Driver Sleep Detection and Alarming System
Final Report

ECE445: Senior Design Project

Team No.15

Team member: Chenyang Xu, Xiangyu Chen, Yixiao Nie
TA: Mustafa Mukadam
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University of Illinois at Urbana-Champaign

Abstract

Feeling sleepy while driving could cause hazardous traffic accident. However, when driving alone on highway or driving over a long period of time, drivers are inclined to feel bored and sleepy, or even fall asleep. Nowadays most of the products of driver anti-sleep detection sold in the market are simply earphone making intermittent noises, which is quite annoying and inefficient. As such, there is a high demand for cheap and efficient driver sleep detection. Therefore, we came up with an idea and successfully developed a sleepy detection and alarming system, which could effectively meet this demand.

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1. Introduction

1.1. Project motivation and purpose

The goal of this project is to develop a system that can accurately detect sleepy driving and make alarms accordingly, which aims to prevent the drivers from drowsy driving and create a safer driving environment. The project was accomplished by a Webcam that constantly takes image of driver, a beagle board that implement image processing algorithm of sleepy detection, and a feedback circuit that could generate alarm and a power supply system.

1.2.Functions and Features

This system has many features that make it unique and functional. These features include:

1. Eye extraction, use open and close to determine sleepiness
2. Daytime and night detection
3. Real time image processing and detection
4. Sound and flashing LED warning system to redraw driver's attention
5. Little inference and potential hazard to driver's normal driving
6. Portable size with car cigarette charger socket power supply

