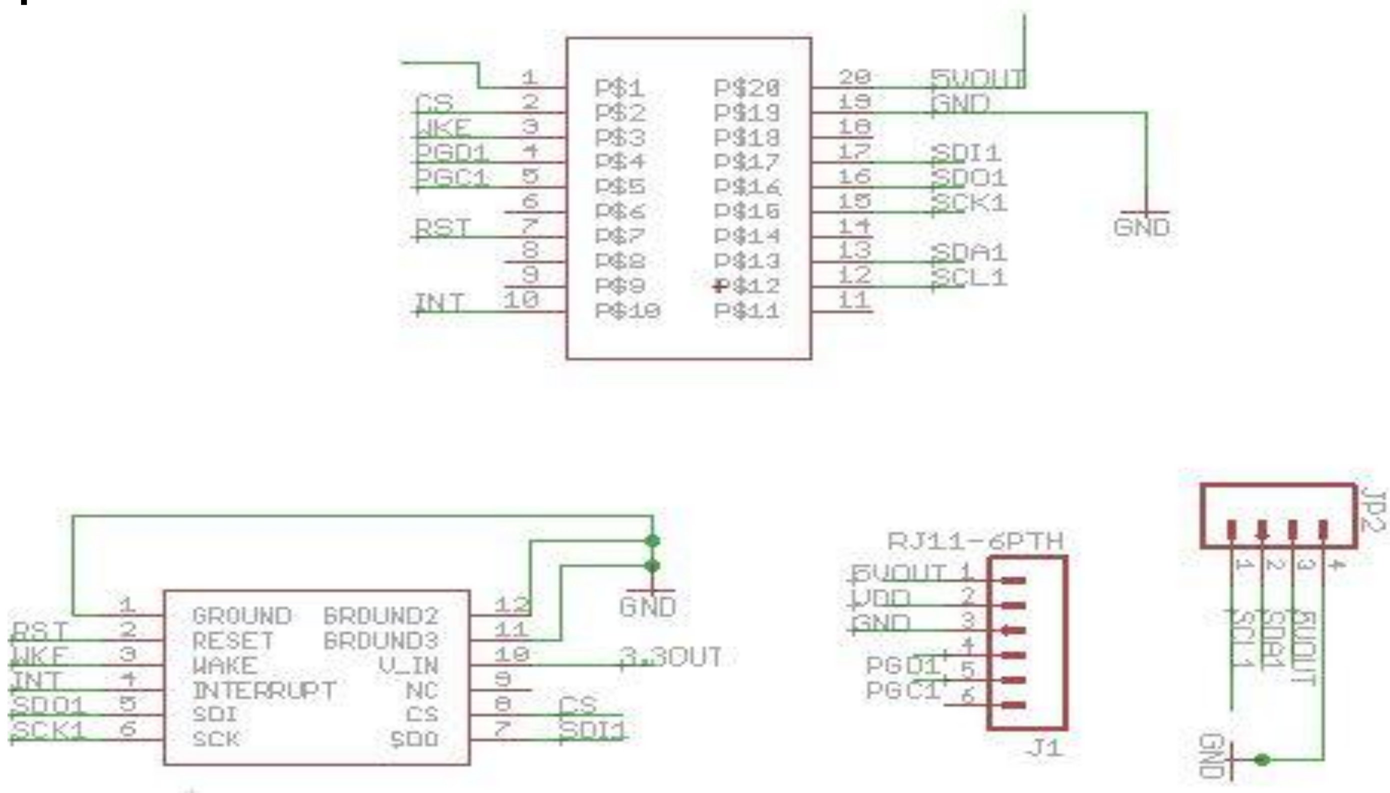
Secondary Microcontroller Minimum Connections

- This is the PIC24F04KA201 and the minimum required connections as described in the data sheet



Secondary Microcontroller with other external connections

- Secondary microcontroller with connections to ZigBee RF transceiver, temperature and humidity sensor, and female RJ11port

