An Automated Natural Gas Shut-Off Valve System

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Abstract

There is no system on the market today that monitors a building or house for natural gas and temperature levels simultaneously and shuts off the gas supply to prevent explosions. This has resulted in numerous explosions as reported in the media. This motivated the development of a cost-effective Automated Natural Gas Shut-off Valve system in a group project in the course of the junior-level Electromechanical Design at Wentworth Institute of Technology in Spring 2009. The objective was to turn off a valve at the beginning of the supply chain, outside the building which in turn would stop gas flow whenever elevated temperatures or elevated levels of natural gas were detected. The system consists of natural gas and temperature sensors placed in different rooms of the building. The sensors are interfaced with a microcontroller, which controls a solenoid valve outside the building. When natural gas is detected above a set gas threshold, or temperature above a set temperature threshold, the microcontroller actuates the solenoid and turns off the gas supply, thus preventing potential explosions and fire. A fully functional scaled modeled was developed and will be demonstrated.

Introduction:

The National Fire Protection Association reported that fire departments throughout the United States of America responded to 2,410 home fires in which natural gas was the first material that ignited. These fires resulted in 43 civilian deaths, 211 civilian injuries, and a massive $48 million dollars in direct property damage [1]. From December 2008 to the current date of May 4, 2009 there have been a total of 4 house explosions within New England itself [2], [3], [10]. The most current of these explosions occurred on February 19, 2009 in Somerset Massachusetts [3] when a house exploded, killing one woman and her dog. This event was so severe that three neighboring houses were damaged to the point that those residents must rebuild before being allowed to move back in. The Fire Marshall believes the explosion was due to a natural gas leak; ironically crews from the New England Gas Co. (the gas supplier) were in the area before the blast occurred. Worldwide, the statistics for damage from natural gas leaks are similar or worse [20], [21]. The Automated Natural

Gas Shut-off Valve System that was designed, built, and tested by this design team, has the potential to put a stop to these needless catastrophes with its intelligent electromechanical system

It has become quite evident by following current events that a system for emergency gas shut off must be developed. The Automated Natural Gas Shut-off Valve System that was developed by this team is capable of turning off the supply of gas to a building and turning on an audible alarm in the event of a gas leak and or fire. This ensures that the structure doesn't explode or have possible combustible elements added to an already dangerous environment and also informs any occupants that the valve is the cause of any non-functioning equipment due to the loss of gas supply. There are a few other features that could be added to this newly developed system. One new feature would be remote communication which would alert the owners, gas supply utility, and first responders that the gas supply has been turned off due to dangerous environmental conditions within the structure. Another possible future addition to the system would be to incorporate seismic sensors to monitor for dangerous seismic activity that could threaten the integrity of the pipes supplying the structure with gas. A system such as this has the possibility to save many lives and millions of dollars in reconstruction costs and property loss each year. This absolute need is the overall driving force for this groups design. The project was undertaken to satisfy the requirements of the semester-long Junior-level Electromechanical Design course. At the beginning of the semester students form groups of 3 to 5 members, brainstorm to come up with a project idea, write a formal proposal, and proceed to develop a prototype. The following is a college catalog description of the course:

> *Students work in teams to design and construct an interdisciplinary project. Teams, with clearly defined individual responsibilities, are required. During the course of the semester, each team undertakes the necessary activities to bring about a successful design project that is well understood, documented, and presented in both oral and written form. Emphasis is placed on research, innovation, project management, decision-making, prototyping, design for manufacturing, design for testability, environmental and ethical issues in design, depth and breadth of analysis, quality of hardware, documentation, and communications. Prerequisites: Junior Status; ELMC160 Electromechanical Design I; MECH302 Mechanics of Materials; ELEC244 Digital Systems; ELEC443 Analog Circuit Design.*

<u>Objectives:</u>

The objectives of this design are as follows:

- Create a system that will turn off a structures gas supply if one or both of the following conditions are met; Elevated levels of gas or if the temperature within a structure is elevated beyond a reasonable level indicating a fire within a structure.
- Manipulate the sensors to be able to communicate with a microcontroller
- Manipulate the output of the microcontroller to be able to control a solenoid gas valve which will turn off a gas main
- Manipulate the output of the microcontroller to be able to control an audible alarm. A flow chart depicting the objectives of this design is presented in Figure 1.

