A Controller Design for a Dynamic Roadway Marking System

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ABSTRACT

A novel system has been developed that can link the evidence shown on a roadway to vehicle performance using an electronic paintball marking system. The field of traffic crash reconstruction uses roadway evidence to infer the dynamics of a vehicle. However, no inexpensive technique exists to verify that the evidence left on the roadway corresponds to particular levels of force or acceleration. This dynamic roadway marking system uses two markers fired simultaneously to gain vehicle orientation and location. Each time the gun is fired, a signal is sent to the same data acquisition system that is monitoring accelerometers and other vehicle parameters. Tests were conducted for severe cornering maneuvers. Results show that tire scuff marks begin appearing at nearly 0.5g of lateral acceleration on a paved, dry parking lot surface. Also, different braking and turning combinations can be tested and the data from the accelerometer traces and the paintball positions can be compared. Sensor drift can be easily measured and bias mitigation techniques can be tested. A circuit diagram and schematic show how to implement this system. Overall, this paintball marker based system provides research, verification, and educational capabilities to the crash reconstruction community and vehicle dynamics engineer.

Keywords: vehicle dynamics, crash reconstruction, microcontrollers, paintball markers, critical speed yaw, physical evidence.

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1 INTRODUCTION

In the field of traffic crash reconstruction, physical evidence is the foundation of the analysis. In other words, the evidence on the roadway and from the vehicles provides much of the basis for crash reconstructions. The evidence on the road has been correlated to movement of the vehicle; however, no one has explicitly tied physical road evidence to measured vehicle performance data, such as accelerations. This paper presents the design of a system that can link physical evidence to vehicle performance.

The Dynamic Roadway Marking System (DRMS) comprises modified, off-the-shelf electronic paintball markers and a central controller. The controller must fire the paintball markers at the same time and send an external signal to a data acquisition (DAQ) system monitoring vehicle performance.

The motivation for the DRMS was prompted by a desire to ascertain whether traditional methods of crash reconstruction are valid. Specifically, what kinds of simple models can we use for post-impact spin analysis and what levels of acceleration/force are required to leave evidence on the road surface. Examples of vehicle trajectories can be found in the literature, e.g. [1]. The results of the trials using the marking system will quantify the limitations of simplifications used in reconstructions calculations.

This paper primarily focuses on a microprocessor implementation for the controller of the DRMS. The paper shows an overall system design and then discusses the implementation of each component. An actual prototype was made and tested and the paper concludes with exemplar data.

2 MARKING SYSTEM DESIGN

2.1 SYSTEM IMPLEMENTATION

The complete system is a combination of several components as seen in Figs. 1 and 2. The overall design is centered on the control system which is made up of the printed circuit board and the supporting control circuitry. The control system is designed around a microprocessor, the various peripherals such as relays, switches, LEDs, and data ports are all controlled by the processor. This hardware is used to create an interface with the paintball markers and the data acquisition system (DAQ). The paintball markers provide the visible output and the DAQ captures time based firing data from the control system. The components are arranged on a printed circuit board for maximum reliability and ease of assembly. This design provides an aesthetically pleasing and easy to maintain package that is capable of operating properly under adverse conditions.

The seven segment displays are common anode displays. The displays are interfaced to the processor through a set of binary coded decimal (BCD) to seven-segment output decoders. The decoders allow the processor to specify the desired display value in a decimal format and significantly reduce the number of input/output (I/O) lines needed to drive the displays. The decoders are connected to the displays through a Darlington pair high current circuit. This circuit allows the LEDs to be driven at full brightness without burning out the decoder chips.