1.3 Hardware system overview/ block diagram

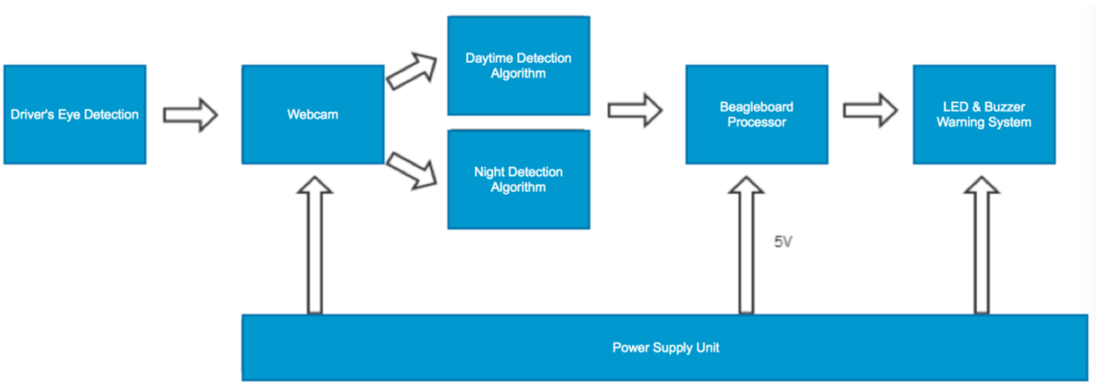

Figure 1. The systematic level block diagram

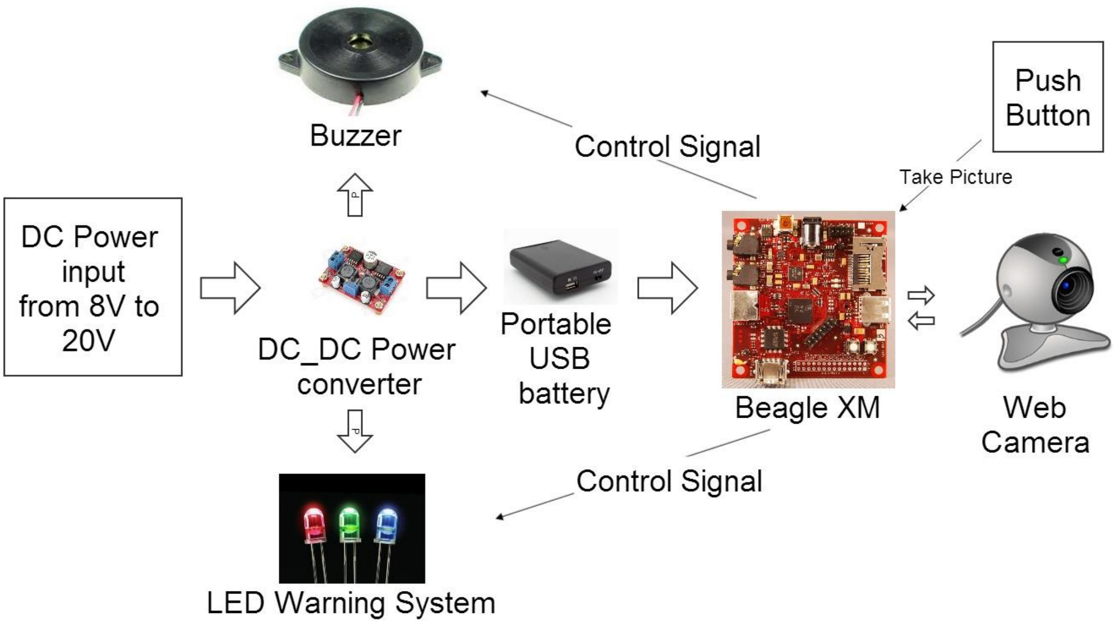

Figure 2. Hardware system connection

2. **Design of Project**

2.1. General design alternatives

The first alternative design between the final implementation and the initial plan, for the software part, is the choice of the camera. We desired to use kinect for capturing the input images at first. However, in pragmatic application, we found out in order to connect the Kinect, three drivers need to be installed, which are OpenNI, NITE and Sensor Kinect. Though these three can be successfully installed on the computer and run the Kinect, the exactly same files could not be installed on the Beagleboard. We found out that was because the Beagleboard could not understand the binary file format. However, despite of this change in our plan, we still successfully implemented both the daytime detection and night detection, based on the advancement of algorithm. The accuracy is pretty high, which reaches 93% at daytime and 82% at night. Another advantage of changing the camera is the significant cost reduction. The new webcam is only 6 dollars while the Kinect is more than 99 dollars. The anther alternative is the adding of the battery. In order to meet the rigorous requirement of power supply of Beagle board, a USB battery module is used intermediately. This alternative solution makes the product more portable and sustainable since the Battery can be easily and constantly charged by the dc-dc power converter. Meanwhile, the dc power converter can be supplied by cigarette power jack installed on the car, which turns this alternative into an advantage.

2.2. Simulation Circuits Schematic and Calculation

2.2.1 Cadence simulation of switching regular

The first stage simulation was done in Spice for the TI 61030 dc-dc regulator. The recommended inductor and capacitor value is calculated. Afterwards, due to the real application requirements, the design used both TI 61030 boost dc-dc converter and TI 2679 buck dc-dc switching regulator in later phase. The figure shows the prime simulation for TI 610303 boost converter. There are tally 5 simulation finished and three of five are shown from figure 3 to figure 5. The input power supply is changed from 1.8V to 5V to simulate the extreme conditions. A sinusoidal function generator is used to emulate the high frequency noise possible delivered from car charger inverter. As the graphs show, the output from the chip can be stabled at 5V regardless of the noise and the input voltage value. Moreover, the noise of the signal is filtered apparently in the output. The simulation is conducted with a load approximated 10 W.