Design:

The final design is described by the block diagram in Figure 1. In the center of the system is the Texas Instruments MSP430 rf2500 microcontroller [9]. This microcontroller has 18 input/output pins, a series of reference voltages to choose from, and a 10-bit analog to digital converter. It can be powered by battery or through the computer USB. In this design two sensors input to the MSP430, the natural gas sensor and the temperature sensor. The natural gas sensor used is the TGS 6810 produced by Figaro Sensors. The temperature sensor used is the LM35 produced by National Semiconductor. The MSP430 will perform an analog to digital conversion on both sensor's data and set these values to user-set variables. If these variables surpass the safety limits that were predetermined decided, an output pin will be set high, at 3.6 V to power an alarm and solenoid. The alarm will sound in the event of a gas leak, temperature increase, or both, and turn off the gas flow to the structure. There are two main parts of the design laid out in Figure 1: the analog design and the programming of the microcontroller. Before the microcontroller and its respective coding can be discussed it is necessary to understand how the sensors, alarm, and valve are conditioned in order to be able to interface with the micro controller. The following section describes the analog design and its key components that allow for flawless communication with the micro controller.

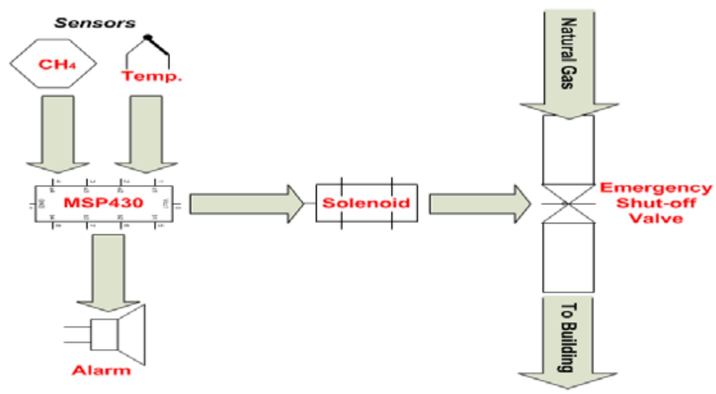

Fig. 1: System block diagram

<u>Analog Design:</u>

The microcontroller in this project accepts as an input 0 volts to 2.5 volts, but the sensors that were purchased for the automatic gas valve only have an output voltage in the mV range. In order to make the sensors compatible with the microcontroller, some analog design had to be implemented which would take these small voltage outputs and amplify them. A weighted summer circuit for the LM35 temperature sensor [8] was used as is shown in Figure 2. where the LM35's output range is 20mV to 1500mV. With this design the group was able to manipulate the output to the proper 0V to 2.5V required by the microcontroller. In order to condition the output signal from the Figaro TGS6810 [11] gas sensor, an AD620 operational amplifier was used (see Figure 2). This was necessary because each Figaro sensor has an offset that needs to be adjusted by means of a differential voltage. The AD620 is capable of amplifying the output of the gas sensor to range from 0V to 2.5 Volts.

Not all components in the system though are intended to aid in amplifying a signal. In the case of the circuitry that controls the actions of the solenoid valve the objective of some of the components is to protect the circuitry and microcontroller from a momentary spike in current. The solenoid that was used has the possibility of drawing a large amount of current when powered off. In order to protect the microcontroller from this surge of current a solid state relay (SSR) was placed within the circuit. (see Figure 2). In order for the SSR to work correctly the output of the microcontroller should be connected to the control input, this connects it to an infrared LED within the SSR. Once this LED is activated it closes a switch within the load portion of the SSR isolating the solenoid from the microcontroller. In order to provide enough voltage to activate the LED a 741C operational amplifier with a gain of two was placed before the positive control of the SSR

In order to power the complete analog design a proper power source had to be created. Figure 3 shows such a source that runs off of Edison power (120V AC). The Edison power is connected to a transformer which steps down the AC voltage to a lower voltage, from there the signal runs through a rectifying bridge which transforms the AC voltage into a DC voltage. This bridge, though effective, doesn't necessarily remove all of the ripple from the power supply. There is still enough ripple left in the supply after passing through the rectifying bridge to cause malfunctions within the circuitry. In order to correct this and make the signal steadier, capacitors are added to the circuit which will act as clipping mechanism to the signal and create a more linear signal. The LM317 and the LM337 voltage regulators were placed within the circuitry to adjust the output voltage to positive twelve volts and negative twelve volts respectively.

Programming:

The programming for the microcontroller needs to be able to accept input data from 2 pins, analyze this analog signal and convert it to a digital (hexadecimal value), set gas and temperature safety limits, and set an output pin high in case this safety limit is breached. The main program is outlined by the flow chart shown in Figure 4.

The input pins for the sensors were set as follows: pin 3 is the temperature sensor and pin 4 is the gas sensor. Also, pin 17 is set as the output pin. The next step is to perform analog to digital conversions on both the sensor input pins.