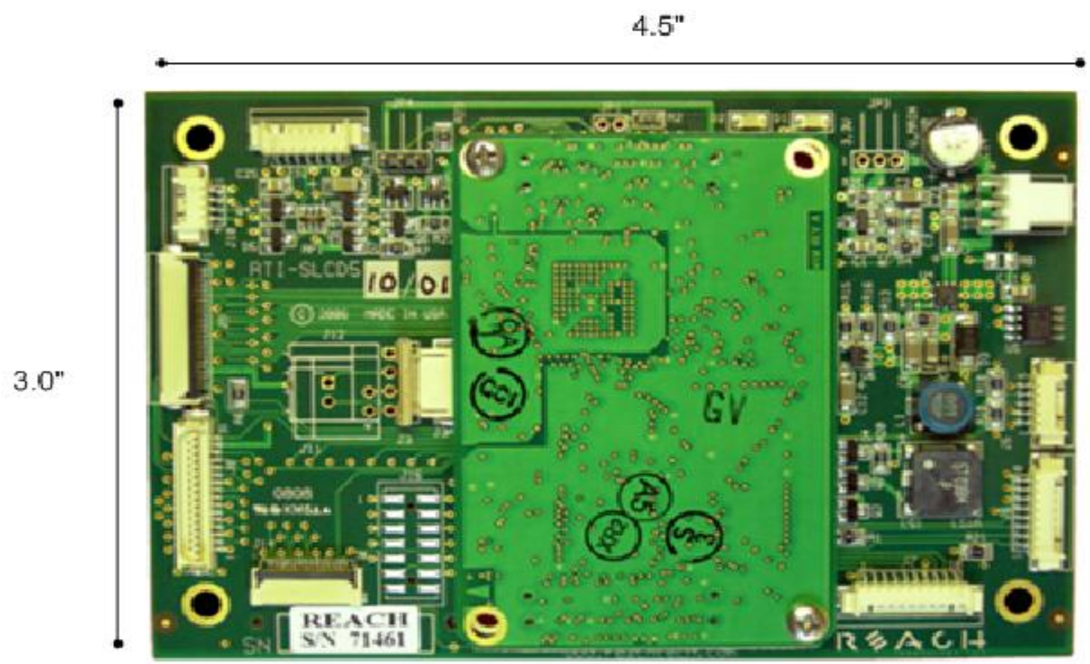


Comparison of LCD Touch Screens (Sponsor Decision)

Company Name	Size of LCD Touch Screen	Controller Name	Controller Specs	Development Kit Price
Evervision	7 inches	SLCD5 Controller	-Power Supply Min 3.0 V to Max 3.6 V - 4 MB of flash memory -16 bit color	$499
Kyocera	5.7 inches	SLCD+ controller	-Power Supply Min 3.0 V to Max 3.6 V - 4 MB of flash memory -16 bit color	$499
NEC	8.4 inches	SLCD5 Controller	-Power Supply Min 3.0 V to Max 3.6 V - 4 MB of flash memory -16 bit color	$799

Advantages of the 7” Evervision Development Kit

- SLCD5 controller was bundled with 7” Evervision LCD screen
- Evervision LCD screen utilizes 4 wire resistive touch technology.
- SLCD5 controller provides easy to use commands to implement bitmaps and macros