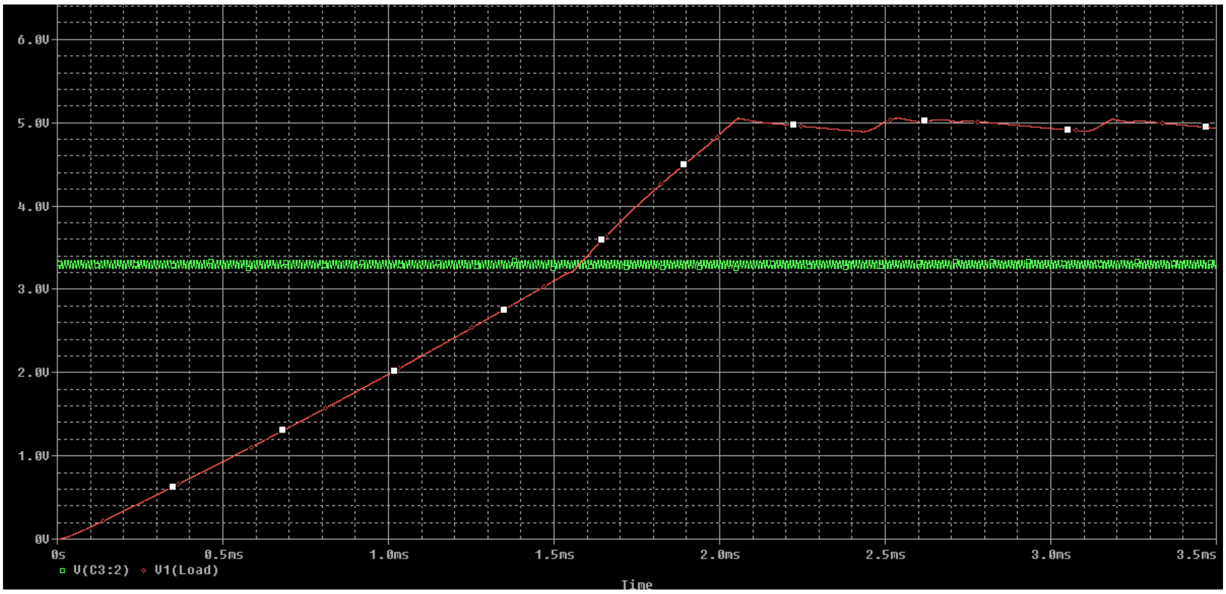

Figure 3. The voltage output (Red) while the input is at low value 3.3 V with small noise with magnitude 0.1 V (Green)

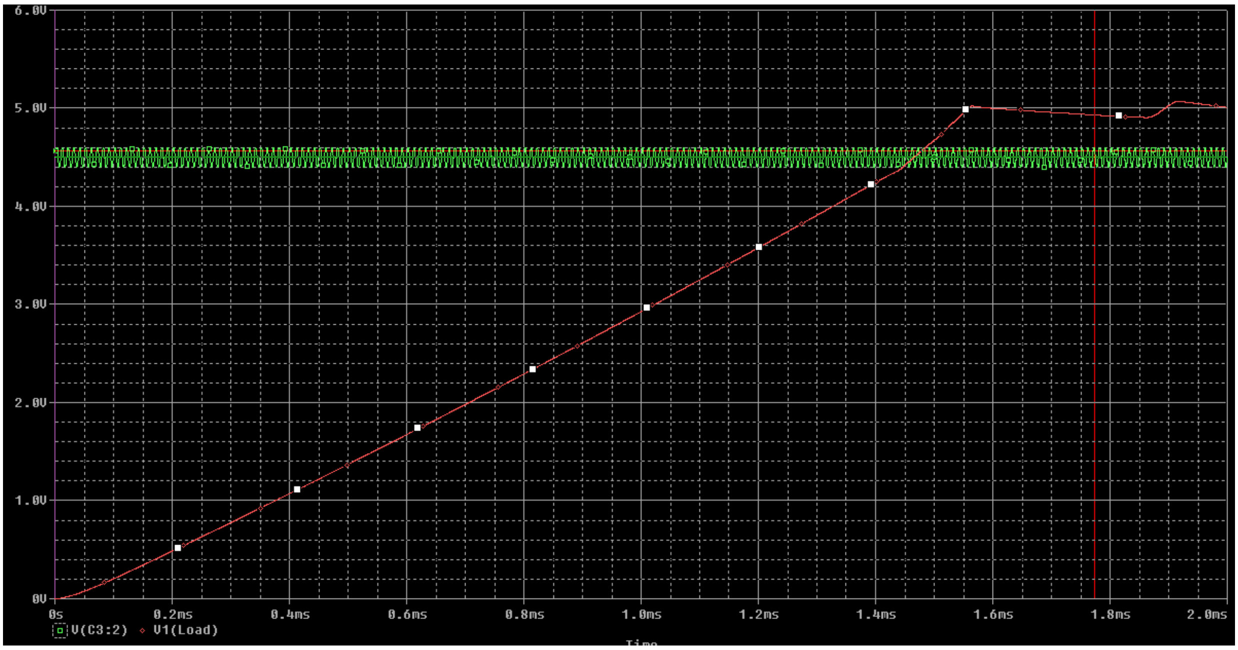

Figure 4. The voltage output (red) while the input is at low value 4.5 V with small noise with magnitude =0.1 V (Green)