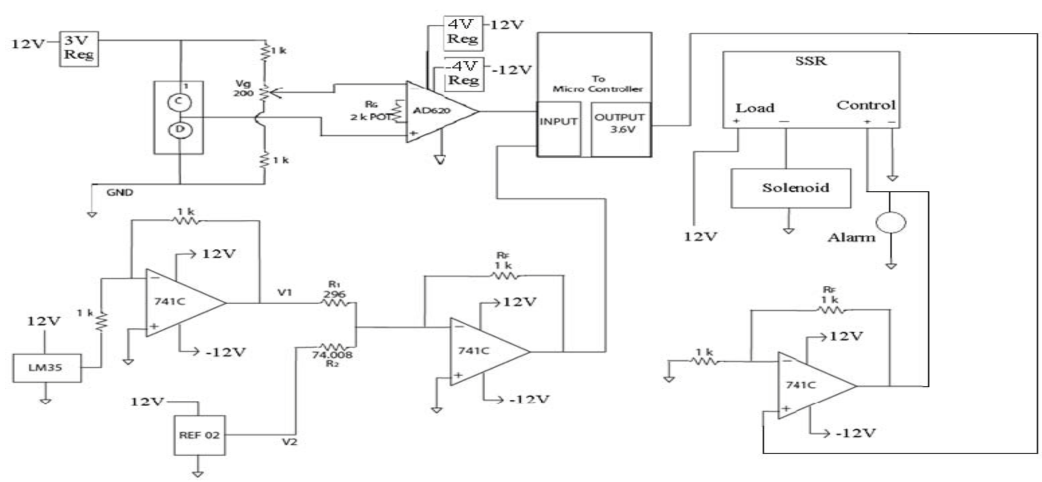

Fig. 2: Circuit diagram of analog interface system

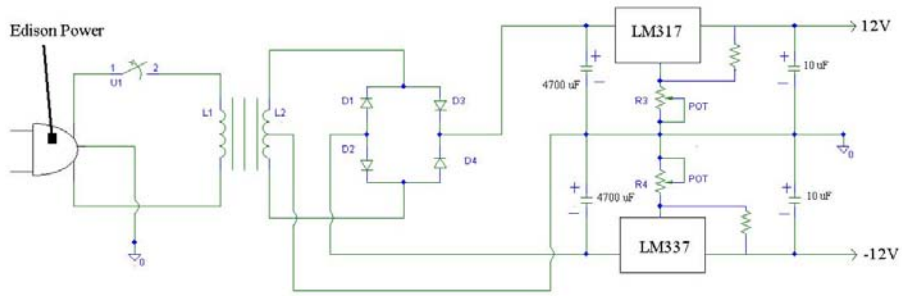

Fig. 3: Circuit diagram of power supply

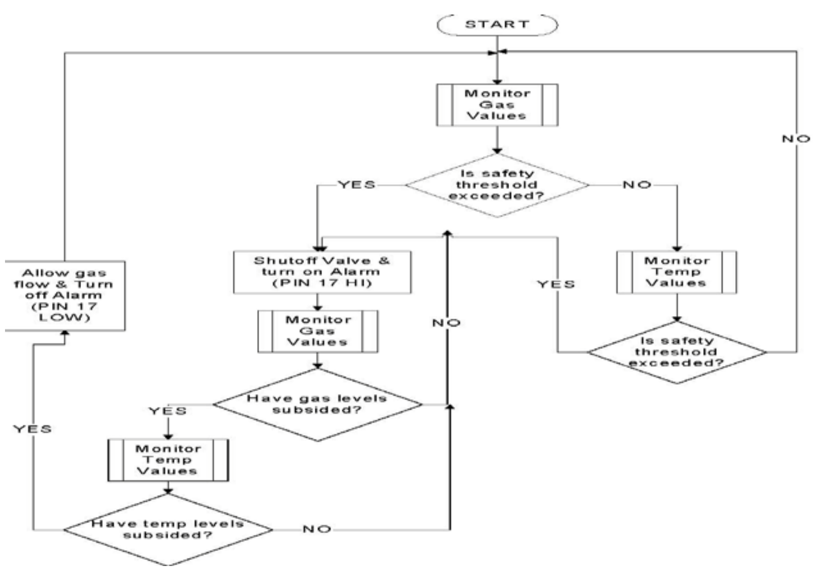

Fig. 4: Program flowchart

Discussion:

The results of this design project are extremely satisfactory. The design group has produced a fully functioning and reliable prototype of the Automated Natural Gas Shut-off Valve System. The completed prototype provides an excellent proof of concept. The members of the design group presented the Automated Natural Gas Shut-off Valve System at a public forum and it was perceived by the design group that none were disappointed or un-impressed by what had been accomplished in the three months allotted for development of the project. Throughout the three months spent by the group members, in design and construction of the final proof of concept, there were four paramount milestones reached. These principal stages consisted of: initial conception and research, analog design/assembly, microcontroller coding, and testing.

