Interactive Home Automation System for Efficient Utilization of Energy

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Abstract

Visions of smart homes have long gotten the consideration of specialists and impressive effort has been put toward empowering homes with automated control. Automation is the use of control systems to decrease human intervention in the production of goods and other services, thereby time and effort is reduced significantly. Recently, the "Internet of Things" - a global network infrastructure, linking physical and virtual objects using cloud computing, data capture, and network communications – has become a tool for enabling remote and seamless management and visualization of sensor data. The applications are endless with Google Apps being the perfect example. But there have been numerous obstacles to applying such perfect control over one's own home. A few of these barriers are high cost of ownership, inflexibility, poor manageability, and difficulty in achieving security. The automation system proposed in this paper is capable of providing homeowners the ability to efficiently manage electricity distribution and control by integrating automation through a cost effective and flexible approach. Electricity is efficiently utilized by using a current sensing transformer to detect spikes in current and overvoltage conditions, and shutting off the outlet accordingly. This system also reaches out to eliminate the standard breaker box, which prevents having to manually go outside and flip a switch to turn on power after an unwanted surge or trip occurs.

Introduction

A smart-home system aims at integrating various sensors for thermostat and humidity control, power flow regulation and control (for lights, fans and other electrical equipment), security and alarm systems and chemo-sensors for measuring carbon monoxide levels during emergencies like fire and leakage. All these can be controlled remotely, using a common control station. In the smart home system, a combination of Solid State Relays (SSR), Integrated Circuits (IC), and current sensing transformers are used to control and monitor power throughout the system [1] [2]. The system is demonstrated using two smart-wall outlets, a three-speed fan as a ceiling fan, a light bulb with a dimming function, a security system with motion and door sensors, and a safety feature with carbon monoxide monitoring. A centrally located touch-screen panel is also interfaced, which gives the user the ability to monitor and control the energy consumption of each outlet and appliance throughout their home. This panel would also be able to turn an outlet on or off regardless of where the outlet is located in the home. The smart outlets are monitored by current sensing transformers which detect spikes in current and overvoltage conditions [3]. The transformer then sends the information to a microcontroller which uses this data to switch a relay off if a surge is detected. Each outlet on the wall panel is individualized to allow for fault isolation. Whenever a fault occurs, only the outlet that has the fault will turn off, instead of shutting down the entire room until the breaker is reset.

The outlet design implements a SSR system. This SSR system is controlled using an Arduino Uno (ATmega328) microcontroller [4]. The Arduino Uno was chosen because it is energy efficient, easy to implement, and has few component requirements. It meets the required specifications while being really inexpensive. The YHDC STC013 [5] is being used as a current sensing transformer for this system. This particular transformer will read the current going through the line and output a voltage between 0 and 1 volt. Given this reading, the microcontroller will be able to detect spikes in current and voltage and shut the outlet off accordingly [6]. Once the electrical line reaches 90% of the receptacle's power rating, the microcontroller shuts the relay off which disables the individual outlet and allow others to still function.

The wall panel selected for this design is the µLCD-70DT provided by 4D Systems. Using a proprietary programming utility, ViSi-Genie, a GUI touch-screen display is designed and implemented into the system. The touch-screen display allows for a user interface with various menus for navigating through system status, controls, schedules and events. 4D Systems touch-screen panel was particularly chosen because ViSi-Genie provided a more efficient implementation of menus and controls into the panel [7]. There are a few similar technologies that are being used as sources of influence. The way that the "Smart Home" project differs is that the user has a visual readout of the consumption the power per outlet. The relay system is currently only applied in larger buildings beyond the size of residential homes. Thus the plan is to be one of the first to implement this technology on a small scale basis such as a house.

Prototype Design

The entire system is controlled using an Arduino microcontroller. The Arduino receives inputs from various sensors throughout the home to control equipment and appliances. Figure 1 shows the overall system features and how they interface with the Arduino.