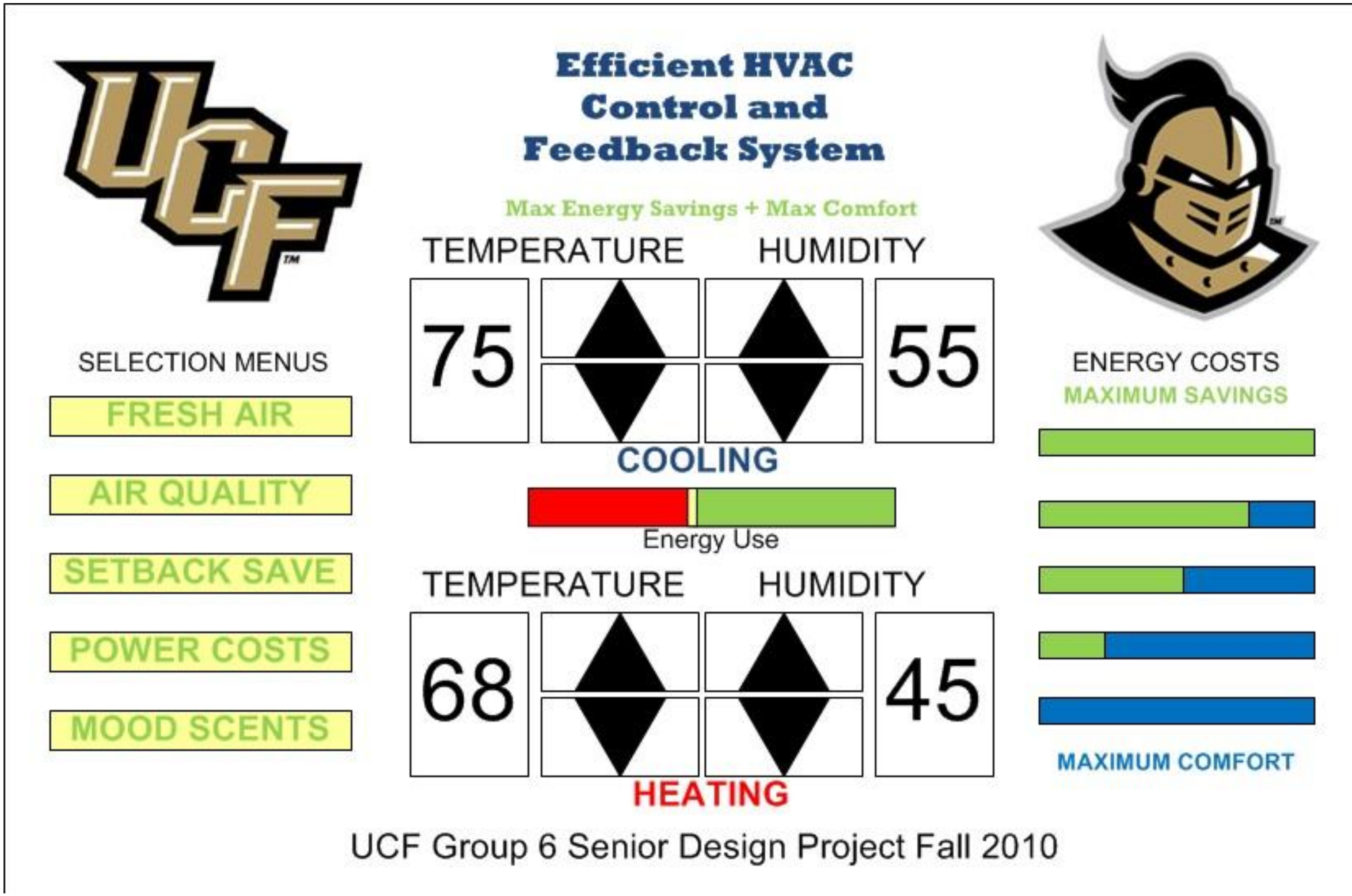


Commands Used in Development of User Interface

- Xi 1 100 200
  - Places bitmap index 1 at pixel location 100x200
- Bd 1 x y “text” dx dy bmp1 bmp2
  - Places a button at x y with text identifier “text” with text offset of dx dy, displays bitmap index of bmp1 in state 1 and bmp2 at state 2
- T “text string” x y
  - Places text at (x, y) in respect to the origin point

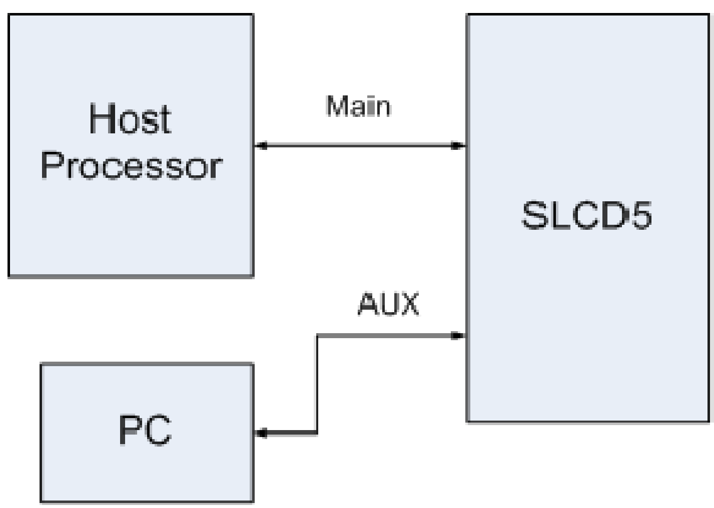
Display of various bitmaps and buttons

Format of LCD Touch Screen User Interface



SCLD5 Communication Setup

- Utilizes RS-232 for serial communication to host microcontroller
- COM0 is deemed the “Main” port and is connected to the embedded processor to control the display
- COM1 port or “Aux” is typically used to update the display of bitmaps and macros
- SCLD5 Communication Setup (2 RS232 Ports)



Wireless Protocols

- The protocols that we researched and considered were the ZigBee, Wi-Fi, and Bluetooth
- The best communication interface for wireless in system communication was ZigBee
- ZigBee was relatively simple and would be easily able to handle the readings we had to send
- Good amount of sample code available
- To enable mobile device connectivity we chose a Wi-Fi transceiver
- Works well because there is normally not an Ethernet connection wired to the thermostat