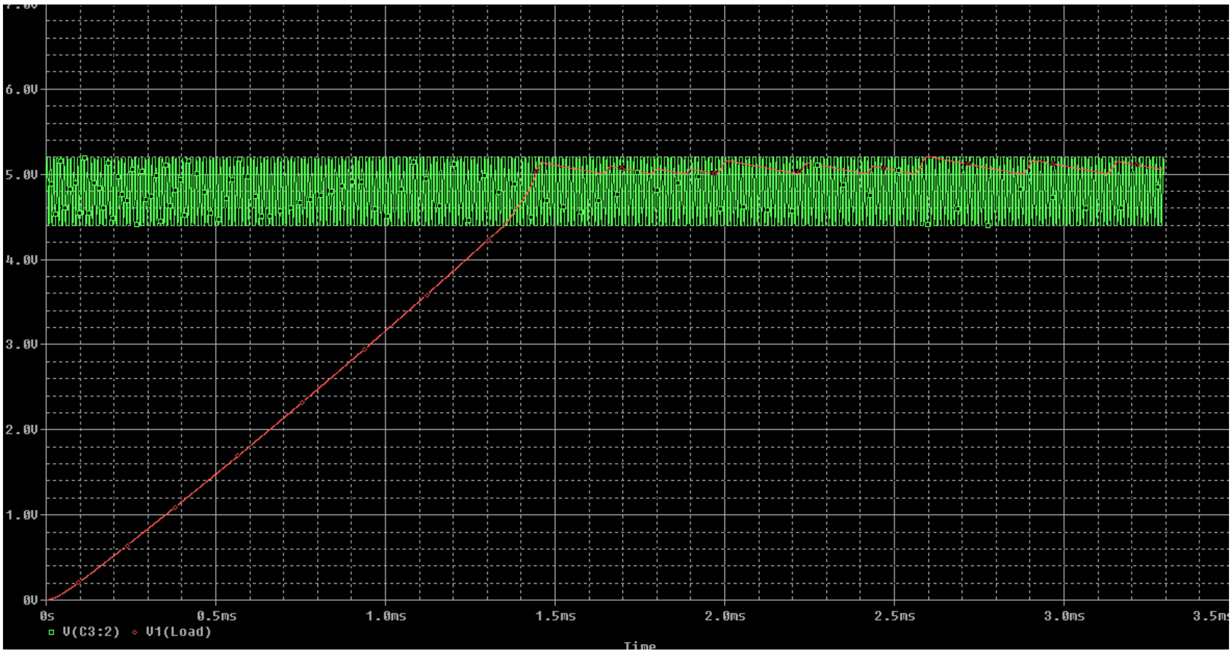

Figure 5. The voltage output (Red) while the input is at low value 4.8 V with large noise with magnitude =0.5V (Green)

The figure 6 and figure 7 shows the simulation circuit schematic for both TI 61030 and TI 2679-5.0 dc-dc switching regulators.