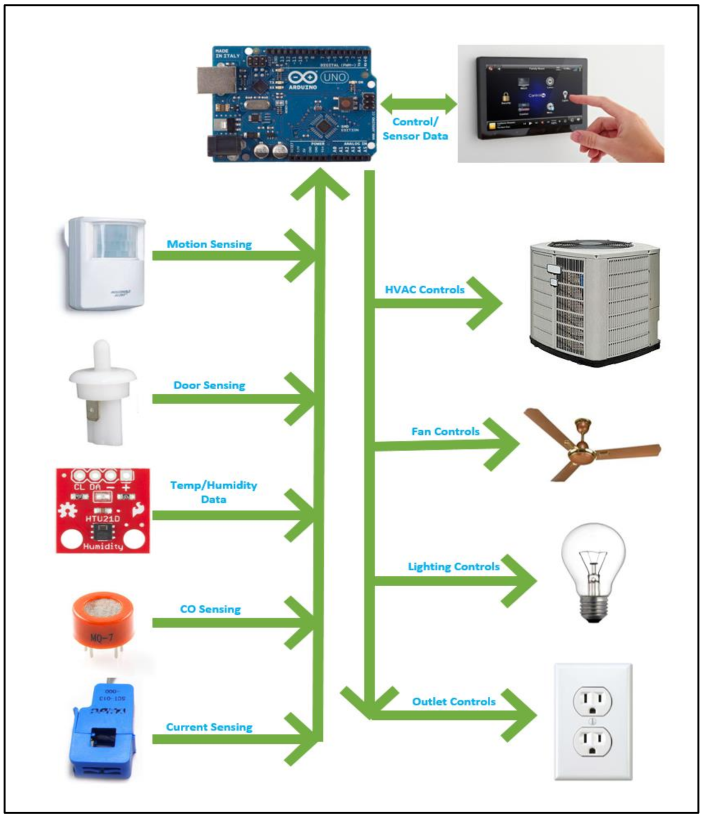

Figure 1: Overall System Features

- Touch-screen Panel - The touch-screen panel is the main interface between the smart home and the user. It is used to view system status and control various appliances and outlets throughout the home.

- Smart Outlets - Provides the ability to shut off and turn on via the touch-screen display remotely throughout the home. Also monitors current being drawn through the outlet to provide the homeowner with power consumption analysis as well as providing automated circuit protection in over-current conditions.

- Temperature and Humidity Monitoring - Temperature and humidity is monitored for displaying current conditions via the touch-screen display. Allows for temperature control.

- Carbon Monoxide Monitoring - Carbon Monoxide is monitored at specified locations for providing the user with actual CO readings via the touch-screen display. Upon reaching an alarmed condition, the system will sound an alarm to notify the user [8].

- Lighting Controls - Lighting throughout the home can be controlled locally, within the same room, and remotely from another room within the home via any touch-screen panel.

Lighting intensity can be set using the dimming function or using pre-set options of half-intensity or full-intensity.

- Fan Controls - Ceiling fans, like the lighting controls, have the ability to be controlled from any room within the home via a touch-screen panel. Fan controls allow for the user to select from three speeds.

- Security Monitoring - Security settings allows for the user to arm the system to “Stay”, “Away”, or “Disarmed”. Security monitoring is performed using a combination of motion and door sensors.

- Door Sensor - The door sensor is a switch used to send a signal to the system when the door has opened or closed. The door sensor is monitored when the security system is armed as “Stay” or “Away”.

- Motion Sensor - The motion sensor is used to send a signal to the system when motion is sensed within that room. The motion sensor is monitored when the security system is armed as “Away”.

- Temperature Control - Temperature may be controlled to a predetermined temperature range as specified by the user via the touch-screen display. Temperature control allows for a heating and cooling option.

- Control HVAC (Heating Ventilation and Air Conditioning) - The HVAC unit is used to maintain the environmental conditions as specified by the user using the Temperature Control feature on the touch-screen panel [9].