Wireless Protocols

Wireless Protocols	Bluetooth (Class 1)	ZigBee (802.15.4)	Wi-Fi® (802.11 b)
Optimal Range (indoor):	~100 meter	10 – 75 meters	30 meters
Frequency Band:	2.4 GHz ISM band	2.4 GHz ISM band	2.4 GHz ISM band
Communication type:	WPANs	PANs	WLAN
Power required to operate:	100mW	1mW	100mW
Cost of implementation:	Low Cost	Low Cost	Medium Cost
Bandwidth:	1 Mbps	0.250 Mbps	11 Mbps
Encrypted:	Yes	Yes	Yes
Primary Use:	Data exchange over short distances	Small, low powered devices	Mobile Internet

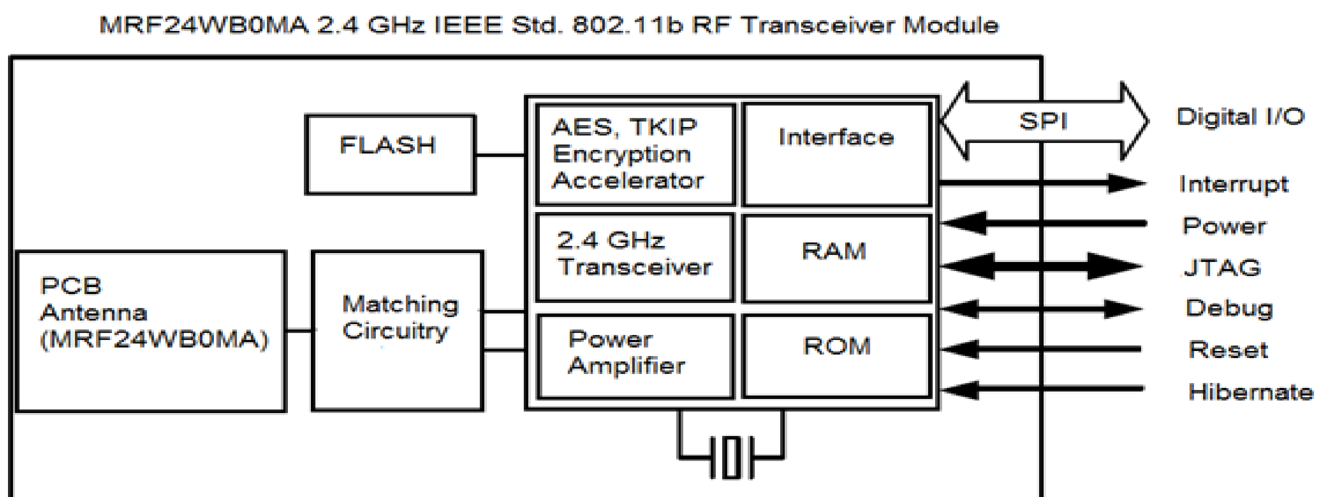
802.15.4 MRF24J40MB RF Transceiver

- The sensors and secondary microcontrollers collect data which needs to be wirelessly sent to the main microcontroller
- Our device that we wanted required low power consumption to increase battery life, low data rate and secure networking
- MRF24J40MB is compatible with Microchip's Microcontroller Families (PIC16F, PIC18F, PIC24F/H, dsPIC33).

Key Features of the MRF24J40MB	
Operates on ISM Band 2.405 – 2.475 GHz freq.	Small size: 22.9 mm x 33.0 mm
Supports ZigBee®, MiWi and MiWi P2p wireless protocols	Surface mountable
Integrated PCB antenna	Up to 4000 ft. Range
Operating voltage 2.4V – 3.6 V (3.3V typical)	
Low current consumption	

802.11 b MRF24WB0MA RF Transceiver

- This radio transceiver contains 36 pin surface mountable module that's dimensions are 21 mm x 31 mm
- Requires low supply voltage: 2.7V – 3.6V (3.3 V is typical standard)
- Operates on the 2.4 – 2.483.5 GHz band, which is the 802.11 b protocol
- Designed to be used with Microchip's TCP/IP software stack and microcontroller families
- The MRF24WB0MA module and a PIC microcontroller operating the TCP/IP stack will allow for implementation of a wireless web server