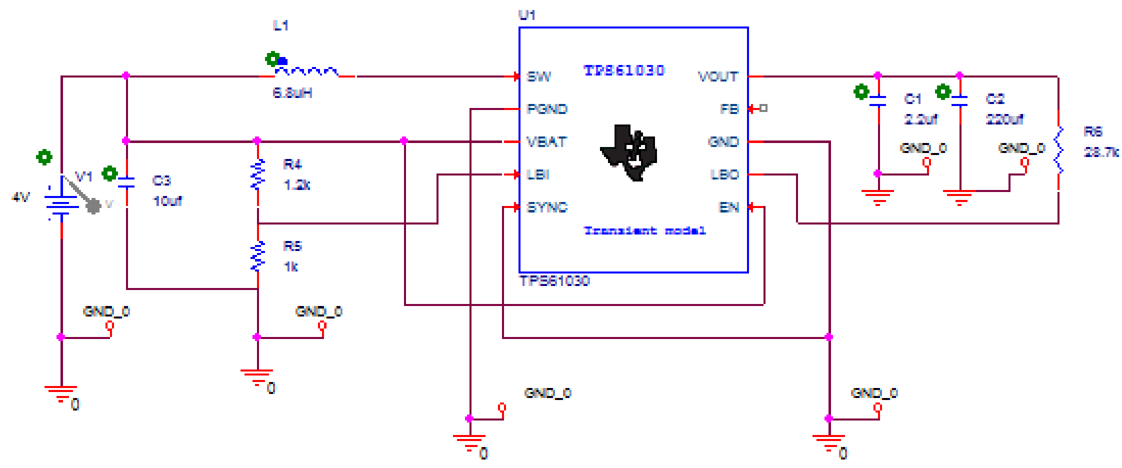

Figure 6. TI TPS61030-32 Chip Spice simulation circuit

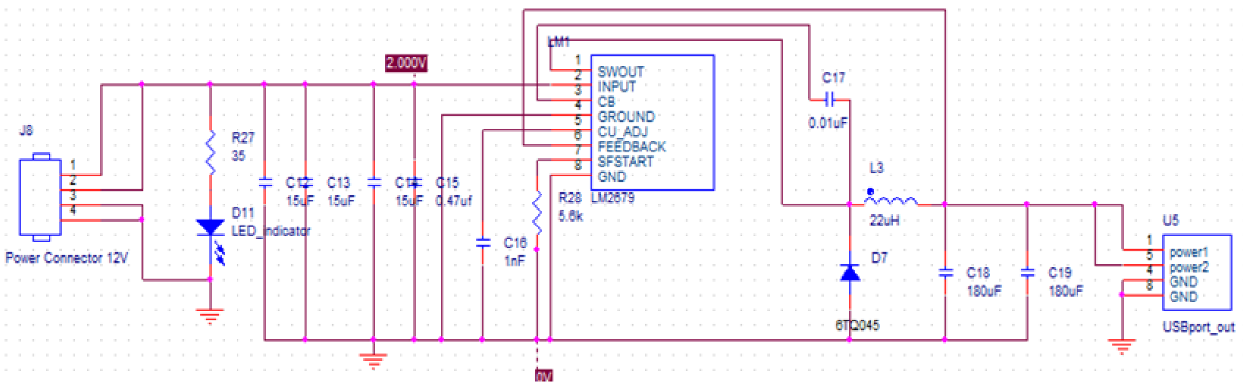

Figure 7. TI 2679 Chip Cadence schematic design

2.2.2 Circuit parameters calculation

TI TPS 61030

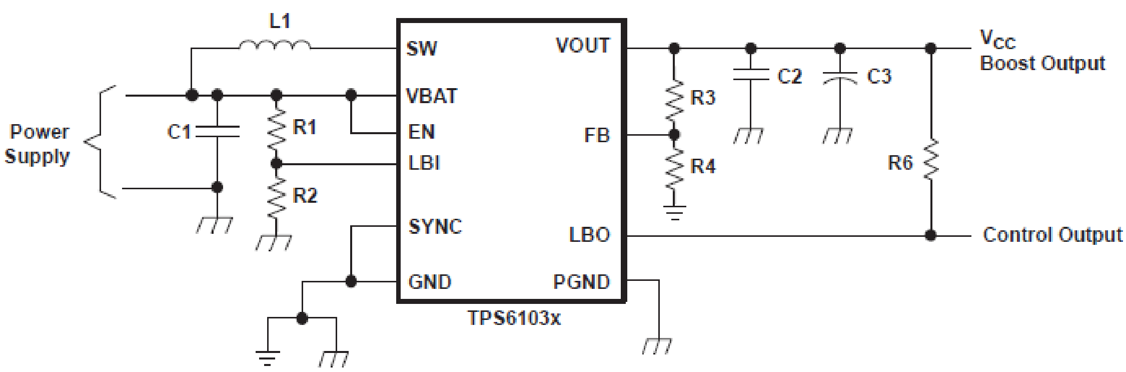

Figure 8. Recommended connection for 5V DC output [3]

