Robotics Laboratory Environment Monitoring, Safety and Control System with GSM Interface

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Abstract

Recently, Toyota Motor Engineering & Manufacturing North America donated a Kawasaki ZB150s industrial robot to the Engineering Technology program at Northern Kentucky University (NKU). To prevent unauthorized students into the working area of the robot, the robot system is installed in a protective enclosure/safeguard cage. A microcontroller-based laboratory environment monitoring and robot safety control system (LEMRSCS) with GSM interface has been designed and developed to provide the highest level of reliability for the safety of students and faculty in the robot lab operating environment. This LEMRSCR is divided into two subsystems: one is the microcontroller-based environmental parameter monitoring, presence sensing, and robot safeguarding subsystem; the other is the global system for mobile (GSM) communication subsystem. The entire LEMRSCR is based on the high performance and low power CMOS 8-bit microcontroller (microchip ATmega1284), which can 1) receive inputs from the multiple environmental sensors to measure indoor light level, temperature, and relative humidity parameters; 2) determine if individuals are within the footprint of the robot safety cage; 3) control the robot power relay to arm/disarm the power supply of the robot system; 4) allow the administrators to change system settings through the on-board keys; and 5) show parameters on the local OLED display. The GSM communication system can wireless transmit text messages to designated cellular phones (lab manager, NKU maintenance, NKU security) when preconfigured parameters are exceeded. Additionally, a text-parsing algorithm would allow remote arm/disarm commands, system status updates and inquires of current environmental data to be sent via GSM from authorized cellular phones to the LEMRSCS. This paper discusses in greater detail the design, development and hardware implementation of the laboratory environment monitoring and robot safety control system.

1. Introduction

Industrial robots have played a major role in modern automated manufacturing operations for all sorts of applications, such as welding, painting, material handling, packaging, labeling, assembling, and product inspection and testing, etc. Incorporating those industrial robotics into current robotics curriculum has become a key component for Mechanical & Manufacturing and Mechatronics engineering technology programs. Recently, Toyota Motor Engineering & Manufacturing North America donated a Kawasaki ZB150s industrial robot to the Engineering Technology program at Northern Kentucky University; half of the mechanical (robotics) lab was rearranged to accommodate this robot. Figure 1 shows the robot system including all the tables and benches, the coordinate measuring machine (CMM), the Fanuc robot cell, the Kawasaki robot, the cabinets, and existing partitions. To prevent unauthorized students from entering the working area of the robot and protect them from crushing injuries caused by the unexpected movement of the robot, the robot system is installed in a protective enclosure/safeguard cage that is built out of extruded aluminum and paneled with recycled Plexiglas and steel wire mesh (Figure 2).

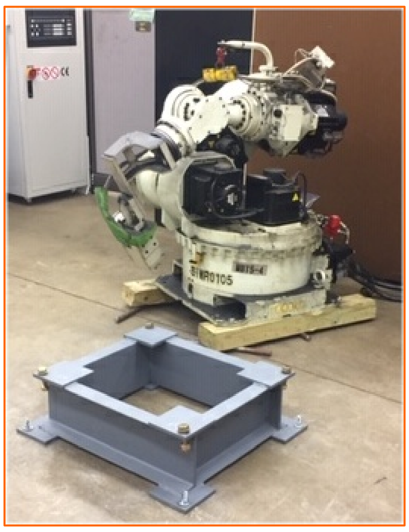

Figure 1. The robot system

Figure 2. Robot assembled in the protective cage

In addition, a microcontroller-based laboratory environment monitoring and robot safety control system (LEMRSCS) with GSM interface has been designed and developed to provide the highest level of reliability for the safety of NKU students and faculty in the robot lab operating environment. There are several prior control systems that share some common aspects of our proposed system. However, none of them is like our LEMRSCS system to integrate the robotic safety control, environmental monitoring, and the global system for mobile (GSM) communications into one control system. Our proposed LEMRSCS includes robotic safety control: studies in Sweden and Japan indicate that many robot accidents do not occur under normal operating conditions but instead during programming, program touch-up or refinement, maintenance, repair, testing, setup, or adjustment. During many of these operations, the operator, programmer, or maintenance worker may temporarily be within the robot's working envelope where unintended operations could result in injuries [1]. To prevent those types of accidents, the microcontroller of the LEMRSCS system receives the presence-sensing signals from the infrared sensors and controls the power relay to disable power to the robot when anyone enters the safety cage. A second element is environmental monitoring: the robotics lab environmental parameters (e.g., temperature, relative humidity, and light levels) are also monitored, recorded, and wireless transmitted to the lab manager's cell phone. Third is GSM communications: many of the control systems [2]-[4] use communication methods to send measurements or security signals to the mobile devices. In this project, environmental parameters and robotic safety control information are wireless transmitted to the lab manager via GSM communications. The GSM text notifications could alert appropriate NKU faculty and staff to occurrences of potentially unsafe operating conditions in the lab. This would allow for a more meaningful interaction among students, lab manager, and engineering faculty with quantifiable and objective data regarding these situations as opposed to subjective reporting or rumors of "near-misses."