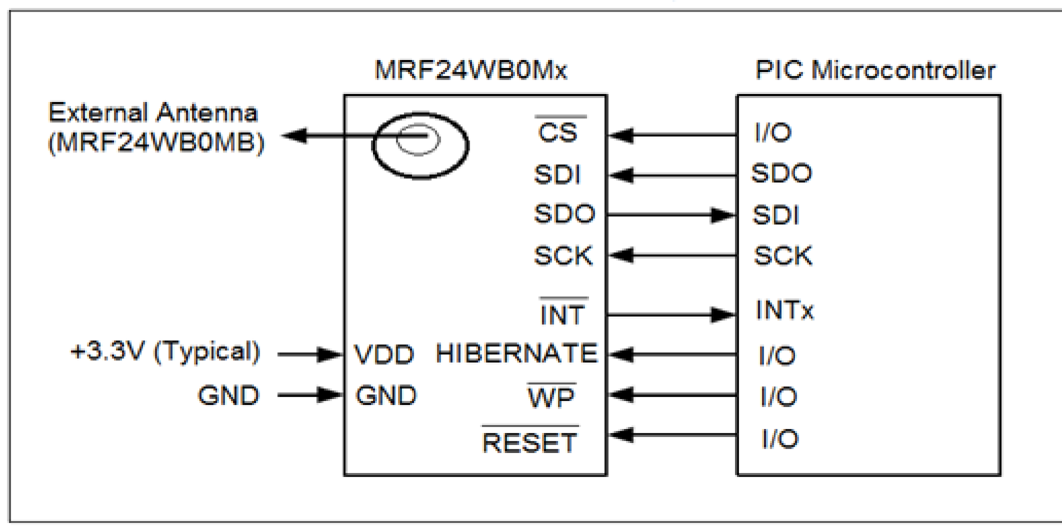


MRF24WB0MA RF Transceiver (cont)

- This module interfaces to the microcontroller via a four-wire serial slave SPI interface, as well as the interrupt, hibernate, reset, power, and ground signals
- Offers different modes of low current consumption depending upon what is recommended by the user
- Receive (RX) mode only uses 85 mA, Transmit (TX) mode only uses 154 mA, Hibernate mode uses < 1 uA, while the Sleep mode uses 250 uA

CS – SPI Chip Select input
SCK – clock
SDI, SDO – SPI data In and data out pins

Microcontroller to MRF24WB0MA/MRF24WB0MB Interface



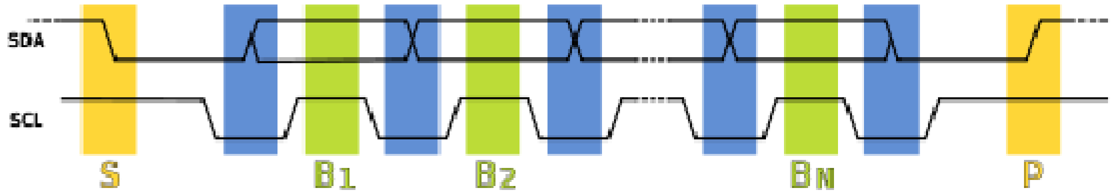
MRF24WB0MA interface to microcontroller

Sensors

- The sensor we chose was the Sensirion SHT21 Humidity and Temperature Sensor
- Uses I^2C protocol to communicate with the microcontroller
- The SHT21 has a normal operating range from 20 ºC to 100 ºC (68 ºF to 212 ºF) at about 8% relative humidity and -20 ºC to 60 ºC (-4 ºF to 140 ºF) at 90% relative humidity
- Default resolution of 12 bits for relative humidity and 14 bits for temperature

I^2C protocol and commands for SHT 21

- Uses two bidirectional lines for the I^2C format: Serial Data Line (SDA), Serial Clock (SCL)
- Data can be sent across the SDA line after a start condition has been met
- The start condition is when the SDA line goes from a high to low while the SCL is high
- When the data is already done sending, a “stop condition” of the SDA going from a low to a high while the SCL is high occurs
- The I^2C protocol once the start condition happens is followed up by a header made up of 7-bit device addresses and an SDA directional bit



Start and Stop Conditions for I^2C protocol

Factors in Calculating Relative Humidity and Temperature Values

- Once the bits measurement is taken and the bits are transferred, it must be converted into a number that makes sense to the user
- Binary number must be converted to a decimal number (called S_{RH} or S_T for relative humidity and temperature)
- Once converted into decimal representation, the value must be plugged into a formula to get the final output