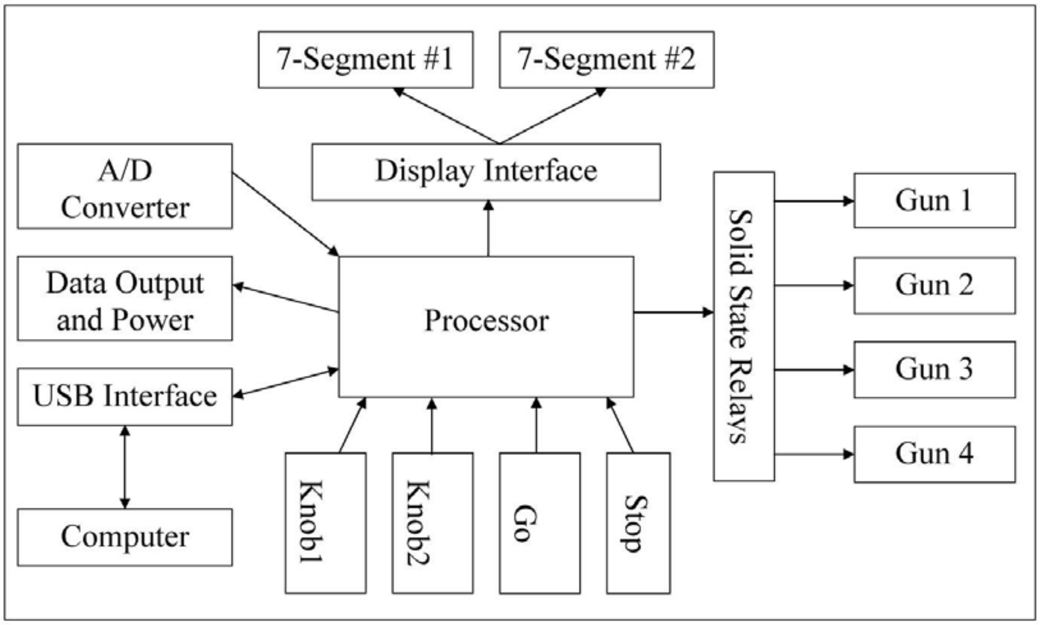

Figure 1: Functional block diagram of the dynamic roadway marking system.

The paintball markers are connected to general I/O pins on the processor. Each gun is connected through a solid state relay in order to isolate its circuitry from the circuitry of the processor and the circuit board.

Each knob has two I/O pins which are connected through a resistor network to the microprocessor. The resistor network gently pulls the signal on the I/O pins low while the pin is in an unconnected state, when the dial connects the input to its common pin the processor reads a signal high. During normal operation, the pattern in which the I/O pins are connected to the common pin indicates the direction of dial rotation.

The fire and abort buttons are connected to the microprocessor through a resistor network. The resistor network pulls the signal on the I/O pins low while the button is in its normally open state. When the button is depressed the I/O pin reads logic high and the processor executes the appropriate block of code.

The analog to digital conversion input is connected directly to the microprocessor, any analog input connected to those pins will be read into the processor and the converted value sent through the USB interface.

The data output port connects the processor to a DAQ for the purpose of sending time based firing signals to the DAQ system. The circuit board can also derive its operating power from this connection.

The USB interface gives the option of gathering analog to digital conversion data and status information with a computer terminal.

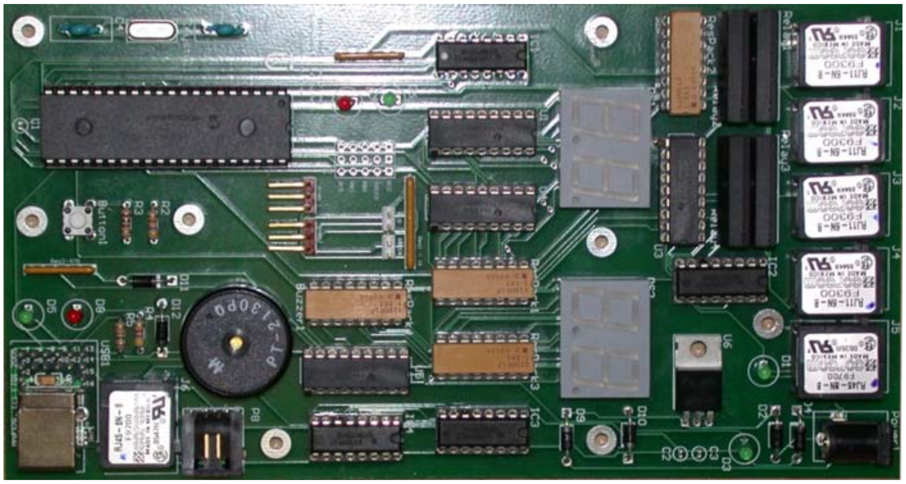

Figure 2: A photograph of the actual implementation of the controller for the DRMS.