2. Materials and Methods

The development of the LEMRSCS came to fruition through a sequence of product development stages. The first stage was a conceptual design in which a conceptual block diagram (CBD) of the system was created to show the basic functions and functional requirements. The next stage was taking the functional requirements and creating their respective performance specifications. These specifications are quantitative measurable values for each of the functional requirements (e.g., power, interface protocol, etc.). The third stage was that a functional block diagrams was made to depict all the parts chosen with pins, signals, and all interfaces required for everything to function properly. Then, the detailed system schematic and the printed circuit board (PCB) layout were drawn based on best practice manufacturing principles using Eagle CAD professional software [5]. Next, the boards were manufactured and populated with all electronic components were populated. Lastly, each hardware unit of the LEMRSCS system was tested and the software was evaluated to make sure the whole system could deliver the overarching functionality.

Figure 3 shows the CBD of the LEMRSCS, which is divided into two subsystems. One is the microcontroller-based environmental parameter monitoring, presence sensing, and robot safeguarding subsystem. This subsystem includes a microchip (Atmel) microcontroller, infrared presence sensors (light curtain), environmental sensors, OLED display, system status indicators, keys, and robot control unit; the other is the GSM communication subsystem.

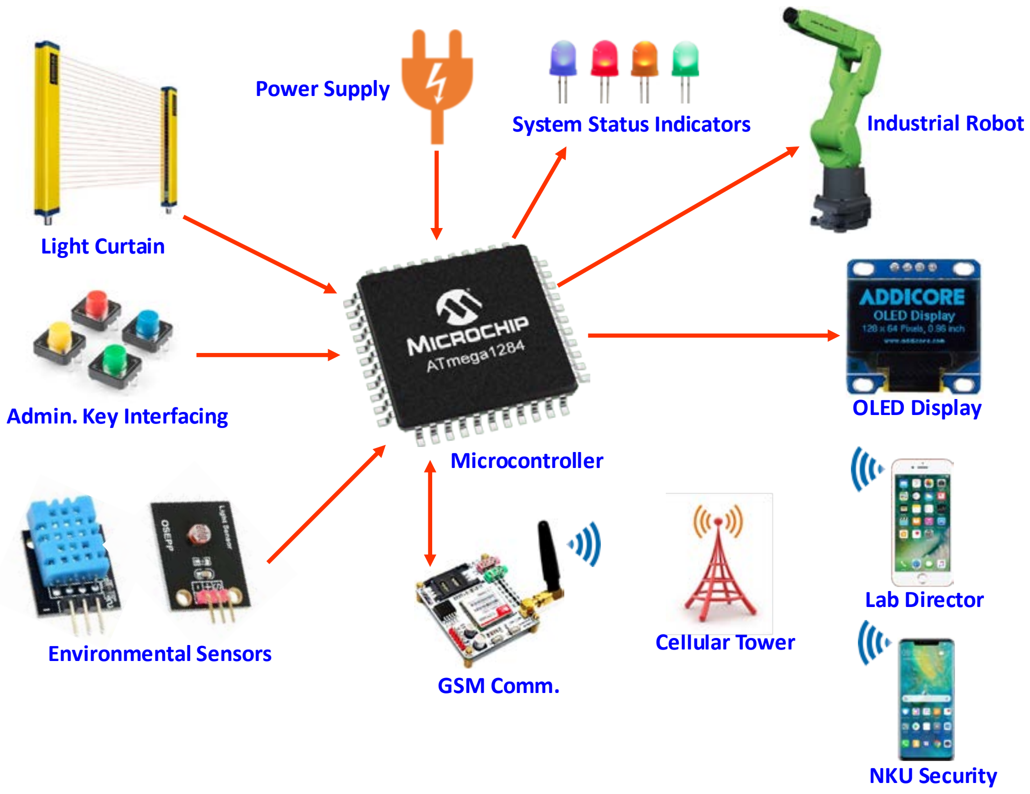

Figure 3. The conceptual block diagram of the laboratory environment monitoring and robot safety control system

