# Modeled Car With Ejector Seat

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## Abstract

An ejector seat has been designed as an idea of improvement to current existing safety tools which protect people when a car crashes. Traditional airbag is limited in that it protects people after car is crashed and in many situations it would be too late, and also it cannot protect people when the car falls off a cliff. The ejector seat ejects people with different weights to the same height when danger is detected.

The results show that it can detect relative distance and speed accurately with a small error of +/-2 cm, and the weight can be measured to a accuracy of +/- 2 grams. The seat is ejected and when relative distance and speed reach a threshold that we calculated to be reasonable for deadly situation, and the springs which are used to eject are compressed to desired position to make sure that different weights are ejected to the same height.

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# 1. Introduction

## 1.1 Statement of Purpose

This project is used to decrease death of car crashes. “The National Safety Council estimates 38,300 people were killed and 4.4 million injured on U.S. roads in 2015, which saw the largest one-year percentage increase in half a century.”(Newsweek, 2015) Highspeed collisions cause largest proportion of deaths every year. Many companies have spent time researching how to make cars safer using more practical methods such as airbags. However, airbags cannot save life in many conditions. It concludes front collision, offset collision, and oblique collision in high-speed condition. Thus, this project adopts ejection seat to save lives of drivers when they face those conditions. This project intends to make a model which can physically eject the drivers free of imminent crashes in a real car. While we acknowledge this is likely not the most practical response in a real-world scenario, the design decisions behind the system could prove a strong proof of concept for future safety projects.

## 1.2 Objectives

### 1.2.1 Benefits and Goals

- A step towards more reliable protection for traffic accidents
- Save lives from front collision, offset collision, and oblique collision in high-speed condition.
- Different weights are ejected to the same height to make the ejector seat more reliable

### 1.2.2 Functions and Features

- Detect deadly situation, i.e. detect condition that relative distance and speed exceed threshold that are calculated reasonable for a deadly situation
- Seat is ejected when deadly situation is detected
- Detect different weights on the seat
- Different weights are ejected to the same height

# 2 Design

## 2.1 Power System

### 2.1.1 Design

The power module will provide power to the detection system, microprocessor, and ejection system. The power system needs to have 5V outputs in order to make sure sensors and microprocessor works. The solenoids and stepper motors that used in ejection system need 12V to work. Thus, we design a 12V batteries power source, it connected to a 5 volt voltage regulator. The voltage regulator outputs a constant voltage at 5V.

### 2.1.2 Circuit

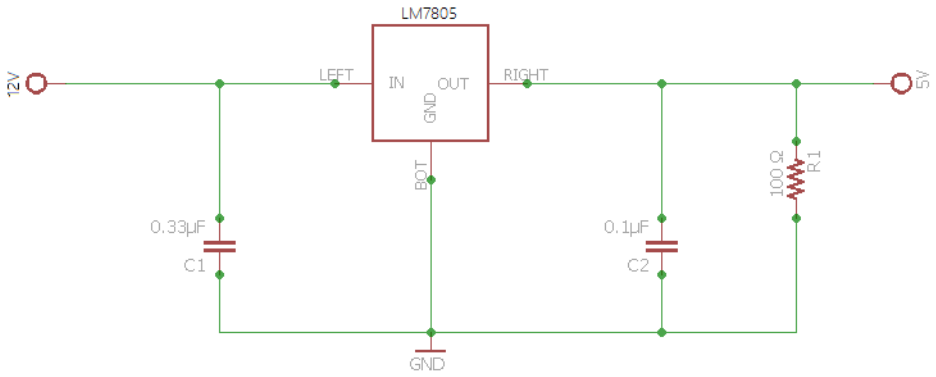



Figure 1. Power system circuit

## 2.2 Detection System

### 2.2.1 Design

For the detection system we use distance sensor to detect the car’ s environment. We use the HC-SR04 Ultrasonic distance sensor to measure the relative distance and speed between the car and the nearest object to the front, oblique and offset sides. We add five sensors like graph below. We do not consider back side crash because car was rarely rear-ended in high-speed condition. Distance sensors will send analogue electrical signals and measurements to microprocessor module.

The detection distance range is from 2cm to 400cm indicated in the datasheet, and the angle detection range is indicated in the 2 pictures below.

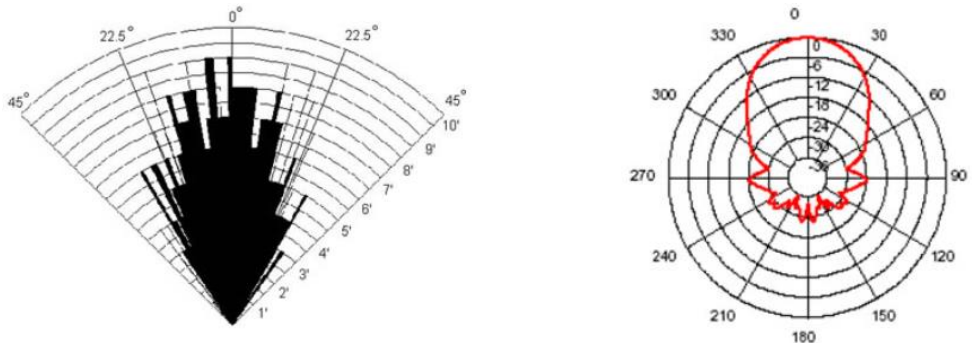



Figure 2. The HC-SR04 ultrasonic distance sensor detection range indicated from datasheet

### 2.2.2 Calculations

The deadly acceleration is 4560 m/s$^2$. (baidu baike) The weakest part of humanbeings is head. The maximum force for head of human-beings is 22.8 kN. According to Newton's laws of the motion, F is equal to the mass m of that object multiplied by the acceleration vector a of the object:

$$F = ma \tag{1}$$

Assume the weight of head is 5 kg. Thus, the deadly acceleration can be defined by :

$$a = \frac{22.8kN}{5kg} = 4560\mathrm{m}/s^2 \tag{2}$$

Because collision time is 0.001 s, we can calculate the deadly speed:

$$v = at = 4560m/s^2 * 0.001s = 4.56m/s \tag{3}$$

In our case of real car, we assume that 15 m/s rated speed is a deadly speed with belt and airbag. The reason for choosing 15 m/s is that 55 kph speed has larger increasing number of death people than that with less than 55 kph speed. (whowantsairbag, 2005) Thus, in our case of model car, 1 m/s rated speed is test speed with 1/15 scale. Also, we will test the acceleration between car and objects. They has to have positive acceleration and 1m/s rated speed in short distance, then the ejection system would work.