The first milestone completed by the design group was with the initial conception of the idea for an Automated Shut-off Valve System and completion of technical and market research. Temperature sensors [8] and gas detectors [11], [12], [14], [15], [16], [19], [22] were researched. The LM355 temperature sensor [8], and the TGS 6810 methane gas sensor manufactured and sold by the Figaro Engineering Inc. [11] were chosen . The TGS 6810 is most sensitive to methane gas, although it is sensitive to other hydrocarbons as well such as butane, ethane, and propane. All of these gases however constitute the composition of natural gas, although methane is the largest component [7], [13], [17]. At first a PIC18 microcontroller was chosen, but after a brief attempt at programming with the PIC the group exchanged it for a Texas Instruments MSP 430. The group spent nearly a month conceptualizing, researching, and purchasing the major components of the Automated Natural Gas Valve System.

The second and third milestones fulfilled by the design group happened in parallel with one another. The second and third milestones were the *Analog Design & Assembly* and *Microcontroller Coding*. Adam Robert and Paul Ellsworth completed the design and assembly of all analog aspects of the system. Benjamin Cadieux and Lee Denaro wrote the necessary coding for the MSP 430 microcontroller which would monitor the sensors and control operation of the solenoid valve and alarm. Paul Ellsworth and Adam Robert designed the analog signal conditioning circuits to interface the TGS6810 and LM35 sensors to the microcontroller. Paul Ellsworth and Adam Robert assembled and tested the sensor signal conditioning circuits with nearly no debugging or troubleshooting needed. After some research, a solid-state (SSR) was found to be the best way to output the relatively high voltage and current required by the solenoid while protecting the microcontroller from possible surges caused by the solenoid. The output of the microcontroller only required small signal amplification in order to operate the control of the solid state relay and alarm and is connected in parallel with the SSR’s control. Testing of the output signal conditioning circuits went very smoothly for Mr. Robert and Mr. Ellsworth. The final, and perhaps most fundamental, aspect of the analog portion of the Automated Natural Gas Shut-off Valve System was the power supply.

The Automated Natural Gas Valve Shut-Off System was successfully able to shut off gas flow in the event of dangerous levels of methane gas and/or dangerous levels of temperature (implicating a natural gas leak or fire). The building of the demonstration board/test rig was completed by Benjamin Cadieux and Adam Robert. The Demonstration board consisted of the entire Automated Gas Shut-off Valve System mounted neatly onto a wooden board. The test rig was simply some plastic tubing connected to a valve which was mounted to a bucket, then connected to the solenoid valve, and finally tubing from the solenoid valve emptied out into another plastic bucket. The construction of the demonstration board and test took only three days.

Conclusion:

The design group was able to successfully design and assemble a prototype which provided proof of concept for the Automated Natural Gas Shut-off Valve System. The prototype is able to detect levels of natural gas and temperature, determine if these levels are safe, and shut off a gas valve in the event of dangerous temperature and/or gas levels. The objectives of this design project were effectively achieved in the allotted time of the semester. The design group was able to conceptualize the idea for a design project, conduct thorough technical and market research, complete analog design and assembly, finish microcontroller coding, and build a demonstration board and test rig to present the final prototype in a public forum. The group did a great deal of independent learning and also received guidance from several colleagues and professors. The design group attained new knowledge involving analog protection circuits, circuit power supply, programming loops, programming flags, analog to digital conversions, programming delays, and solenoid operation. The group as a whole greatly increased their experience and familiarity with engineering design.

The successful completion of this project has left the members of the Automated Natural Gas Shut-off Valve project with several options for the future. The fully functioning prototype gives the group a proof of concept and a very possible opportunity for filing a patent. The requirements for a filing a patent are; the invention must be new, useful, and non-obvious [4]. The Automated Natural Gas Shut-off Valve System, presented in this report, meets all three of these requirements for patent. The one restriction on patenting this design is that a presentation has recently been made in a public forum, therefore the group has one year from the date of the presentation to file for a patent. The members of the design group have perceived a possible market niche for the Automated Natural Gas Shut-off Valve System and the possibility for selling rights to for the product or creating an enterprise is a realistic option. The members of the group have several ideas for continuing design on this project. Some possibilities for future work on this project include: internet connectivity involving an email notification system for a homeowner/gas company, text messaging notification system, seismic sensors for earthquake protection, website control by use of LabView, and possibly a ventilation system for the event of a gas leak. Regardless of the future of this project, the members of the group are very satisfied with their accomplishments and have optimistic hopes for the Automated Natural Gas Shut-off Valve System to a bright future.

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Biography:

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