2.2 PAINTBALL MARKER ALTERATIONS

The paintball makers used in the dynamic roadway marking system are equipped with electronic trigger mechanisms. The trigger on the paintball gun is a contact closure switch, when the switch is pressed, the contacts are closed and the gun fires. The roadway marker system must be able to fire the guns remotely and simultaneously. To achieve this, wires have been soldered onto the contact closure points to add an auxiliary switch to the electronic trigger mechanism, as shown in Fig. 3. To get inexpensive reliable electrical connections, standard phone cables and RJ11 terminators are used to connect the paintball marker to the controller. By closing the contacts on the left side of the RJ11 connector to the contacts on the right side of the RJ11 connector, the trigger mechanism is activated, just as if the actual trigger had been pulled. This activation is performed using solid state relays. The change in the closure position is transparent to the electronic trigger mechanism in the paintball marker.

Figure 3: Modifications to an off the shelf electronic paint ball marker. The mechanical micro switch is bypassed with a remote solid state relay.

3 DETAILED CONTROLLER DESIGN

The paintball marker controller is designed around the Microchip PIC18F4525 micro-controller [2]. This microcontroller is well suited for the project because if its 40 pin structure which includes up to 13 channels of 10 bit analog to digital conversion, a USART (Universal Asynchronous Receiver/Transmitter) port for computer connectivity and a wide operating voltage range. It would be convenient in many circumstances for the marking system to fire a variable number of shots at a specified frequency. The control system includes a pair of seven segment displays and dials. Using this interface, values for shot frequency and total number of shots can be entered using the dials and the current settings monitored on the seven segment displays. The marking system has fire and abort buttons which can start and end the firing sequence. The control system fires the paint ball markers by closing a relay on the circuit board. Data from the firing system can be transmitted to a data acquisition system through an 8-pin RJ45 connector, or to a laptop through a standard USB link. The control system also allows for up to six channels of analog data acquisition. A parts list is included in Appendix B.

3.1 DAQ INTERFACE

The control system has an on board RJ45 connector that allows for the connection of a DAQ interface. The connector is configured with pin 1 as input power, pin 8 is ground and pin 2 is the output signal. The input power exists to derive power from the data acquisition system if needed. For instance, this same pin and connector configuration is used by Vericom in their VC3000 performance computer and the Vericom unit can provide up to 500mA at 12V [3].The microprocessor sends +5 volt 5 millisecond pulse through the signal pin on the RJ45 connector when the gun fires so that the event can be captured by an external data acquisition system. Under most circumstances the control system derives its operating power through this connector.

3.2 MARKER INTERFACE

The paintball marker guns have been modified to include electronic trigger mechanisms with trigger bypass hardware attached. When the bypass circuit is closed, the gun fires one shot. The bypass mechanism is connected to the controller through standard phone cables and RJ11 connectors. Each paintball gun can be individually fired by the microcontroller through a set of solid state relays. The solid state relays are capable of momentarily switching loads up to 8A at 120VAC, this allows for the connection of a wide range of marker hardware.

3.3 ANALOG INPUT

The control system has an on board RJ45 connector that functions as a six channel, 100Hz, analog sensor input. The analog input interface is integrated in the microprocessor. The microprocessor has up to thirteen 10-bit analog to digital conversion ports. In this project, six of those ports are wired into an RJ45 connector. The connector has pin 1 as regulated 5V power, pin 8 as ground and pins 2-7 as the analog inputs. Information from the analog input sources can be transmitted digitally through the DAQ interface or to a computer through the USB link. Analog input sources must maintain an impedance of less that 1.5kΩ . This feature allows for external sensor data from accelerometers, digital compasses and other transducers to be captured and processed without any additional components.

3.4 HUMAN INTERFACE

The human interface portion of the design consists of a pair of double digit LED displays and dials for each. When firing the markers, it would be convenient if the fire rate and duration were adjustable. The controller is designed so that the left display shows the total number of shots to be fired, and the right display shows the rate, in hertz, that the markers will be fired at. There is a dial located underneath each display that can increase and decrease this value to meet the demands of the current trial.