The overall functional block diagram of the LEMRSCS was generated (Figure 4) to support simultaneous design and development of both hardware and software. As can be seen in Figure 4, the core of the entire system is the microchip (Atmel) microcontroller (Atmega 1284) that can 1) receive inputs from the multiple environmental sensors to measure indoor light level, temperature, and humidity parameters; 2) determine if individuals are within the footprint of the robot safety cage based on the infrared presence sensing signals; 3) control the power relay to arm/disarm the power supply of the robot system; 4) allow the administrators to change system settings through the on-board keys; and 5) show parameters on the local OLED display. The GSM system can wireless send text messages to designated cellular phones (lab manager, NKU maintenance, NKU security) when preconfigured parameters are exceeded. Additionally, a text-parsing algorithm would allow remote arm/disarm commands, system status updates and inquires of current environmental data to be sent via GSM from authorized cellular phones without the need for a separate application.

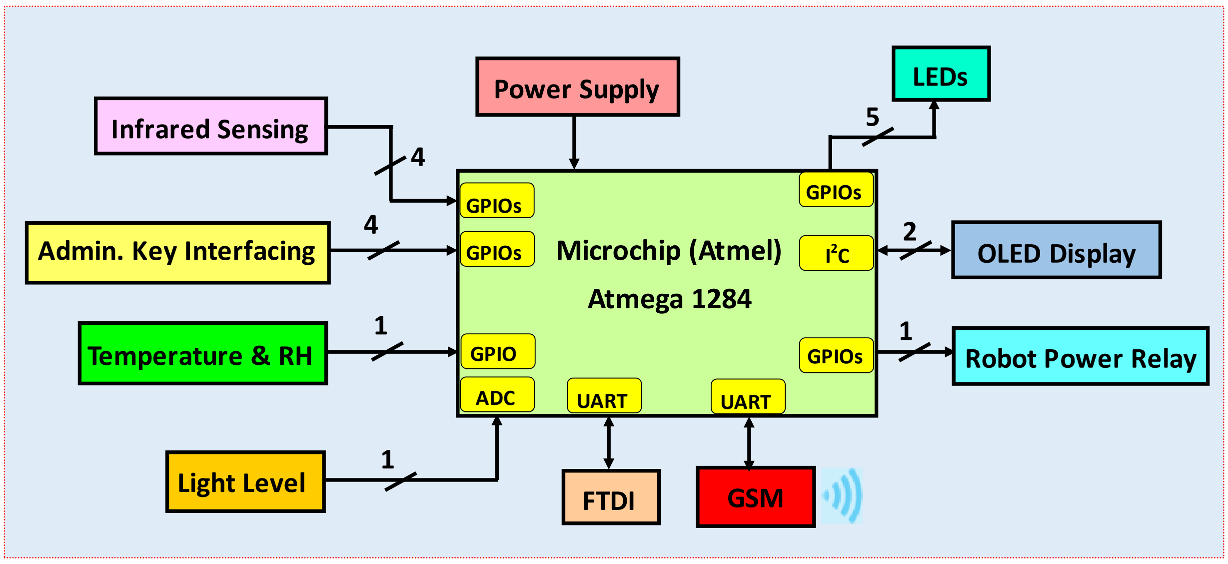

Figure 4. The overall functional block diagram of the laboratory environment monitoring and robot safety control system.

3. The Microcontroller-based Environmental Parameter Monitoring, Presence Sensing, and Robot Safeguarding System

Figure 5 exhibits the schematic of the microcontroller-based environmental parameter monitoring, presence sensing, and robot safeguarding subsystem.