Formulas for Calculating Relative Humidity and Temperature Values for the User

$$RH = -6 + 125 * (S_{RH} / 2^{16}) \rightarrow \text{units \% RH}$$

$$T = -46.85 + 175.72 * (S_T / 2^{16}) \rightarrow \text{units } ^{o}C$$

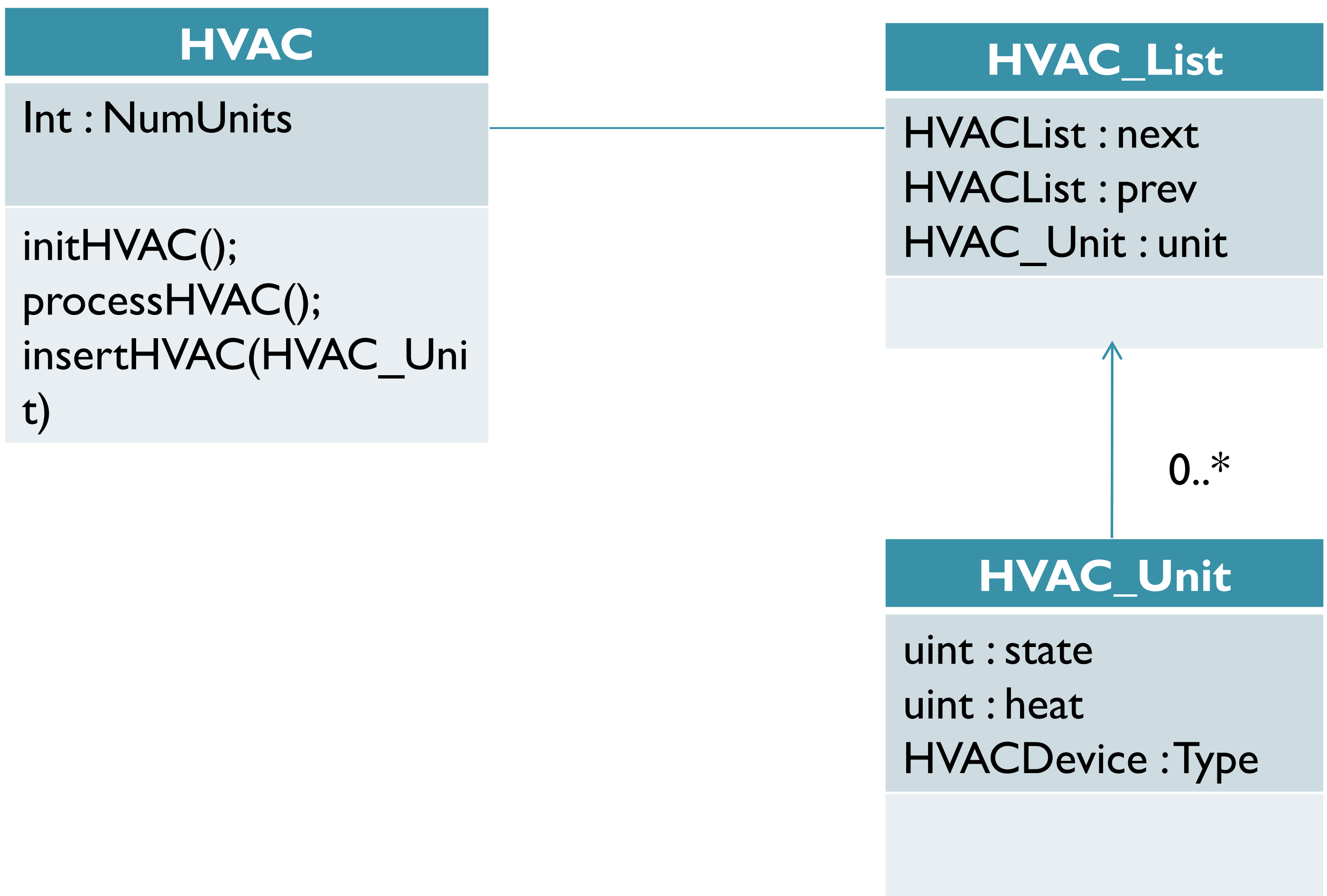
Selected Battery

Type	Pros	Cons
Alkaline (AA)	- Long battery life - Has Energy Capacity of 2850 mAh	- Drain rate affects the capacity
Lithium - Ion	- Produce nominally 3.6 to 3.7 V (very powerful) - Generates high current - Has an energy capacity of 2250 mAh - Relatively low self - discharge rate	- Most expensive in cost
Nickel Cadmium (AA)	-Decent discharge rate - Nominal cycle life of over 1,000 cycles	-Short term battery life - Max current is approx 400 mA - Being prone to damage by overcharging