The fire button is a green contact closure switch that sends a signal high to the microprocessor. At this time the microprocessor will begin firing the paintball markers at the rate and durations indicated on the displays. The top button is a red contact closure switch, when the signal is read by the microprocessor the sequence is immediately halted. There is a 4-pin auxiliary input port on the control system. It allows an external fire switch to be connected to the control system. This could be used to add a wireless activation switch or a brake pedal switch. A high output buzzer is included in the design to provide audible confirmation that the guns are firing or the knobs are turning. The buzzer is connected to the PIC's Pulse Width Modulator (PWM) port so that the processor can vary the intensity and tone of the buzzer. A reset button is included on the board. In case of a software error, hardware error or overheating, the reset button can restart the processor and place it in a known state for debugging or continued use. Several LEDs are placed on the board in strategic locations. Each is used to verify a function such as fire, power status, data transmit and data receive.

3.5 COMMUNICATIONS

A type-A USB port is included and interfaces to the microprocessor through the printed circuit board. The interface consists of a FTDI serial to USB converter chip. The chip is wired to the USART port of the microprocessor and can communicate bi-directionally. This allows the processor to transmit live data from the analog to digital converter and the firing mechanism to a computer, and allows the computer to change the settings on the control system. The data can be accessed through a terminal program or a computer application

3.6 ENCLOSURE DESIGN

The enclosure was designed to contain the printed circuit board and the necessary electronics components in an impact resistant and aesthetically pleasing case. The case was created from machinable plastic since the material is extremely impact resistant and easy to work with. The parts were cut with a CNC mill and assembled with a plastic bonding adhesive. There are gaps in the case to allow for easy access to all of the I/O ports on the controller. A more economical enclosure could be injection molded.

3.7 SOFTWARE DESIGN

The software for the PIC microcontroller was designed using Microchip's MPLAB. Due to the precise timing needs of the project the software is written in assembly language. The software is largely interrupt driven. Events such as button presses and dial rotation create events in the microprocessor firmware that are handled by the software. A fully commented code listing is available upon request.

5 RESULTS AND DISCUSSION

The controller design presented in the previous sections is used in conjunction with the paintball markers to evaluate vehicle performance and the evidence so produced. This section describes some tests conducted in Mason, Ohio on March 9, 2004. These tests proved the concept of the DRMS and the controller used was a simple 555 timer based circuit.

The externally mounted paintball markers are shown in Fig. 4. These markers are both controlled by the same control unit. The activation of the start sequence is initiated inside the cab by depressing the start switch.

In Fig. 5, the evidence from a combined steering and braking maneuver performed and recorded using the DRMS is shown. The signal from the controller was captured with an on board data acquisition system, the VC3000. The acceleration and yaw rate data, taken 100 times per second, was distilled into a graph shown in Fig. 6.

(a) Side view showing both markers

(b) Paintball marker mounted on rear bumper.

(c) Paintball marker on front bumper

Figure 4: Paintball markers mounted on a Dodge Dakota for initial testing.

The discrete points on the graph in Fig. 6 correspond to the fire pulses from the paintball marker. The error bars signify the variation of the data signal for a 7-point bilateral range. Based on this graph, the number of shots (discrete points) and the number of paint marks should correspond. Counting the marks is all that is required to link the roadway evidence to the accelerations or other recorded data. A researcher could annotate the accelerations from the DAQ on the ground and photograph the evidence for a more detailed record.

Preliminary results suggest the evidence left on the road begins to appear around 0.5g. However, a detailed study of the marks on the road and the accelerations that caused them are beyond the scope of this paper.

The controller design and prototype presented in this paper have some noteworthy features. First, the operation of the unit is software driven. This allows for adaptation and expansion of the system if necessary. For example, there are some extra pins on the microprocessor that can be used for analog inputs. These inputs can be reduced and interpreted if the source code is modified. This is a powerful feature in that no rewiring is required.

Figure 5: Typical road evidence and paint marks from a test run. The different color paint balls signify the front or rear of the marker.

Another critical feature is the ability to change the frequency and duration of the shots fired. If higher speeds and shorter events are of interest, the researcher may want a higher frequency shorter duration firing sequence, whereas longer, more gradual events may only need a few marks from the paintball gun. This economy can save on paintballs and bottled gas.

There are, of course, some limitations of the DRMS and the controller. Foremost is the mechanical limitation of the rate of fire. Current implementations achieve nearly 10 shots per second; however, some paintball markers claim higher fire rates.