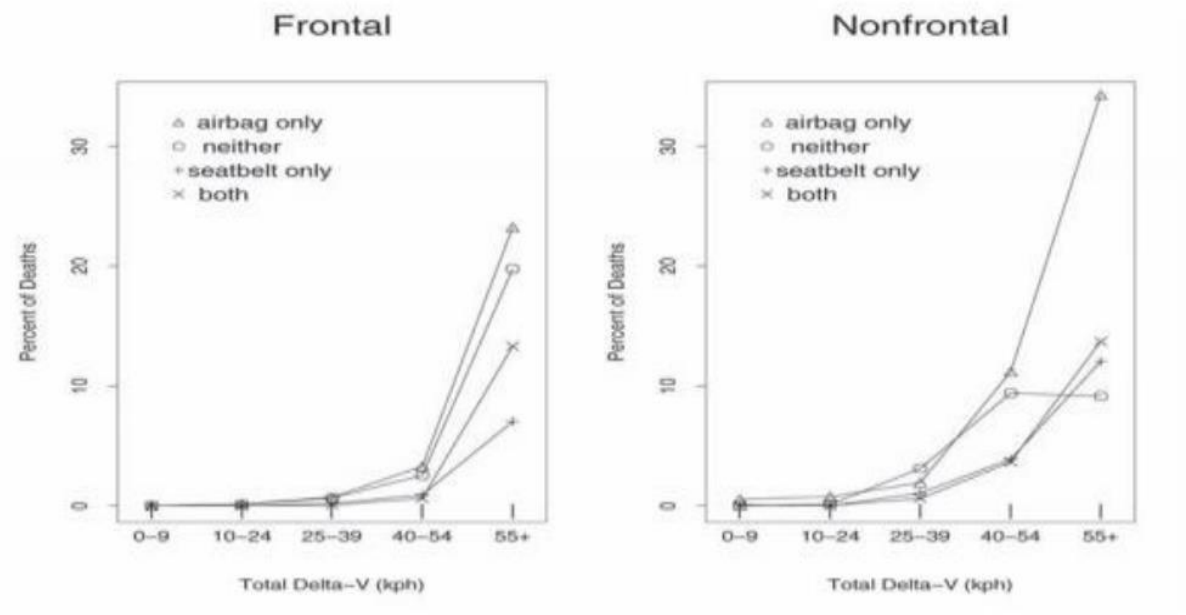



Figure 3. The relation between total delta-V to percent death

For distance sensor, we assume 60 meter is enough distance to find acceleration and speed. Thus, we pick HC-SR04 Ultrasonic sensor to find acceleration and speed in range of 0.02 m to 4 m. It is works well in scale of 1/15. Because we use the magnetic lock, ejection seat could eject driver immediately. Thus, we give 1.5 s to ejection system to eject. In our case of real car, the ejection seat will eject when car is in 22.5m front of collision. In our case of model car, the ejection seat will eject when car is in 1.5m front of collision. This is our understanding of deadly condition. We cannot find exactly measurements by searching online, but this condition is logical.

### 2.2.3 Circuit

The sensors use 5 V power supply and has two data pins that send data to microcontroller(see section 2.4). The setup of the sensor is shown in figure 4.

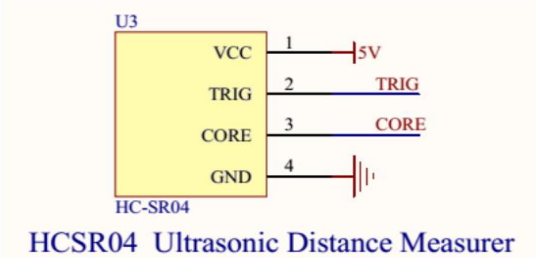



Figure 4. Circuit schematics of HC-SR04 ultrasonic distance sensor

## 2.3 Ejection System

### 2.3.1 Design

The ejection system is designed to eject people when the deadly situation is detected, and also eject different weights to the same height. We use mechanical springs and solenoids to eject the seat: springs are compressed and solenoids lock them in place, and once the deadly situation is met, the solenoids will pull back and unlock the spring to eject the seat. For ejection height control, we use the load sensor to measure the weight on the seat, and based on different weight, the stepper motors and sprockets will compress the springs to the length that can eject different weight to the same height which is 0.5m.

### 2.3.2 Calculations

The total potential energy gained when ejected to height h=0.5m, with weight m and gravity constant g=9.8m/s$^2$:

$$mgh \tag{4}$$

The total potential energy of the spring with compressed length x and constant k=2500N/m:

$$\frac{1}{2}kx^2 \tag{5}$$

According to law of conservation of energy, we equate (1) and (2) to get:

$$mgh = \frac{1}{2}kx^2 \tag{6}$$

The equation the calculates the number of steps needed for a stepper motor to rotate o distance x:

$$\#steps = \frac{d}{C} \times (100cm/m) \times \frac{360°}{aps} \tag{7}$$

C: circumference of motor, C=16.35cm

aps: angle per step, aps=0.018°

So by equation (6) and (7) we can get the number of steps that is need for the stepper motor to rotate (i.e. to compress the spring) to a certain length that can eject different weights to height 0.5 meters.

### 2.3.3 Filter Design for Load Sensor

A filter is designed for the purpose of decreasing noise in weight measurement, and so that the measured weight is more stable and accurate. In our design, we designed a second-order Low-pass filter. We choose Chebyshev type because its output is more stable compared with butterworth filter. Even its passband is not stable until cut-off frequency, Chebyshev would reach our goal with gain is equal to 1 and less cut-off frequency.