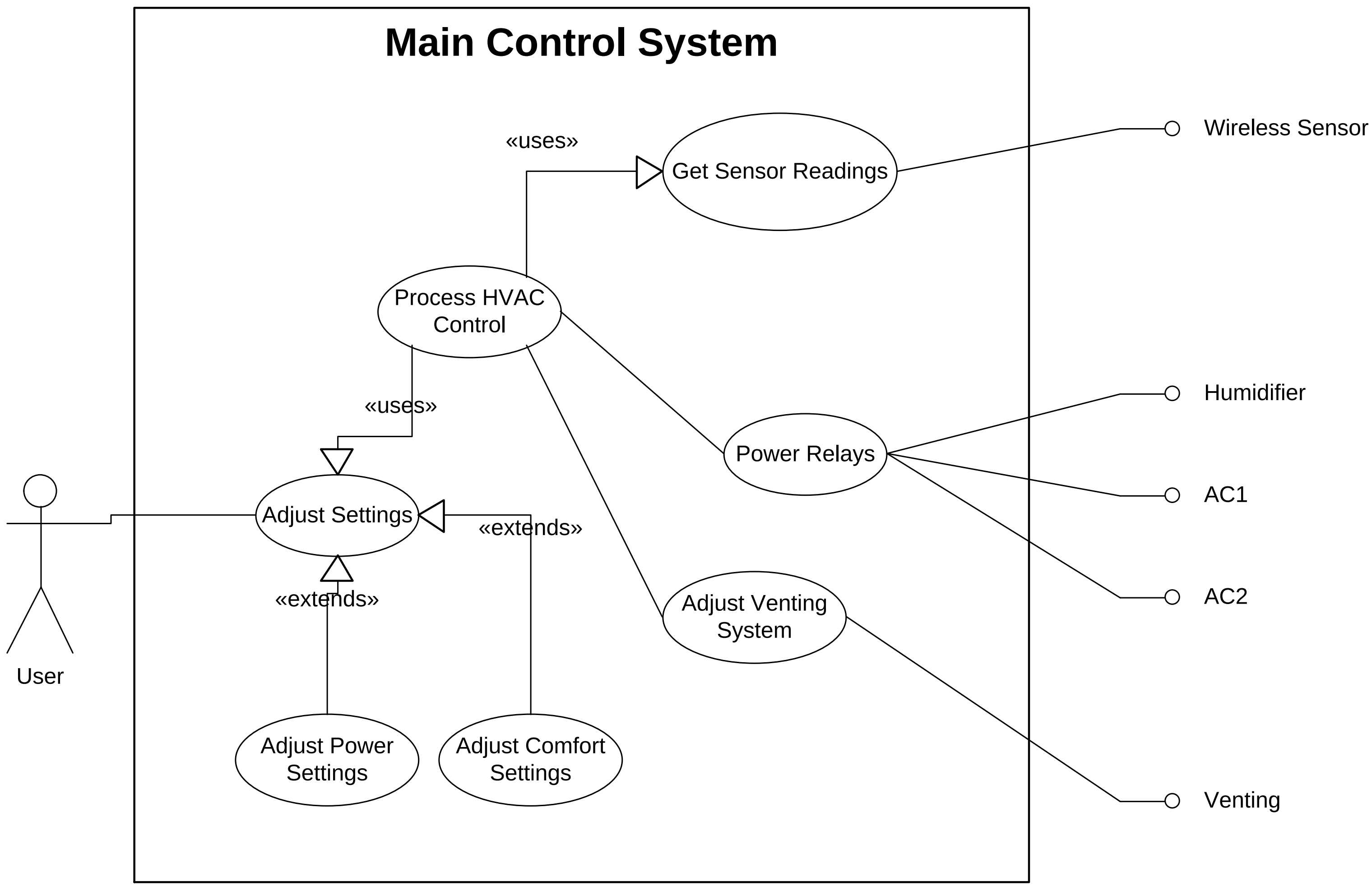
Software Overview

- C language used to code compiled with C30 compiler from Microchip
- LCD Interface programmed through microcontroller
- TCP/IP Stack and web server provided by Microchip

HVAC Data Structures



Use Case Diagram



Design Issues

- Structs in C compiled with the C30 compiler are not word aligned and cause an address error trap when accessed
- Delays caused by lack of library support for PCB components
- Original 802.11 chips unavailable. Had to change to external antenna model.