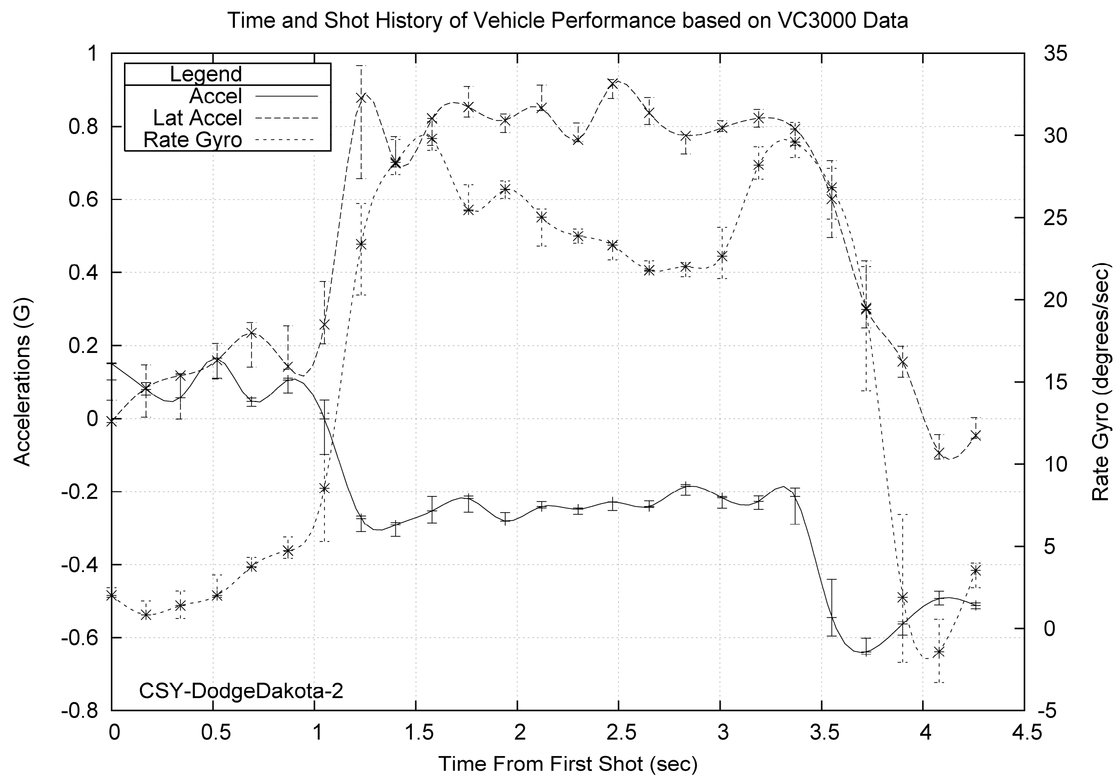

Figure 6: An example plot of vehicle motion with points (with uncertainty) marked when paintballs were fired. The acceleration scale is on the left and the yaw rate scale is on the right.

Another consideration is the time lag from when the marker is told to fire and when the paint hits the ground. This depends on the distance the paintball gun is from the ground, the length of the barrel, and mechanical triggering delay. Before conducting a test, this time delay needs to be quantified. Atypical time delay is about 50 msec.

As a test for positional consistency, a sequence of shots was fired from two markers equal length apart, as shown in Fig. 4. The center location of each mark was measured using a total station. From the CAD file generated from the total station data, the distance of each pair of shots was measured. From a sample size of 24 pairs, the coefficient of variation was 0.86%. So, for a 4meter distance between the markers, the 95% confidence interval of measured distance is close to 7cm. This uncertainty is better than GPS for position but may be less accurate than some motion picture analysis or triangulation scheme.

The delay from the fire pulse and the positional uncertainty can be analyzed after the data has been gathered. These aspects need to be considered when linking the evidence to the performance data.

6 CONCLUSIONS

A novel controller design was presented to fire and control a paintball based dynamic roadway marking system. The controller is based on a microprocessor and can control up to four paintball markers. This system provides traffic crash reconstruction researchers the ability to link roadway evidence to measured data from an on-board data acquisition system. These data give investigators better defined thresholds of acceleration values when performing a traffic crash reconstruction. Overall, this paintball marker based system provides novel research, verification, and educational capabilities to a crash reconstructionist and vehicle dynamics engineer.