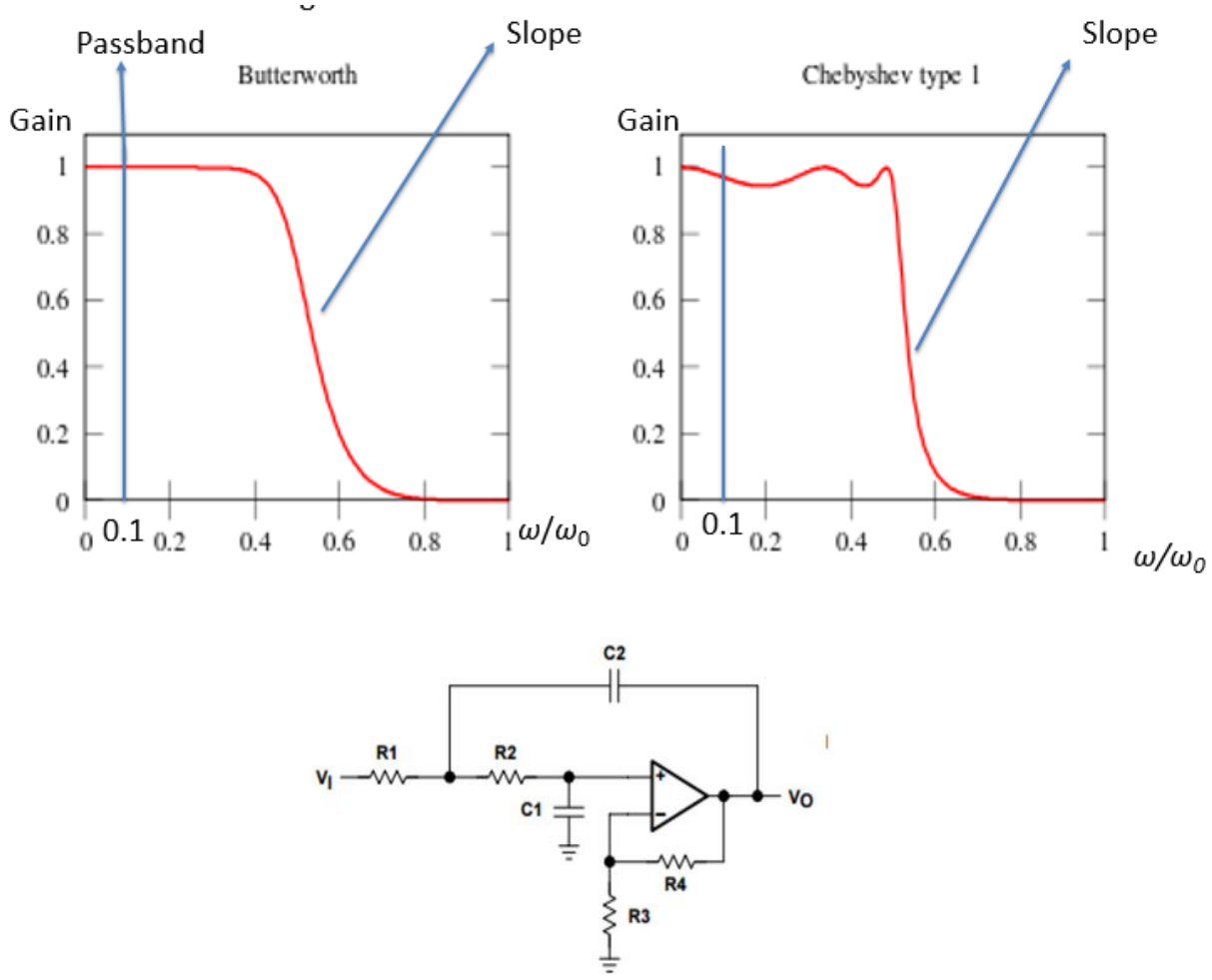



Figure 4. Circuit for the filter for load sensor

$$\mathrm{H(f)} = \frac{\frac{R3+R4}{R3}}{(J\omega)^2(R1R2C1C2) + J\omega(R1C1 + R2C2) + 1}$$

$$\mathrm{K} = \frac{R3+R4}{R3} = 1$$

$$\mathrm{R4} = 0 \text{ if } \mathrm{K} = 1$$

Then, we set R3 to be zero because R3 would not influence anything in this filter.

$$\mathrm{H}(f) = \frac{K}{-(\frac{f}{0.8414fc})^2 + 0.9107\frac{jf}{fc} + 1}$$

Finally, we got :