The main program loop of the smart-home system starts by setting the baud rate, the pin modes and resetting the panel. The CO sensor starts running first, and the room temperature for its running is adjusted accordingly. From the main panel, we can control the thermostat, security system and all lights and fans in the house. Figure 2 shows the flow diagram of the main program loop. HVAC Working: The HVAC has a three-way switch for ‘ON – AC Mode’, ‘ON – Heater Mode’ and ‘OFF – Mode’. Based on which setting has been selected, we can use the HVAC to control the thermostat of the smart home. The HVAC system works as a simple feedback loop, dynamically changing the room temperature to the required temperature. On selecting the ‘AC’ setting, the system records the room temperature and compares it with the temperature setting. If the room temperature is more than what is specified, the HVAC pushes the thermostat to cool down the room temperature. This loop keeps repeating till the room temperature is either equal to or below the specified temperature. Once the target temperature is achieved, the HVAC halts the thermostat, thereby saving power. The ‘Heater’ mode works in the exact same way, only the loop checks if the room temperature is lower than the specified temperature and increases the room temperature accordingly.

Flow Diagram for the system

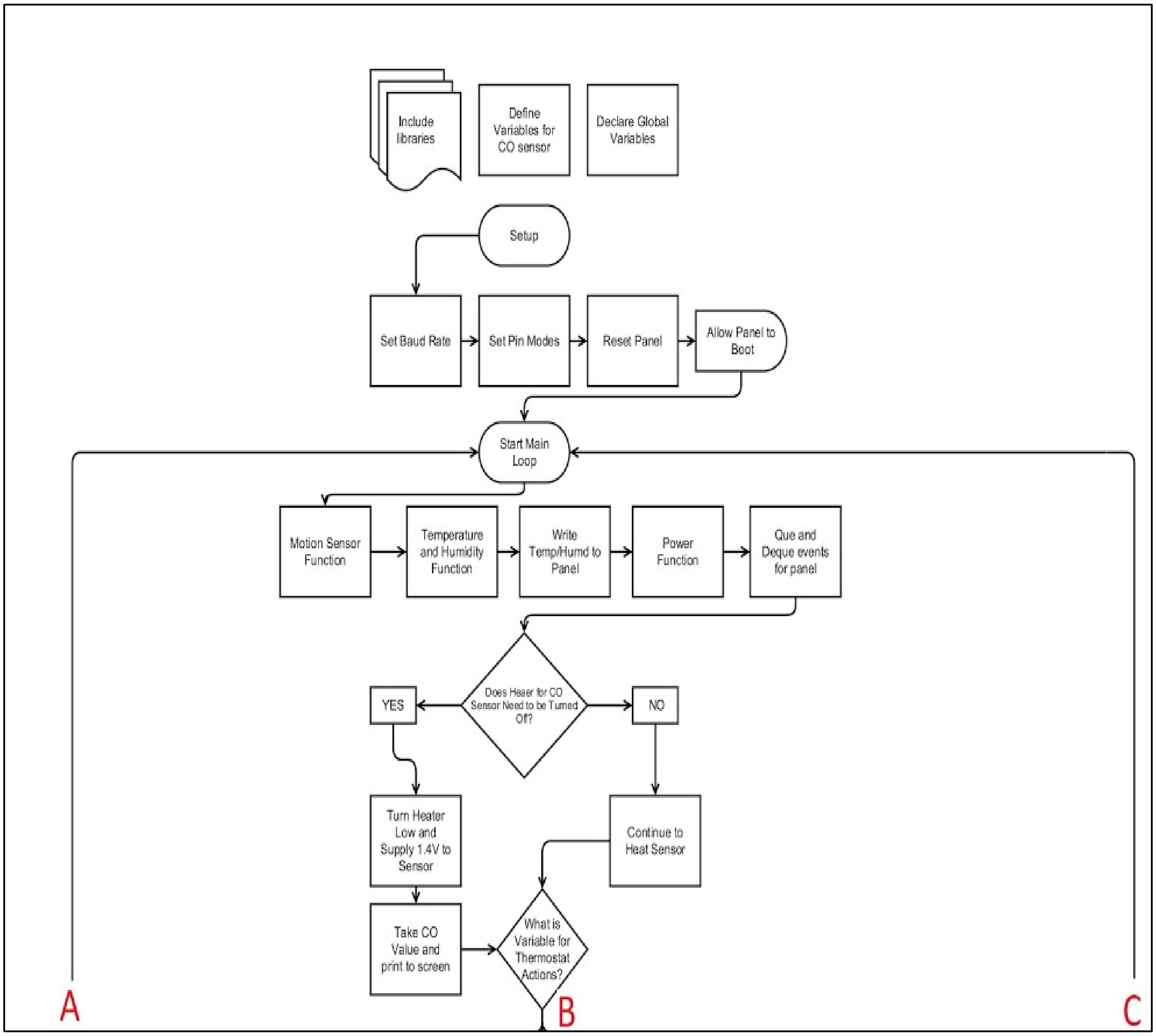

Figure 2: Flowchart for Setup and Start of Main Loop

Security System Working: Just like HVAC, the security system also has 3 modes of operation – 'Arm System', 'Disarm System' and 'Arm At-Home System'. 'Arm-System' is selected when there are no residents in the house, and the home is empty. When selected, the setting switches off all the lights and fans in the house (after a delay, to allow the user to exit his house), and activates the motion sensors in the house. If it detects any discrepancy, it automatically sounds an alarm which can only be switched off if a button is pressed. 