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APPENDIX A: SCHEMATIC

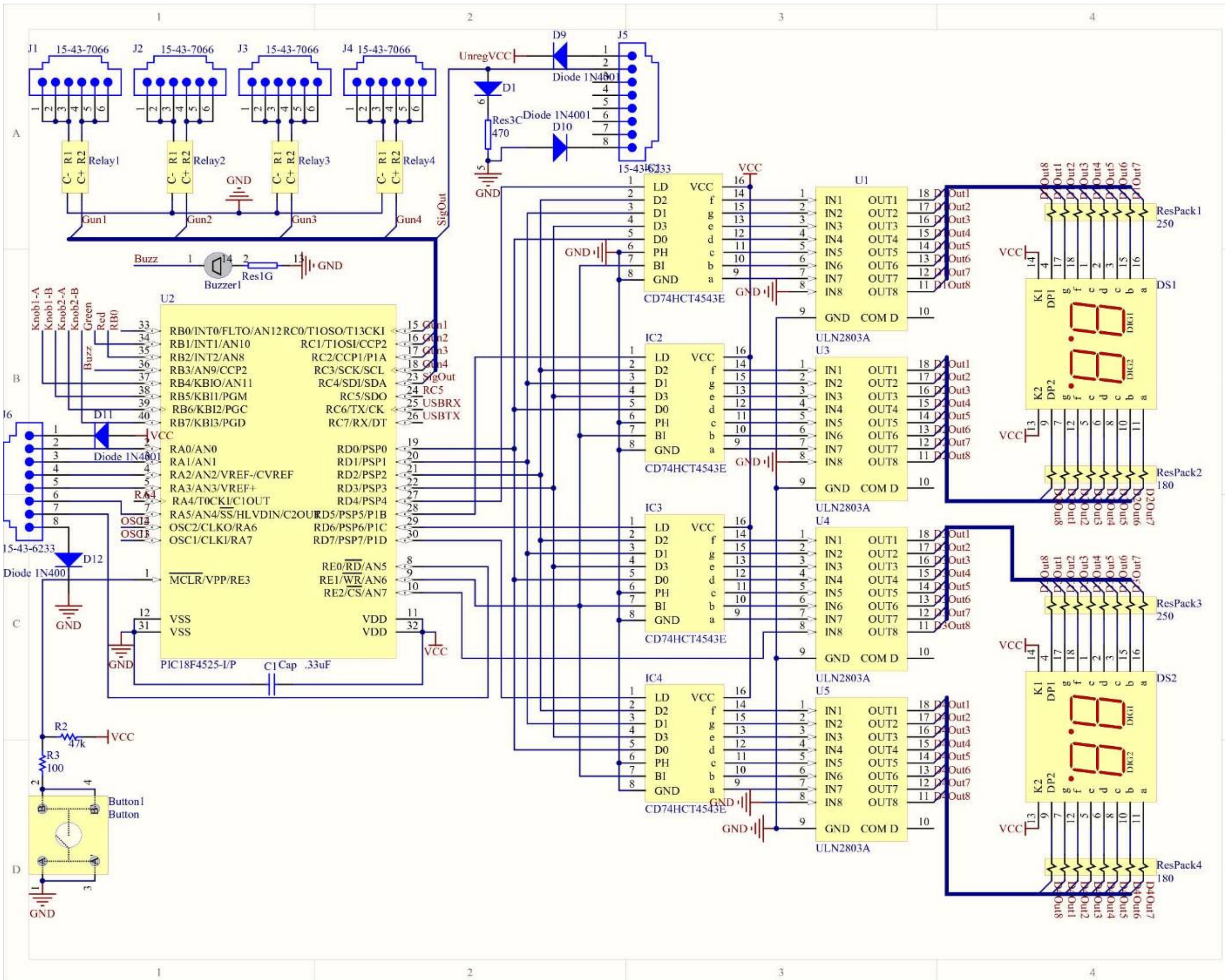

Figure 7: Schematic of the controller (page 1 of 2).