$$\mathrm{R1R2C1C2} = 3.58e^{-6}$$

$$(\mathrm{R1} + \mathrm{R2})\mathrm{C1} = 0.00145$$

We assume R1=R2=20 K Ω

C1 = 36 pF

C2 = 246 pF

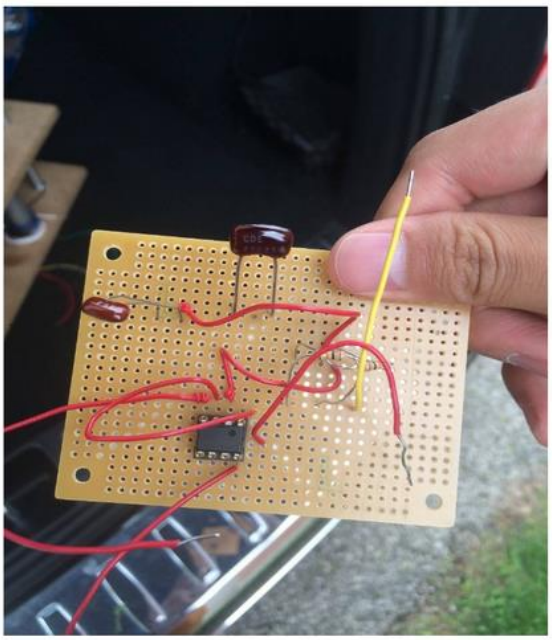
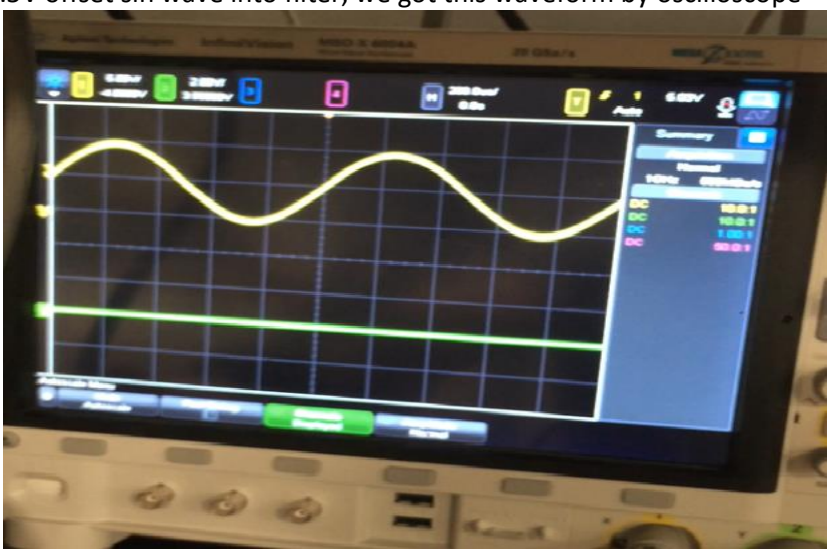
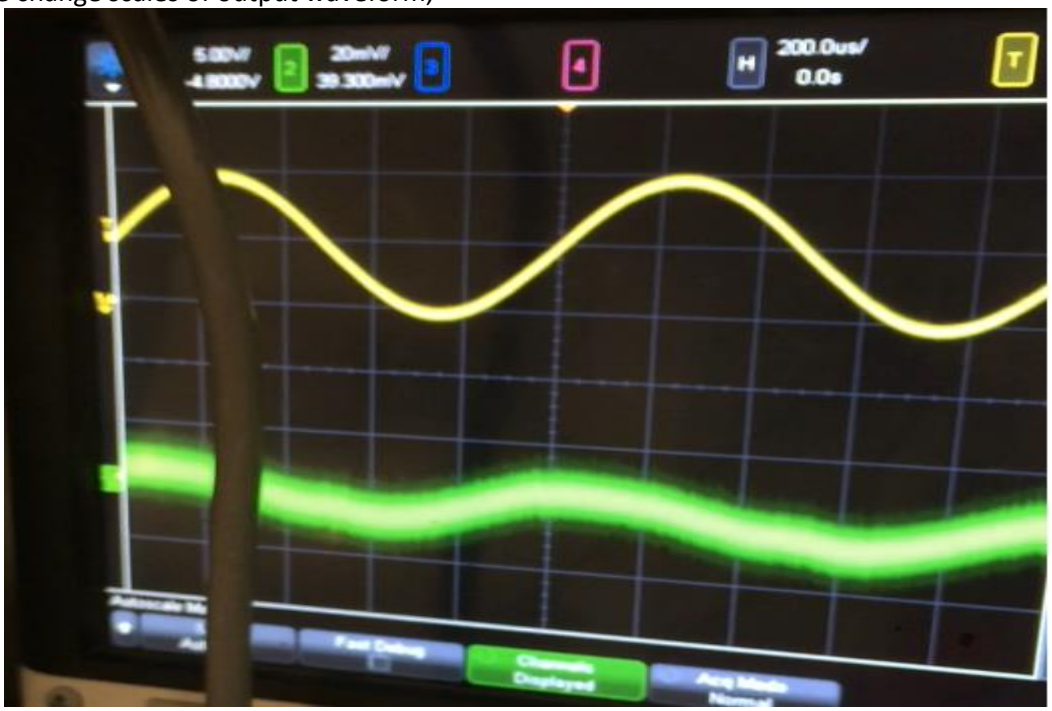


Figure 5. Circuit for the filter for load sensor in perf board

Give 1KHz, 5Vpp, 2.5V offset sin wave into filter, we got this waveform by oscilloscope



Once we change scales of output waveform,




It is still a sin waveform, but it is more stable than input waveform.

## 2.4 Microprocessor

All the data from sensors will be send to this microprocessor AT89c51, and it outputs to solenoids/stepper motors after processing the data.