(1) Microcontroller

The microchip (Atmel) ATmega1284 [6] was chosen as a major system controller as it is a high performance and low power CMOS 8-bit microcontroller, which features 128KB ISP flash memory with read-while-write capabilities, 4KB EEPROM, 16KB SRAM, 32 general purpose I/O lines, 32 general purpose working registers, a real time counter, three flexible timer/counters with compare modes and PWM, two USARTs, a byte oriented 2-wire serial interface, an 8-channel 10-bit A/D converter with optional differential input stage with programmable gain, programmable watchdog timer with internal oscillator, SPI serial port, a JTAG (IEEE 1149.1 compliant) test interface for on-chip debugging and programming, and six software selectable power saving modes. Also, an additional strength of the ATmega1284 is the RISC (reduced instruction set) based programming model that it utilizes. By using the Visual Micro plugin for Microsoft Visual Studio 2017, the code can be written in C and loaded to the microcontroller via the use of an FTDI-equipped USB cable.

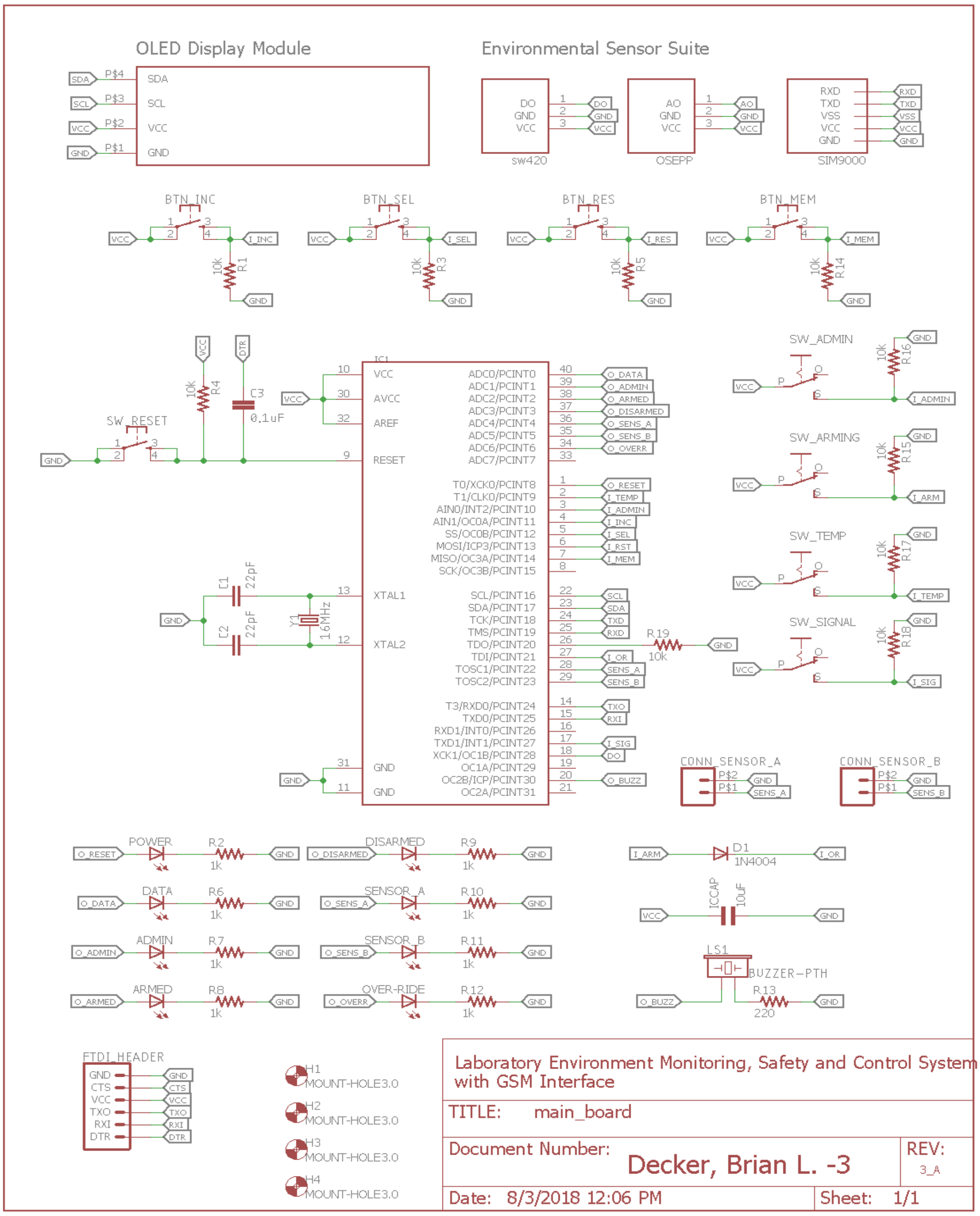

Figure 5. The schematic of the main board for the LEMRSCS

(2) Presence Sensing and Robot Power Control

Four retroreflective cylinder amplifier photoelectric sensor switches (PNP E3F-R2P1) were utilized to form a light curtain (Figure 6). This light curtain can detect if a person is present within the robot safety cage and send the detection signal to the microcontroller ATmega1284.