The parameter of capacitor, inductor and resistors including R1, R2, R3, and R4 are calculated. The C1 C2 C3 are selected based on the recommendation values provided from the datasheet. It denotes C2 is 2.2uF, C3 is 220uf and C1 is 10uf to achieve the best filter and energy conversion result under 5V output condition.

Resistor selection

The DC_DC regulator requires the voltage on FB and LBI no large than 500 mV. Moreover, the current through the resistive divider is required to be about 100 times greater than the current into the FB pin. The typical current into FB is 0.01 uA according to datasheet. To fulfill all these requirements and keep the divider current more than 1 uA, the R4 is chosen to be 180 kΩ. To achieve 5V output, according to the equation below, it requires the R3 to be 1620K Ω. Thus, the total resistance on output current divider is 1800 K Ω. The current flow through the branch is 2.5 uA which is greater than 100 times of 1uA. The voltage on FB pin is 500 mV as required. The output is programed to be 5V.

$$R3 = R4 \times \left(\frac{V_O}{V_{FB}} - 1\right) = 180\ k\Omega \times \left(\frac{V_O}{500\ mV} - 1\right)$$

The LBI pin is reference voltage threshold generated on-chip. The lowest possible voltage supply, that is, Vbat in the equation below is 3 V as the lowest input voltage. In order to fulfill the current requirement, the R2 is recommended to be 390K Ω.

$$R1 = R2 \times \left(\frac{V_{BAT}}{V_{LBI-threshold}} - 1\right) = 390\ k\Omega \times \left(\frac{V_{BAT}}{500\ mV} - 1\right)$$

Therefore, the R1 is calculated to be 1950 K Ω.The current flow through is 2.13uA. The exact value selection of the R1 R2 R3 R4 is not rigid. Only the ratio, current limit and voltage limit should be considered to implement the desired output.

Inductor selection

Using same calculations shown below, inductor value can be chosen. The Vbat is using 3V and the frequency of the chip is 600KHZ. The delta I_L is maximum the current ripple, which is 10% of 3A according to our design. The output voltage is 5V.

$$I_L = I_{OUT} \times \frac{V_{OUT}}{V_{BAT} \times 0.8}$$

$$L = \frac{V_{BAT} \times \left(V_{OUT} - V_{BAT}\right)}{\Delta I_L \times f \times V_{OUT}}$$

The calculation result of the current through inductor is 6A and the required inductor is 6.7 uH. In the simulation, the value of inductor is set to be 6.8uH due to the availability of the inductor. This effectiveness of this value is validated by the simulation result.