### 2.4.1 Circuit

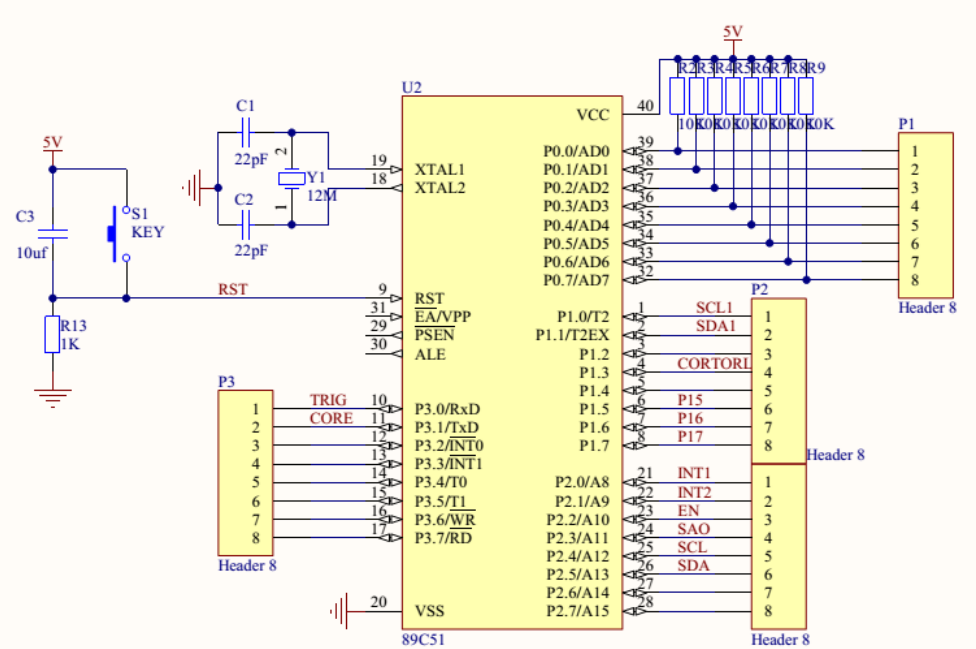



Figure 6. Circuit schematics of AT89c51

# 3 Design Summary

## 3.1 Block Diagram

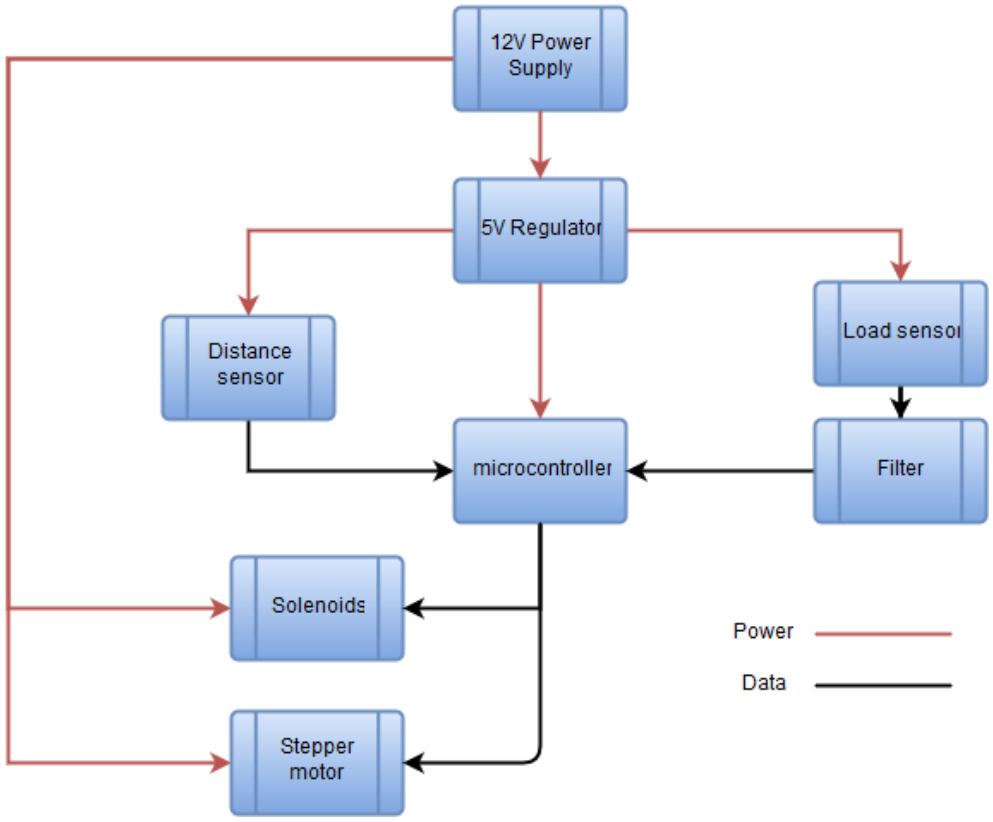



Figure 7. Top-Level Block Diagram

## 3.2 Circuit Design Schematics

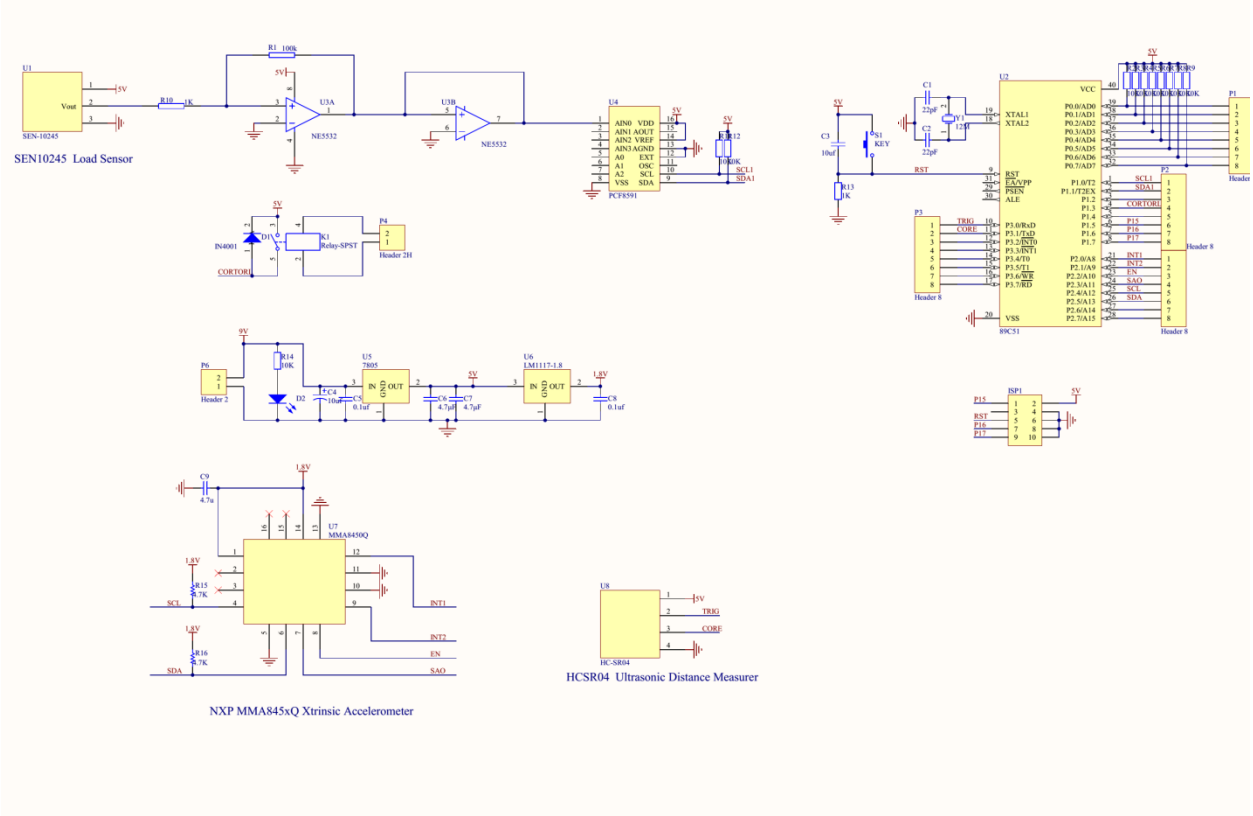



Figure 8. Circuit schematics

## 3.3 Microcontroller Logic Flowchart

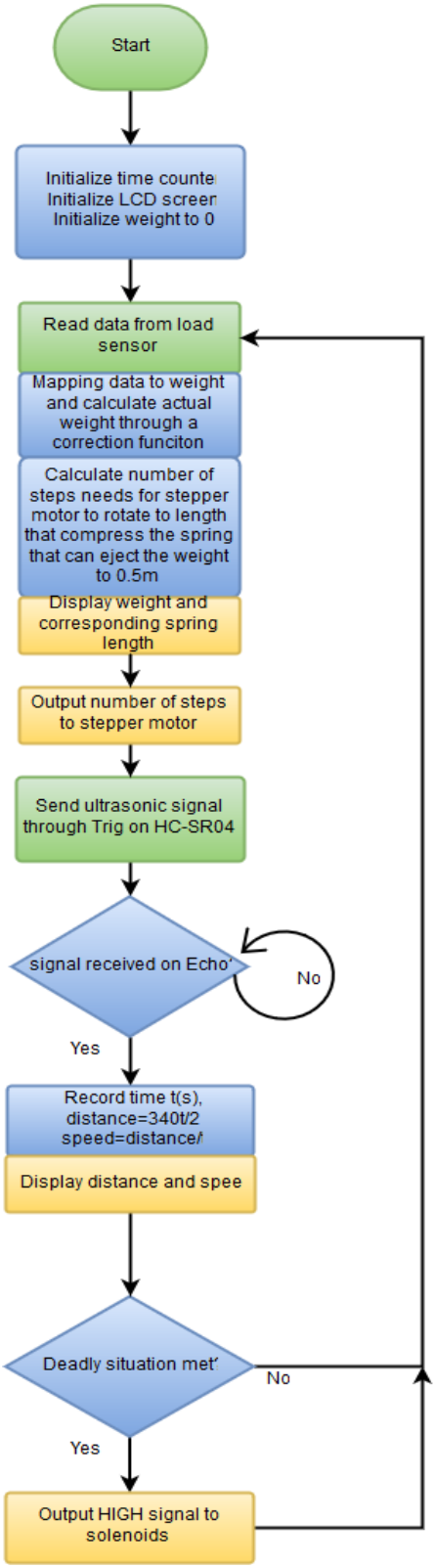



Figure 9. The flowchart showing the logic running on microcontroller AT89c51

# 4. Verification

The Requirements and Verification table is in Appendix A.

## 4.1 Detection System

The ultrasonic distance sensor can detect in range 3cm to 200cm in our experiment with an accuracy of +/- 