As soon as the microcontroller receives the input signal, it will energize the power replay to shut off the power supply of the robot. The robot power on/off could be manually controlled by the switch (Figure 7).

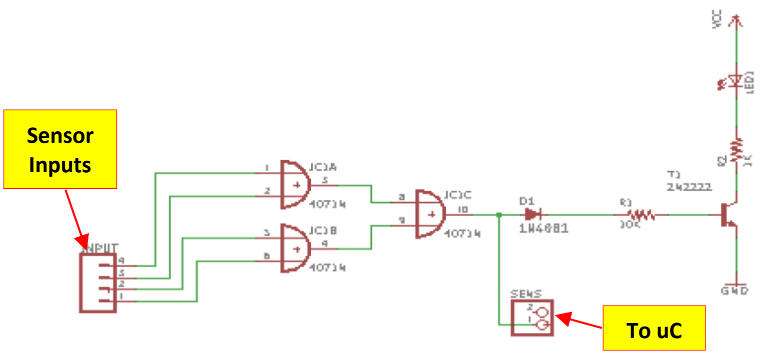

Figure 6. The schematic of the light curtain circuit

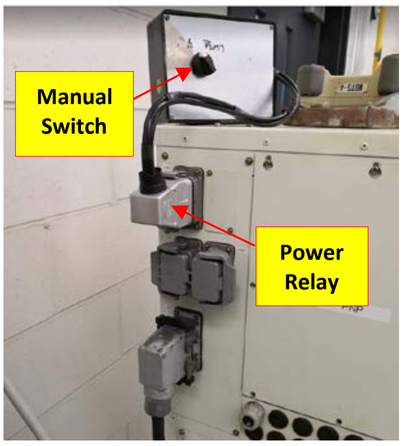

Figure 7. The robot power replay and the manual switch

(3) Environmental Parameter Monitoring

One of the environmental and security criteria tracked via the LEMRSCS is the light level status (Figure 8) of the mechanical/robotics lab. The light level is obtained via the use of a Cds photo-resistor (OSEPP) which generates an analog signal between 0v and 5v depending on the strength of the light it is exposed to. By processing this voltage via the ATmega1284 ADC (analog to digital converter), it is possible to assign values representing both basic light conditions – “on” or “off” – as well as lighting gradients “dim”, “bright”, etc. The ATmega1284 can differentiate voltages to within 1/2048th volt – data points representing changes in light far too discreet for the human eye to make a meaningful determination. Currently, the light sensor is configured for a binary input outputting “on or “off” based on the voltage output level.

The two other environmental sensors, for temperature and humidity levels, are combined into one module. The DHT-11 (Figure 8) utilizes solid state sensors and an onboard ADC to interpret the signal from the sensors and transmit a single digital signal to the LEMRSCS main controller which then parses the data and stores it as a sting in the text buffer. Each sample is compared to the text buffer, and only updated when a change in parameter is received. To avoid errors to temperature and/or humidity levels due to heat generated by the power supply, the DHT-11 module is mounted externally on top of the LEMRSCS enclosure and connected to the main PCB via a 3-line ribbon cable providing VCC, GND and signal paths. The three environmental parameters can be viewed directly on the OLED display screen or queried via GSM by texting the command “ENV” to the LEMRSCS. This will trigger the command language parsing function and return a text to the phone issuing the query that includes the current temperature, humidity level, and lighting status.