TI 2679-5.0

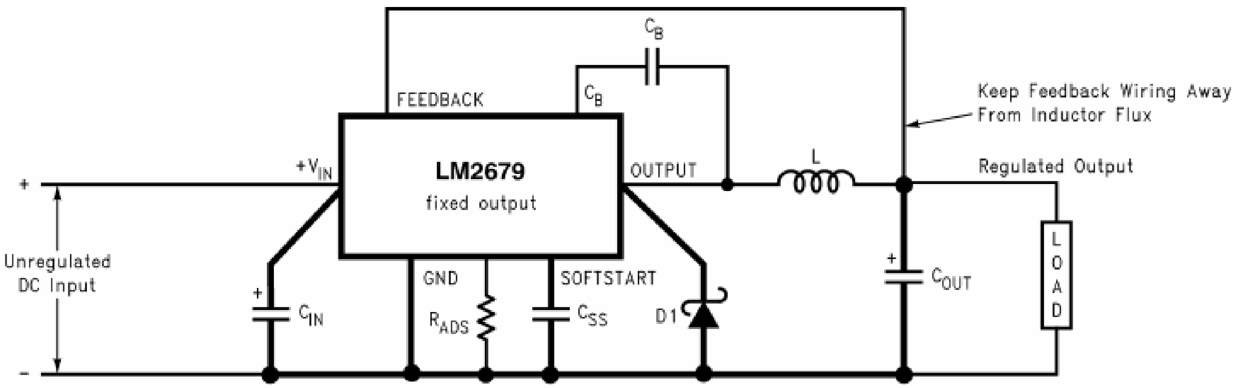

Figure 9. Recommended connection for 5V DC output [4]

The boost capacitor, soft start capacitor, inductor values are selected according to recommendations provided by [4]. The input, output capacitor and current adjust resistor values are adjusted by the testing of PCB performance.

Table 1. Components selection for TI 2670-5.0

C_{IN}	C_{Out}	C_{Boost}	Inductor (L)	R_{adj}	C_{ss}
90uF	300uF	0.01uF	22uH	5.3 K	1nF

2.3. Block description

2.3.1 Software flow chart and algorithm description

The algorithm aims to accurately detect the sleepiness of the driver by open eye and close eye recognition. The sleepy detection algorithm is built on C++ and OpenCV library. The test was first implemented and tested on the computer, then on the Beagleboard. The algorithm includes two parts: daytime detection and night detection. First and Foremost, based on the average intensity of pixels, the algorithm classifies the environment as daytime or night. For daytime, the image quality is good enough, therefore no image enhancement is required; for night, because the poor contrast of the images, histogram equalization, a method to expand the color range of the image from 0 to 255, is implemented. In this case, we need a light the slightly illuminate the driver.

In the next step, as soon as the driver has entered the car, two base images are recorded automatically – open eye as well as close eye. These two images are used as the base for further determination of whether the drivers' eye is open or close.

Afterwards, the driver could start driving. The detection algorithm is in real time and the eye portion is extracted by using the iterative Haar Classifier. After the current eye portion is extracted, we use template matching function built in OpenCV to determine if the eye is open or close. If the eye has been closed for more than two seconds, sleepiness is detected and the program will send a signal to Beagleboard. The detailed flow chart of the algorithm is shown below.