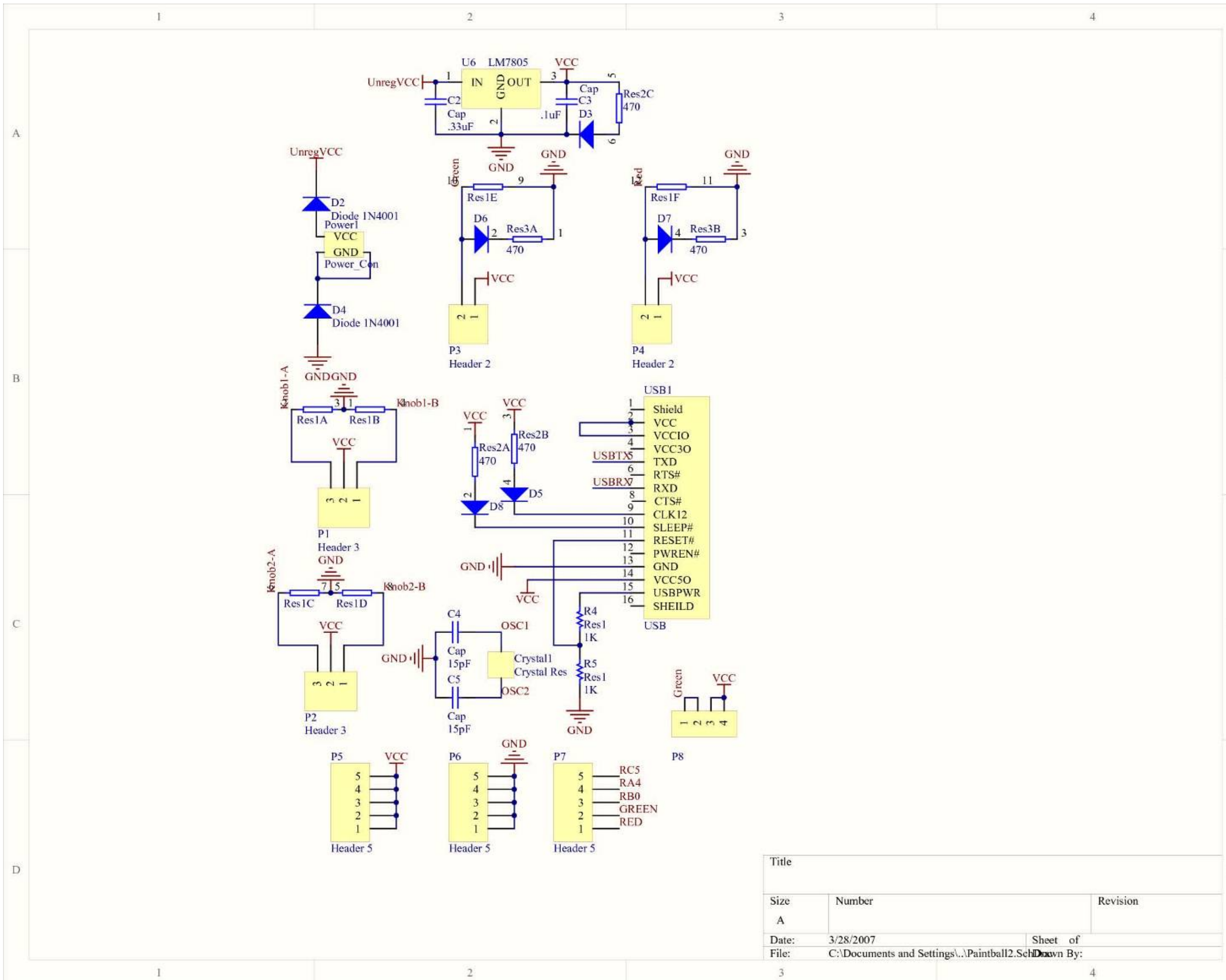

Figure 8: Schematic of the controller (page 2 of 2)

APPENDIX B: PARTS LIST

Qty	Supplier	Supplier Part#	Manufacturer Part #	Description	Cost/Item	Total Cost
4	Mouser	595-ULN2803AN	ULN2803AN	LED Driver	$1.35	$5.40
1	Mouser	850-59-312	59-312	RED Stop Button	$9.74	$9.74
1	Mouser	850-59-313	59-313	GREEN Go Button	$9.74	$9.74
4	Mouser	652-4116R-1LF-180	4116R-1-181LF	Resistor Pack 180ohms	$0.48	$1.92
1	Mouser	520-HCU2000-20X	ECS-200-20-4X 20.0	Cyrstal Resonator 20MHz	$0.46	$0.46
1	Mouser	626-DLP-MM232R	MM232R	USB Module	$18.00	$18.00