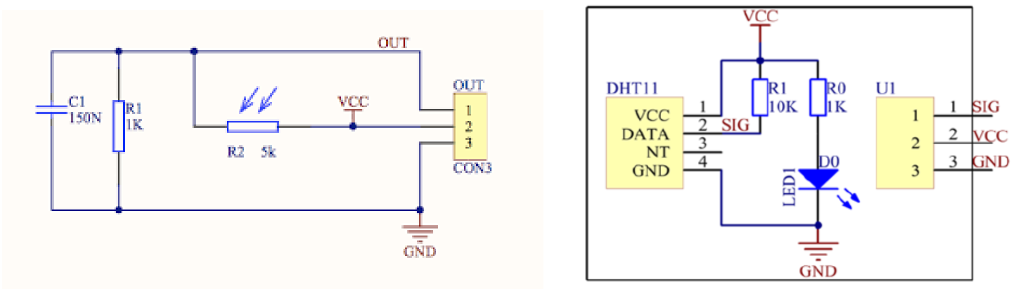

Figure 8. The schematic of light sensor module (left) and DHT-11 module (right)

(4) Key Interfacing and OLED Display

In operation, the appropriate LEMRSCS state (“armed,” “disarmed,” “run,” “admin.”) is selected by the setting of the multi-position keyed safety switch. The system state is displayed on the OLED display screen and the appropriate status LED illuminates. The following is a list of I/O actions for each LMCS state:

- Armed: When the key switch is in the "armed" position or the "system armed" text message has been sent from a designated cellular phone, the LEMRSCS will enter the "armed" state. The OLED will display a rotation of "system armed," temperature and humidity, and time and a RED LED will be illuminated. A signal from the presence sensors will generate a warning tone until the presence is removed, and a preconfigured GSM text message will be transmitted to the designated cellular phones.

- Disarmed: When the key switch is in the "disarmed" position or the "system disarmed" text message has been sent from a designated cellular phone, the LEMRSCS will enter the "disarmed" state. The OLED will display a rotation of "system disarmed," temperature and humidity, and time and a GREEN LED will be illuminated. In this state GSM inquiries may be sent to the LEMRSCS, but it may not be remotely armed, and the presence sensors will not generate any tones or messages.

- Run: When the key switch is in the "run" position the system will enter the "run" state. The OLED will display "system run" and a blue LED will be illuminated along with a double beep. A signal sent from the presence sensors will switch the SSR (solid-state relay) off, disabling the robot and sound an alarm tone. In this state GSM inquiries may be sent to the LEMRSCS, but it may not be remotely armed, and the presence sensors will not generate any tones or messages.

- Admin.: When the key switch is in the "admin." position the system will enter the "admin." state. The OLED will display the primary phone number programmed into the LEMRSCS and a yellow LED will be illuminated along with a double beep tone. The SSR will be OFF and in this state GSM inquiries and commands are disabled. While in the "admin." mode, the four momentary pushbuttons on the control panel become active and allow the user to:

- Set the time displayed on the OLED.
- Change, add or delete phone numbers stored in the LEMRSCS phone number data table ROM so that data will be preserved in the event of a power failure or system reset.
- Change temperature display from Celsius to Fahrenheit.

(5) The GSM Communication Subsystem

The unique feature of this laboratory environment monitoring and robot safety control system is that the alert text messages along with the environmental information can be wirelessly transmitted to designated cellular phones (lab manager, NKU maintenance, NKU security) via GSM communications. The remote arm/disarm commands, system status updates and inquires of current environmental data can be also sent via GSM from authorized cellular phones to the LEMRSCS. By utilizing the global 2G data network and a quad band (850, 900, 1800, and 1900 MHZ) transceiver, the GSM module (SIM900) can be easily implemented globally and tied to any cell provider. The SIM900 module comes with a UART adapter, which can be directly interfaced to the microcontroller ATmega1284 through the UART peripheral - TX and RX pins. Because the LEMRSCS leverages the global GSM network and quad band transmission, its hardware can be easily implemented anywhere within the 90% of the globe that is covered by 2G. Unlike devices that rely on local radio networks such as Bluetooth or Wi-Fi, there are none of the distance, network, or security concerns that accompany those solutions.

(6) The Main Board Manufacturing and Evaluation

The main boards of the laboratory environment monitoring and robot safety control system have been manufactured, assembled, and tested. Figure 9 shows the PCB circuit design, board assembled, LEMRSCS prototype, and final LEMRSCS in the standard locking non-metallic industrial enclosure. This enclosure contains the system 120VAC to 5VDC 2amp power supply, custom PCB, GSM module, external antenna, keyed system state switch, OLED display, audible tone generator, LED indicators and momentary pushbuttons to allow for user interface and inputs such as updates to the LEMRSCS phone number data table, setting the system time or adjusting the display parameters for environmental data. Connections are provided for 5V (logic level) data signals from the light, temperature, humidity and presence sensing devices and the control signal to the SSR handling control power to the robot.