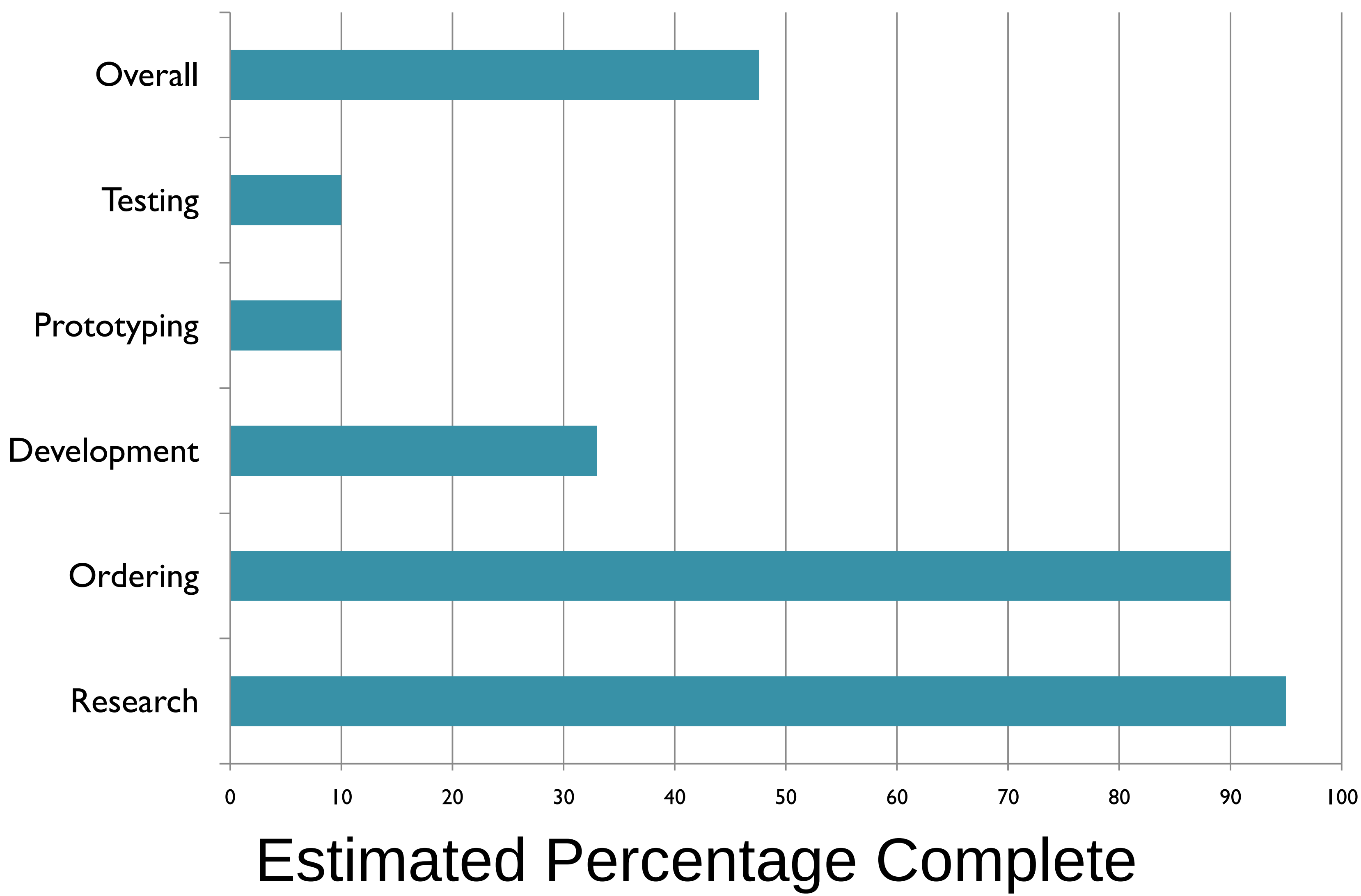
Successes

- Uploading initial layout for the LCD screen in progress.
- One of two PCB designs is complete.
- Progressing through software development
- All main components have been ordered and received.
- Under budget

Budget and Financing

Component Description	Part Number	Manufacturer	Total
7” Evervision LCD Development Kit	52-0102-12	Evervision Reach Technology	$499
MRF24J40MA PICtail Daughter Board	AC164136-4	Microchip	$60
MRF24J40MB PICtail Daughter Board	AC164134-2	Microchip	$30
Explorer 16 Kit	DV164037	Microchip	$299
Battery Holder	1024K-ND	Keystone Electronic	$7.59
PIC24F16KA102 Plug-in Module (PIM)	MA240017	Microchip	$25
MRF24J40MB Zigbee Wireless Module	MRF24J40MBT- I/RM	Microchip	$34.74
dsPIC33FJ256GP710A Main Microcontroller	DSPIC33FJ256GP710	Microchip	$17.08
PIC24F04KA201 Secondary Microcontroller	PIC24F0KA201-I/SO	Microchip	$1.72 **Grand Total: $974.13**

Current Progress



Questions