2	Mouser	81-DEA1X3F150JCDB	DEA1X3F150JCDB	15pF Capacitor	$0.18	$0.36
1	Mouser	571-1036733	103673-3	4way Board Connector	$0.50	$0.50
1	Mouser	571-1039573	103957-3	4way IDC connector	$0.53	$0.53
2	Mouser	652-4606X-1LF-470	4606X-101-471LF	SIP, 470ohm, Bussed, 5 Restr	$0.19	$0.38
1	Mouser	652-4608X-1LF-1K	4608X-101-102LF	SIP, 1kOhm, Bussed, 7 Restr	$0.23	$0.23
3	Mouser	538-22-10-2051	22-10-2051	Header, 5way, inline, vertical	$1.16	$3.48
2	Mouser	140-L50V.33-RC	140-L50V.33-RC	.33uF capacitor	$0.18	$0.36
2	Mouser	140-L50V.1-RC	140-L50V.1-RC	.1uF capacitor	$0.18	$0.36
6	Mouser	512-1N4001	1N4001	Diode	$0.06	$0.36
4	Mouser	575-199318	110-99-318-41-001000	18pin dip socket	$0.17	$0.68
8	Mouser	575-199316	110-99-316-41-001000	16pin dip socket	$0.62	$4.96
2	Mouser	538-22-12-2021	22-12-2021	Right Angle 2P Conn	$0.45	$0.90
2	Mouser	538-22-12-2031	22-12-2031	Right Angle 3P Conn	$0.53	$1.06
1	Mouser	538-68806-0001	68806-0001	USB Cable	$2.36	$2.36
2	Mouser	450-6017	450-6017	Metal Knobs	$3.09	$6.18
4	Digikey	CD74HCT4543E-ND	CD74HCT4543E	BCD-7 Segment Decoder	$0.53	$2.12
1	Digikey	LM7805CT-ND	LM7805CT	5V LDO regulator	$0.78	$0.78
1	Digikey	AE9840-ND	A40-LCG	Processor IC socket 40pin	$2.43	$2.43
1	Digikey	458-1080-ND	PT-2130PQ	Buzzer	$2.76	$2.76
2	Digikey	CCM1500-ND	RJ45-8N-B	RJ45 Ethernet Jack	$4.24	$8.48
4	Digikey	CCM1394-ND	RJ11-6N-B	RJ11 Phone Jack	$4.02	$16.08
2	Digikey	CT3002-ND	288T232R161A2	ROTARY ENCODER	$2.58	$5.16
4	Digikey	67-1062-ND	SSL-LX3044GD-5V	Green LED	$0.33	$1.32
2	Digikey	67-1068-ND	SSL-LX3044ID-5V	Red LED	$0.33	$0.66
1	Digkey	PIC18F4525-I/P-ND	PIC18F4525-I/P	Pic Processor	$11.35	$11.35
4	Digikey	Z1196-ND	G3MC-101PL-DC5	5V Relay	$3.40	$13.60
1	Digikey	P8006S-ND	EVQ-PAC04M	Reset Switch	$0.29	$0.29
1	Digikey	T977-P6P-ND	EPS050100-P6P	Power Wall Adapter	$5.64	$5.64
1	Digikey	CP-102BH-ND	PJ-102BH	Power Connector	$0.42	$0.42
2	Digkey	67-1461-ND	LDD-A516RI	LED 7-SEG .56 DUAL S-RED	$3.69	$7.38
1	Digikey	4.7KH-ND	CFR-50JB-4K7	4.7k Resistor	$0.26	$0.26
1	Digkey	47KEBK-ND	CFR-12JB-47K	47k Resistor	$0.26	$0.26
1	Digikey	100EBK-ND	CFR-12JB-100R	100ohm Resistor	$0.26	$0.26
1	Digikey	10KEBK-ND	CFR-12JB-10K	10k Resistor	$0.26	$0.26
					Total	$147.47