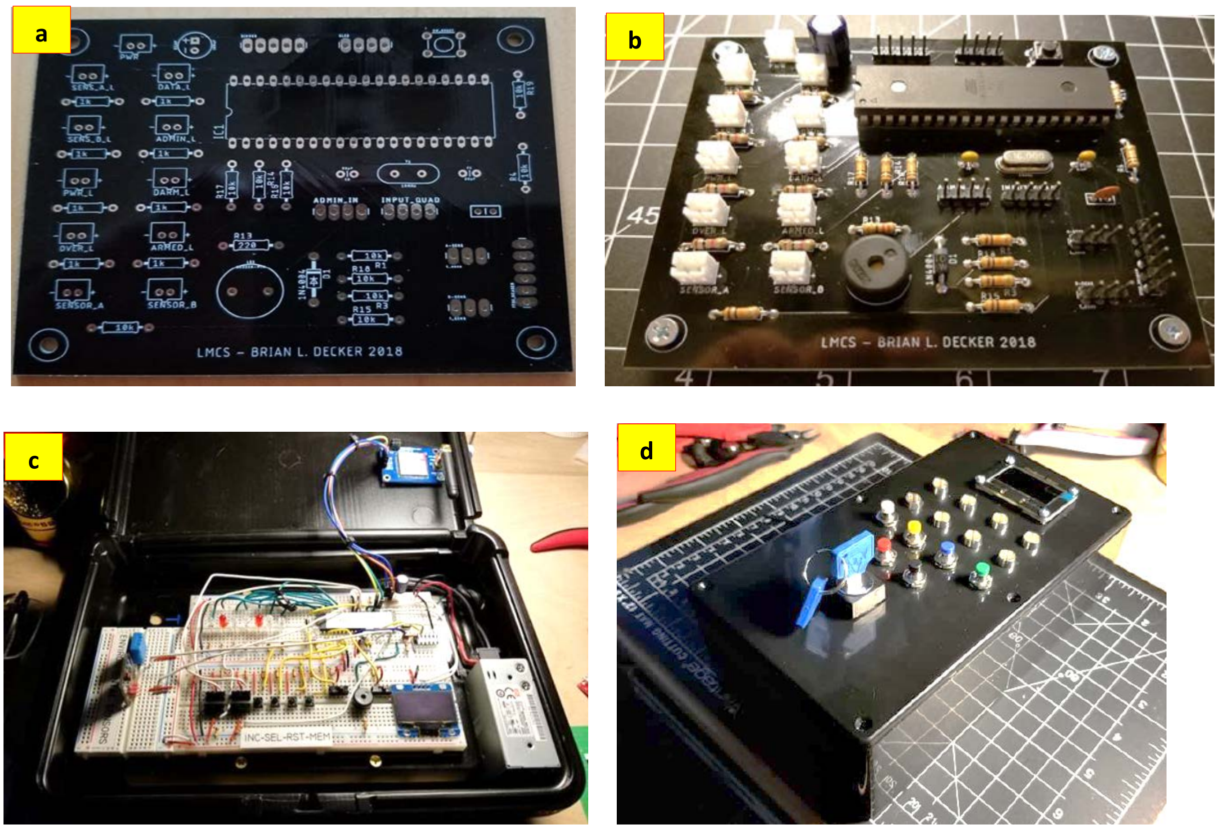

Figure 9. (a) PCB circuit design; (b) board assembled; (c) LEMRSCS prototype; and (d) final LEMRSCS in the enclosure

3. Conclusions

This paper presents the overall design, development and hardware implementation of a microcontroller-based laboratory environment monitoring and robot safety control system (LEMRSCS) with GSM interface in order to prevent unauthorized students into the working area of the robot and protect them from crushing injuries caused by the unexpected movement of the robot. This system will also be constructed using a modular hardware and software schema allowing for the provided functionality to be easily reconfigured to support other scenarios of use. An example would be the replacement of the presence sensors with input from an anemometer and rain sensor allowing the system to serve as a remote weather station that would send text alerts if a wind gust exceeded a set value or an hourly transmission of current conditions. By replacing the 120-volt AC power supply with a solar array and rechargeable battery, the system could be placed in a remote area and, due to the use of global GSM, maintain all functionality without the need for any external connections.

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