2cm. Speed is calculated as the average speed in each measurement and we assume it is the real time speed. The speed measurement has an accuracy of +/- 2cm/s.

When distance and speed reaches threshold, solenoids can pull back immediately.

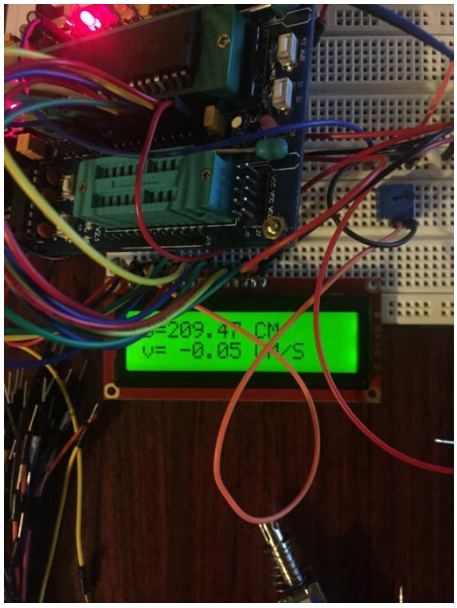



Figure 10. Display of distance and speed

## 4.2 Ejection Control System

The load sensor can measure weight in range 0 to 5kg, with accuracy of +/- 2g.

The bench test for the filter for load sensor to make the measurement more stable and accurate is shown in figure12. The yellow wave is the input wave, and the green wave is the output wave. We can see that the green output wave is much more stable than the input wave.