'Arm At-home System' setting is used when the user is at home. This setting does not activate motion sensors, instead activating the required door sensors. If there is any discrepancy, like a door opening when it is not supposed to, the system sounds an alarm continuously and displays the location of the breach on the screen. The alarms can only be deactivated by the press of a button by the home-owner. Finally, the 'Disarm-System' selection disarms all the motion and door sensors in the house, completely deactivating the security system. All buttons for HVAC, Light-fan control and security system are interfaced with the main loop using switch cases.

Hardware

There are multiple hardware components needed to construct the project such as the microcontroller, relays, sensors and a touch-screen panel. The microcontroller is used to run a GUI software on the touch-screen panel along with interfacing of the sensors and relays. The relays are being used as individual circuit breakers, allowing "trips" to be isolated unlike in a traditional home circuit breaker system. A touch-screen panel is used to interact with the system. The specific model that is being used is 4D Systems' uLCD-70DT. The touch-screen is 7 inches and has its own built in processor, 32kb RAM and flash memory. Most importantly, it has the ability to connect and interact with an Arduino microcontroller via serial breakout cable. In addition, the back of the touch-screen has multiple GPIO inputs and a slot for micro SD cards that contain programs.

As with most homes, sensors are used to detect hazards and emergencies. CO sensors are put to use to ensure that the home is carbon monoxide free. The sensor(s) is interfaced to the microcontroller which is programmed to sound an alarm if any sensor(s) detects a level of danger. The CO sensor being used is connected to the system and is able to detect CO levels. The sensor being used was tested and calibrated. The circuit design for the CO sensor takes the incoming 12V and lowers it to 5V using a voltage regulator. The 5V is used to heat the coils in the sensor to burn off excess debris and dirt that has built up. The relays to the CO sensor switches the 5V to 1.3V. This change to 1.3V happens every 2 ½ minutes to be able to output accurate data to the Arduino that is then read on the touch-screen. Figures 3 shows the CO sensor data comparisons and readings calibrated to read in parts-per million (ppm) respectively. Table 1 shows the CO readings recorded by the 3 meters. Figures 4 & 5 show the CO sensor readings inside and outside CO-rich environment respectively.

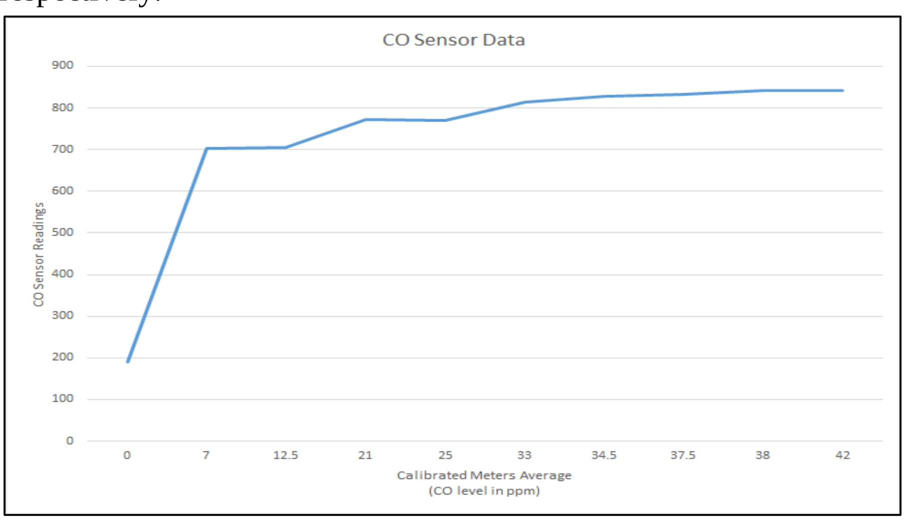

Figure 3: CO Sensor Readings

CO Sensor	Meter 1	Meter2	Meter 3
702	7	7	7
706	12	13	10
770	25	25	22
773	20	22	18
813	33	33	28
827	33	36	30
832	38	37	32
842	41	43	38
842	39	37	36

Table 1: CO Sensor Readings

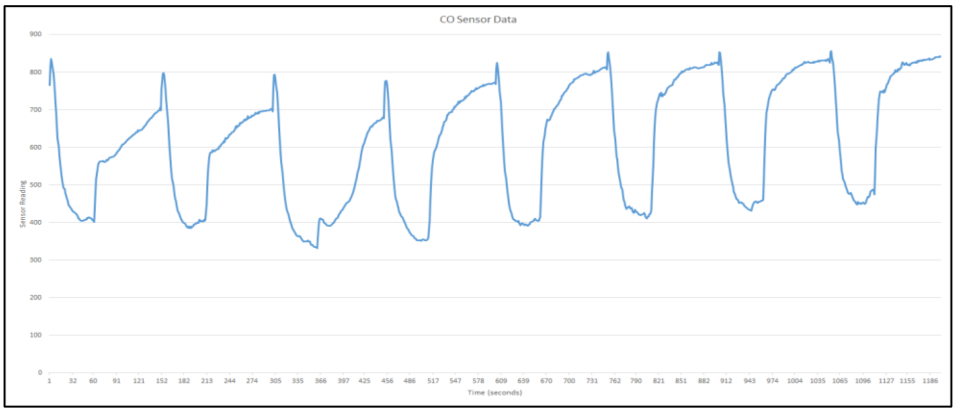

Figure 4: CO Sensor Data (In CO Environment)

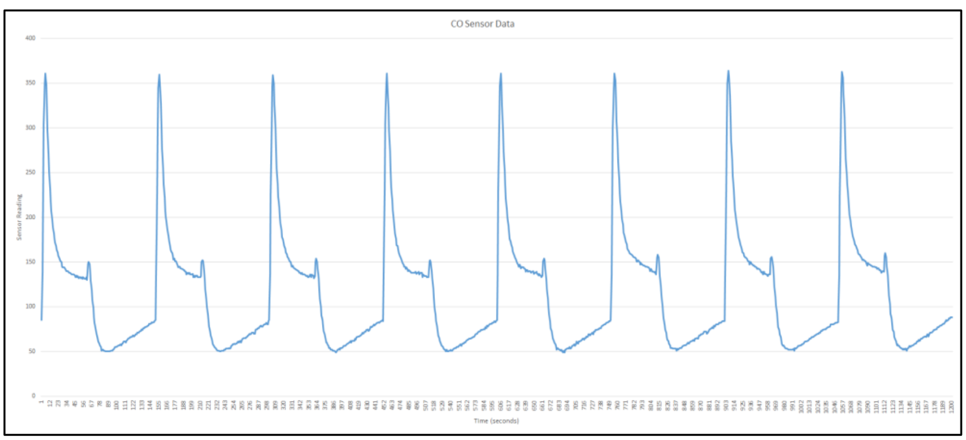

Figure 5: CO Sensor Data (Outside of CO Environment)