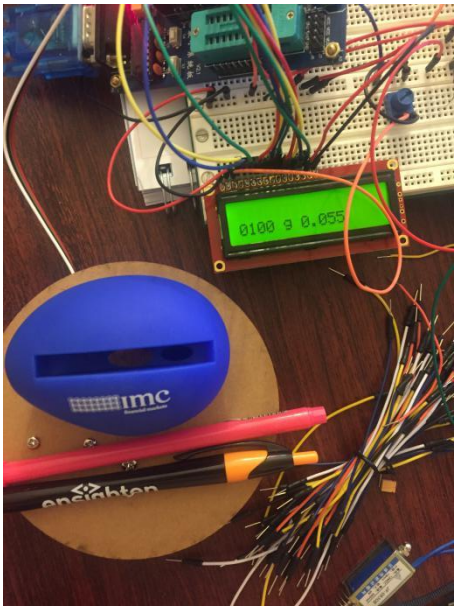



Figure 11. Display of weight and corresponding spring length

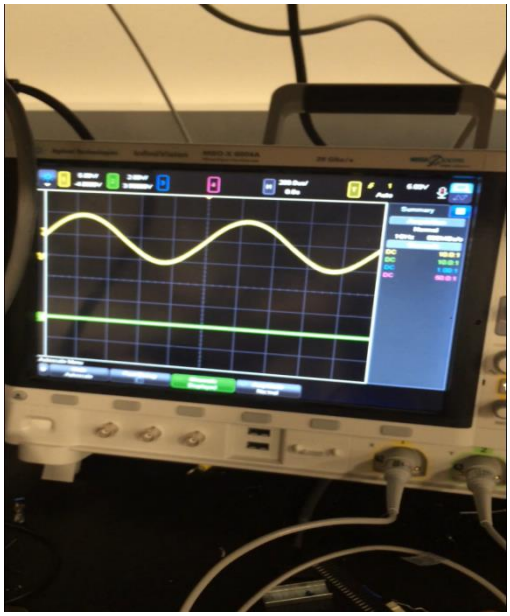


Figure 12.Bench test of filter

The stepper motor can rotate to the distance that is calculated based on the weight on the seat with an error <1.5 cm.

## 3.2 Power System

Our power system consists of a 12V voltage supply and a voltage regulator to provide 5V. The 12V voltage supply reads 12V+/-0.12V in experiment, and the 5V voltage regulator supply reads 5V+/-0.05V in experiment.

# 5. Costs

## 5.1 Parts

Table 1. Parts Costs

| Name | Unit cost | Number of units | Total cost |
|---|---|---|---|
| Load sensor | $10.99 | 1 | $10.99 |
| Microcontroller 89C51 | $12.01 | 1 | $12.01 |
| Accelerometer | $5.99 | 1 | $5.99 |
| Detection Sensor | $4.99 | 5 | $24.95 |
| 110V AC to 12V DC converter | $8.42 | 1 | $8.42 |
| Nema 14 Stepper motor | $31.46 | 2 | $72.92 |
| Stepper motor driver | $21.44 | 2 | $42.88 |
| Idler Sprocket | $24.73 | 2 | $49.46 |
| Shoulder Screw | $1.47 | 2 | $2.94 |
| Screw Hub | $4.99 | 2 | $9.98 |
| Springs | $12.99 | 1 | $12.99 |
| No.25 Chain | $12.99 | 1 | $12.99 |
| Solenoid lock | $9.99 | 2 | $19.98 |
| Burner kit | $12.99 | 1 | $12.99 |
| Sprocket | $7.95 | 2 | $15.90 |
| Total cost | | | $315.39 |

## 5.2 Labor

Table 2. Labor Costs

| **Name** | **Ideal Salary ($)** | **Total Hours Spent (hr)** | **Total = Ideal Salary x Total Hours Spent x 2.5 ($)** |
|---|---|---|---|
| Xiaoyi Chen | 25 | 200 | 12,500 |
| Xiangjian Gao | 25 | 200 | 12,500 |
| **Total** | | 400 | **25,000** |

## 5.3 Total Cost

Table 3. Total Cost

| Name | Total Cost |
|---|---|
| Labor cost | $25,000 |
| Part cost | $315.39 |
| Total cost | $25315.39 |

# 6. Conclusion

## 6.1 Accomplishments

Because we accidentally connected 6V to AT89c51 and burned it, we used Arduino in our demo. And before the AT89c51 broken, we have tested each module successfully, including relative distance and speed measurement, weight measurement and number of steps calculation, displaying distance, speed, weight and spring length on the LCD screen, solenoids pulling back when given ejection signal, and output PWM to stepper motor to make it rotate to certain step. As a system, we have achieved solenoids pulling back when deadly situation is detected, and we were working on combing weight measurement and stepper motor rotating when the microprocessor broke, so we did not finish this on AT89c51. On Arduino we demonstrated our two features successfully including solenoids pulling back when deadly situation detected, and stepper motor moving to certain steps according to different weight in order to compress the springs to a length that can eject “people” to 0.5 meters.

## 6.2 Uncertainties

We encountered a mechanical restriction in out ejection system. Due to friction, the solenoids we chose did not have enough pulling force to unlock the spring when the ejection signal is received, so we have to choose more powerful solenoids.  Another challenge is that we originally designed to use several distance sensors to cover the front and also the side of the car, but because the sensors share a single time counter in the microcontroller, we cannot measure the distance and speed accurately when we were measuring using more than one distance sensor, and our solution is to have one microcontroller for each distance sensor, and send the output through a OR gate and than send the signal from the output of the OR gate to the solenoids. Due to limited quantity of microcontroller, we did not tested this solution , but it is feasible theoretically.

## 6.3 Future work/Alternatives

Ethical concerns are minor, but those which could be identified can be found in Appendix E.

The main focus for future improvement is improving the reliability of our design.

First, we need to fix the problem the our current solenoids are not powerful enough to unlock the spring, so we will either choose more powerful solenoids, or reduce the friction by using a pulley that is the same as the one used on drawers.

Second, a parachute should open when people are ejected to the highest point and is about to falling down to make sure that people land safely.

Third, the roof of the car should open at the same time that the ejector seat is ejected.

The last one is that we should eject people to the back-right direction. Due to inertia, people will keep their initial velocity when they are ejected, and this might cause them hitting object in front of them. Also, we will eject to the right direction to prevent placing people on the road considering that cars run on the right side of the road.

There are a few more things that we can improve. We can improve the accuracy of distance and speed measurement. Also, we can improve our power system by using green energy and renewable energy.

## 6.4 Ethical Consideration

Ethical concerns that are relative can be found in Appendix B.