Volts	Amps (Measured)	Amps (Calculated)
0.66	0.1	0.106034
0.87	0.15	0.142763
1.18	0.2	0.196982
1.53	0.25	0.258197
1.69	0.29	0.286181
2		0.3404
2.5		0.42785
3		0.5153
3.5		0.60275
4		0.6902
4.5		0.77765
5		0.8651

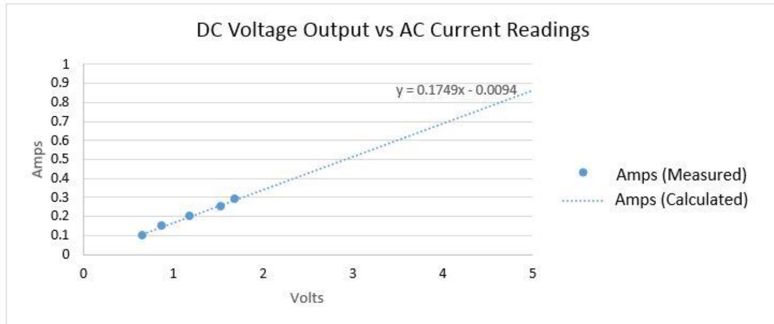

Figure 6: Table and Graph of DC Voltage Output vs AC Current for CO Sensor

A sensor (HTU21D-F) is used to read both temperature and humidity and it requires no calibration before use. It works with an Arduino microcontroller and requires 3V supply [10]. The sensor is connected to the Arduino using analog pins so it can provide constant readings. The fan being used is a simulation of a ceiling fan in the home and requires 120V. It uses 3 SSRs to control the fan speed as well as turning it completely on or off. The SSRs connect to the touch-screen using digital pins to control fan speed settings. Each SSR is associated with a specific speed setting (high, medium or low) of the fan. The fan turns off when no voltage is supplied to any of the SSRs.

The touch-screen controls a light dimmer using a potentiometer like arrangement, with different resistances causing different intensity levels of the light [11] [12]. If the knob of the dimmer is rotated fully on, the potentiometer is set to a resistance high enough to absorb most of the power before it goes through the light. If the knob is rotated fully off, the resistance is so low that the light still gets nearly all the power from the receptacle to still be considered maximum brightness.

A motion sensor and a momentary switch are implemented to work in conjunction with the home security system [13]. The motion sensor is used to detect movement inside the home. A signal is sent to the touch-screen indicating the room in which any movement was detected. The momentary switch is used on a door and detects the opening and closing of that door. The compression and release of the switch sends signals to the touchscreen control station which, in case of a discrepancy, sounds an alarm. This feature is being used in both the away mode and the home mode of the security system to indicate that a door has opened.

Current transformers for each outlet are interfaced with the system to monitor the power usage of the home. This allows individual outlet receptacles to be monitored in real-time. Additionally, a 20A SSR replaced the mechanical switch of the breaker box. This allows for turning the power to the outlets ON and OFF remotely. Power conditioning is implemented for accurate power monitoring. The AC current at the outlet is converted to a DC current. The AC sine wave is chopped in half by using an instrumentation amplifier. This also amplifies the signal from millivolts to a readable level at 50 times the magnitude. Then the signal is passed through a diode, performing half-wave rectification.

Design Constraints

One constraint of the project would be that it is most cost efficient to install while a home is being built. If it were to be installed after the home has been built, the entire electrical system will have to be replaced with the new proposed system.

If users expand their homes (i.e. add any additional rooms that require power outlets), it would be difficult to expand our system into those new rooms. The programming of the wall panels will have to be modified to include the additional outlets.

Summary and Conclusions

A complete and affordable smart home monitoring and security system is designed using Arduino Uno interfaced with an array of sensors and actuators. The system can be controlled using an attractive GUI interface (touch-screen). The entire system integrates thermostat and humidity control, power flow regulation and control (for lights, fans and other electrical equipment), security and alarm systems and a chemo-sensor for measuring carbon monoxide levels during emergencies like fire and leakage.

In this system, control is implemented via the touch-screen which can only be accessed from inside the home. User control can be extended beyond the touch-screen to devices such as a smartphone using cloud computing for greater control and accessibility. Additional sensors and actuators can be easily added to the system at a small expense to make the system even more complete.

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