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# Appendix A Requirements and Verification Table

## A.1 Detection System

Table A.1. Requirements and Verification: detection system

| Requirement | Verification | Points |
|---|---|---|
| Accelerometer under stationary condition outputs 0V~0.45V | Connect the accelerometer's Vcc to 5V and GND to ground, and put it on a flat surface, and connect a voltage meter, positive to pin 9 and negative to pin 11. The output should be 0V~0.45V | 1 |
| Accelerometer can detect a free fall and sends a signal of 4V~6V | Connect the accelerometer's Vcc to 5V and GND, and connect a voltage meter, positive to pin 9 and negative to pin 11. Drop the accelerometer. The output should be 4V~6V | 1 |
| Distance sensor can measure the distance of an object to the sensor in range 3cm to 160cm. | Connect pin Vcc to 5V, and GND to ground. Connect pin Trig to pin12 and pin Core to pin13 on Arduino uno. Run the written test program. The distance will be displayed on the Monitor. The displayed distance should be in the tolerance range if it's in range 3cm~160cm | 3 |

## A.2 Power System

Table A.2. Requirements and Verification: power system

| Requirement | Verification | Points |
|---|---|---|
| The Power supply could provide 12V +0.25V/-0.12V | Connect a voltage meter to output of the power supply with positive to positive and negative to negative. The output should be in range from 11.88V to 12.25V. | 3 |

| | | |
|---|---|---|
| The 5V voltage regulator provides 5.00V +/- 0.25V, and it has input voltage 12+/-0.3V. | Connect a voltage meter to output of voltage regulator with positive to positive and negative to negative. The output should be in range from 4.75V to 5.25V. Connect a voltage meter to input of voltage regulator with positive to positive and negative to negative. The output of voltage meter should be in range from 11.7V to 12.3V | 3 |

## A.3 Ejection System

Table A.3. Requirements and Verification: ejection

| | | |
|---|---|---|
| The motor driver ST-7128 has 5V +/- 0.12V for Pul+ to Pul- and Dir+ to Dir-. | Connect a voltage meter to motor driver. The positive of voltage meter connect to pin Pul+ and negative of voltage meter connect to pin Pul-. It should read value in range of 4.88V to 5.12V.<br><br>Next, the positive of voltage meter connect to pin Dir+ and negative of voltage meter connect to pin Dir-. It should read value in range of 4.88V to 5.12V. | 3 |
| The solenoid lock could pull and release lock. The input voltage is 12V +/- 0.3V. | Connect a voltage meter to solenoid lock with positive to positive and negative to negative. The voltage value should read in range from 11.7V to 12.3V. Check the solenoid lock release and pull. | 2 |
| The motor could rotate and compress spring 3.2cm +/- 0.2cm distance via sprockets and chain. | Connect motor to motor driver and motor driver to power supply. Connect motor to hub and sprocket. The ejection seat should be compressed distance in range from 3.0cm to 3.4cm. | 3 |
| The ejection seat could eject to backward direction. | Connect ejection seat to springs with backward angle. With compression springs, the ejection seat would eject to backward direction. | 1 |

| | | |
|---|---|---|
| The load sensor could show the weights of objects (0.1kg, 0.2kg, 0.3kg) on screen. | Connect load sensor, op-amp. Connect load sensor to power supply. Put 0.1Kg, 0.2Kg, 0.3Kg weight objects on load sensor. The computer screen could show the weight of object with correct values(0.1kg, 0.2kg, 0.3kg) | 3 |
| The ejection seat could eject objects with different weights to 50cm +/- 5cm | Once the compressed spring be set by ejection system, control solenoid lock to release. The object should be ejected to height in range from 45cm to 50cm. | 3 |
| Filter Design | Connect Filter to waveform generator. Give 5Vpp, 2.5 offset, 1KHz frequency sin wave into filter. During Oscilloscope screen, the output should be more table. | 3 |

## A.4 Microprocessor

Table A.4. Requirements and Verification: microprocessor

| Requirement | Verification | Points |
|---|---|---|
| The microprocessor has 5V +/- 1V input voltage. | Connect microprocessor to voltage regulator LM7805. Connect a voltage meter to microprocessor with positive to positive and negative to negative. The read value should be in range of 4V to 6V. | 2 |
| The microprocessor can control solenoid lock to release and pull, and reaction time should be in range of 0.1s to 0.3s. | Connect microprocessor to solenoid lock. Check condition of release and pull for solenoid lock. The reaction time should in range of 0.1s to 0.3s. | 3 |

| | | |
|---|---|---|
| The microprocessor has 5V +/- 0.3V output, and the microprocessor could control motor to rotate. | Connect microprocessor to motor driver with positive to PUL+ and DIR+ and negative to PUL- and DIR-, motor driver to motor, and motor to sprocket. Connect a voltage meter to motor driver with positive to PUL+ and negative to PUL-. The read value should be in range of 4.7V to 5.3V. Connect a voltage meter to motor driver with positive to DIR+ and negative to DIR-. The read value should be in range of 4.7V to 5.3V. Finally, the motor can rotate and bring sprocket to rotate. | 5 |
| The microprocessor can give high signal to solenoid lock when surrounding conditions satisfy serious dangerous condition by detection system. | Connect detection system to microprocessor. Connect a voltage meter to microprocessor with positive to output and negative to ground. The read value should change from 0.0 +/- 0.2V to 5.0V +/- 0.2V when we place a dangerous situation to detection system. | 5 |
| The microprocessor can control motors to compress springs in exactly distance by load sensor and ejection system for different weight | Connect load sensor to ejection system. Connect microprocessor to ejection system (motor, motor driver, and compression spring). Place different weight objects on load sensor. The springs should be compressed different distances. | 5 |
| Total | | 50 |

# Appendix B Ethical Considerations

We, the members of the IEEE, in recognition of the importance of our technologies in affecting the quality of life throughout the world, and in accepting a personal obligation to our profession, its members and the communities we serve, do hereby commit ourselves to the highest ethical and professional conduct and agree:

1. to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;

2. to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist;

3. to be honest and realistic in stating claims or estimates based on available data;

4. to reject bribery in all its forms;

5. to improve the understanding of technology; its appropriate application, and potential consequences;

6. to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations; to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;

7. to treat fairly all persons and to not engage in acts of discrimination based on race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression;

8. to avoid injuring others, their property, reputation, or employment by false or malicious action;

9. to assist colleagues and co-workers in their professional development and to support them in following this code of ethics.