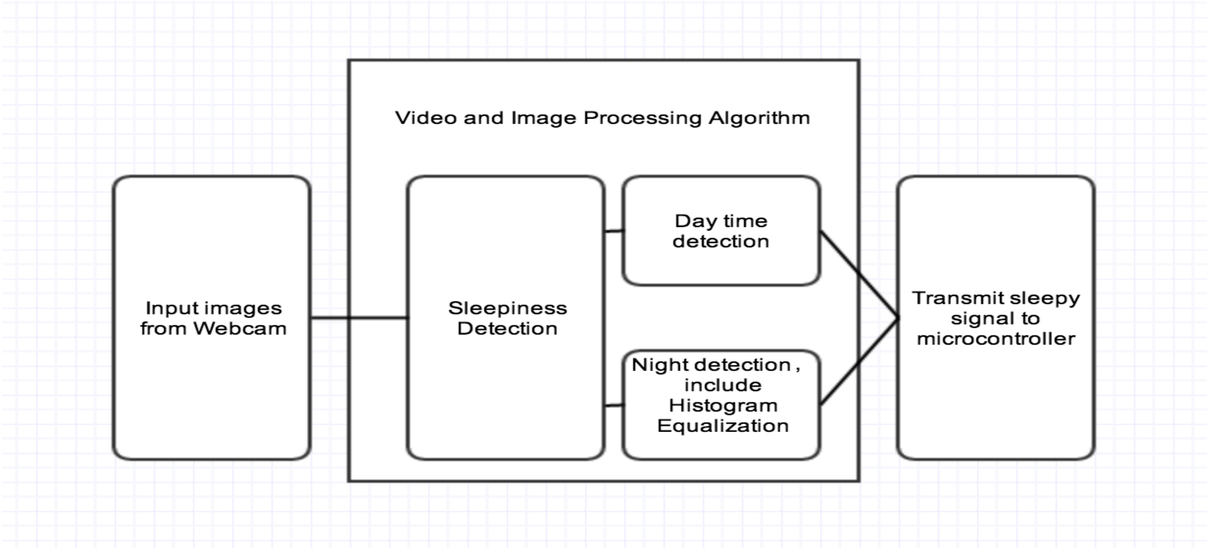

Figure 10. Framework of Algorithm

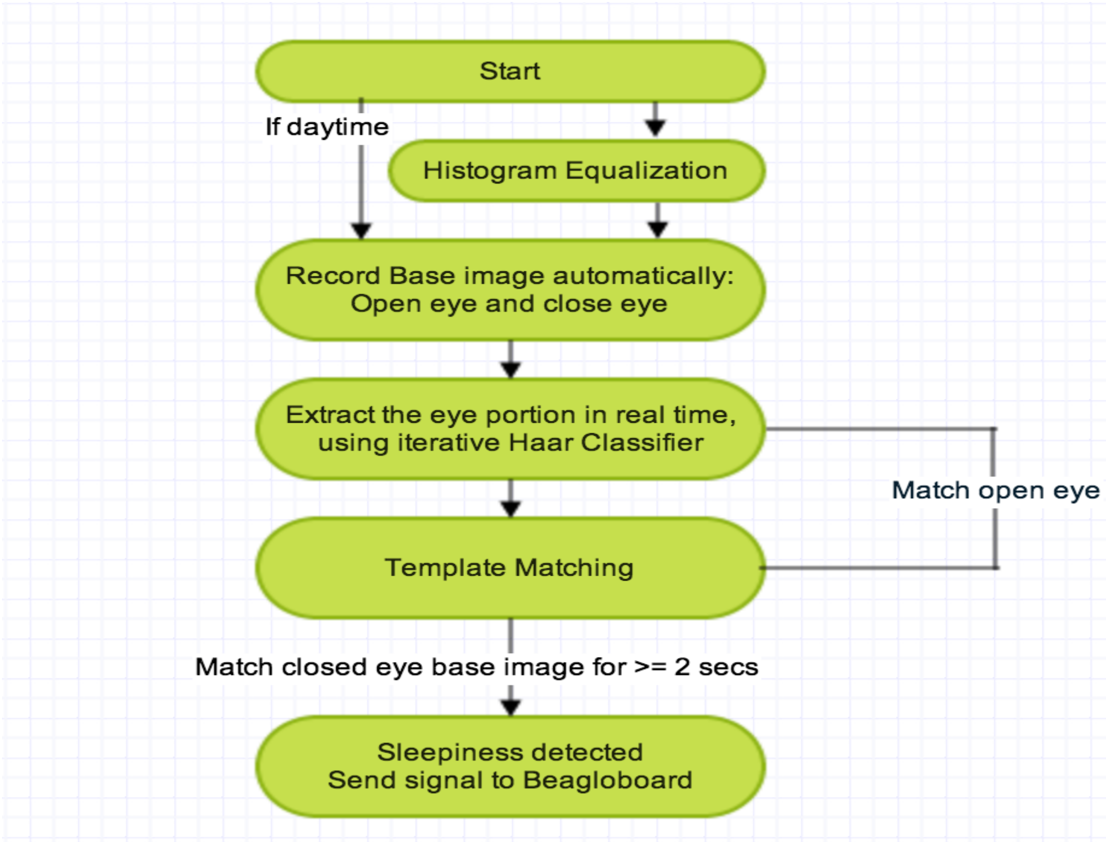

Figure 11. Flow chart for algorithm

Histrogram Equalization:

The histrogram Equalization is an image enhancement algorithm that could effectively expand the color contrast. Due to the poor quality of contrast, this algorithm is specifically used for night detection. Traditional histogram equalization is implemented on black and white images; for our design, we used it for each channel of the images, which are R, G, and B. In detail, a cumulative distributive function of the image is generated and we get a statistical model, then we assign new value to each pixel so that the CDF can be more evenly distributed in the range from 0 to 255. The flow chart is shown below.

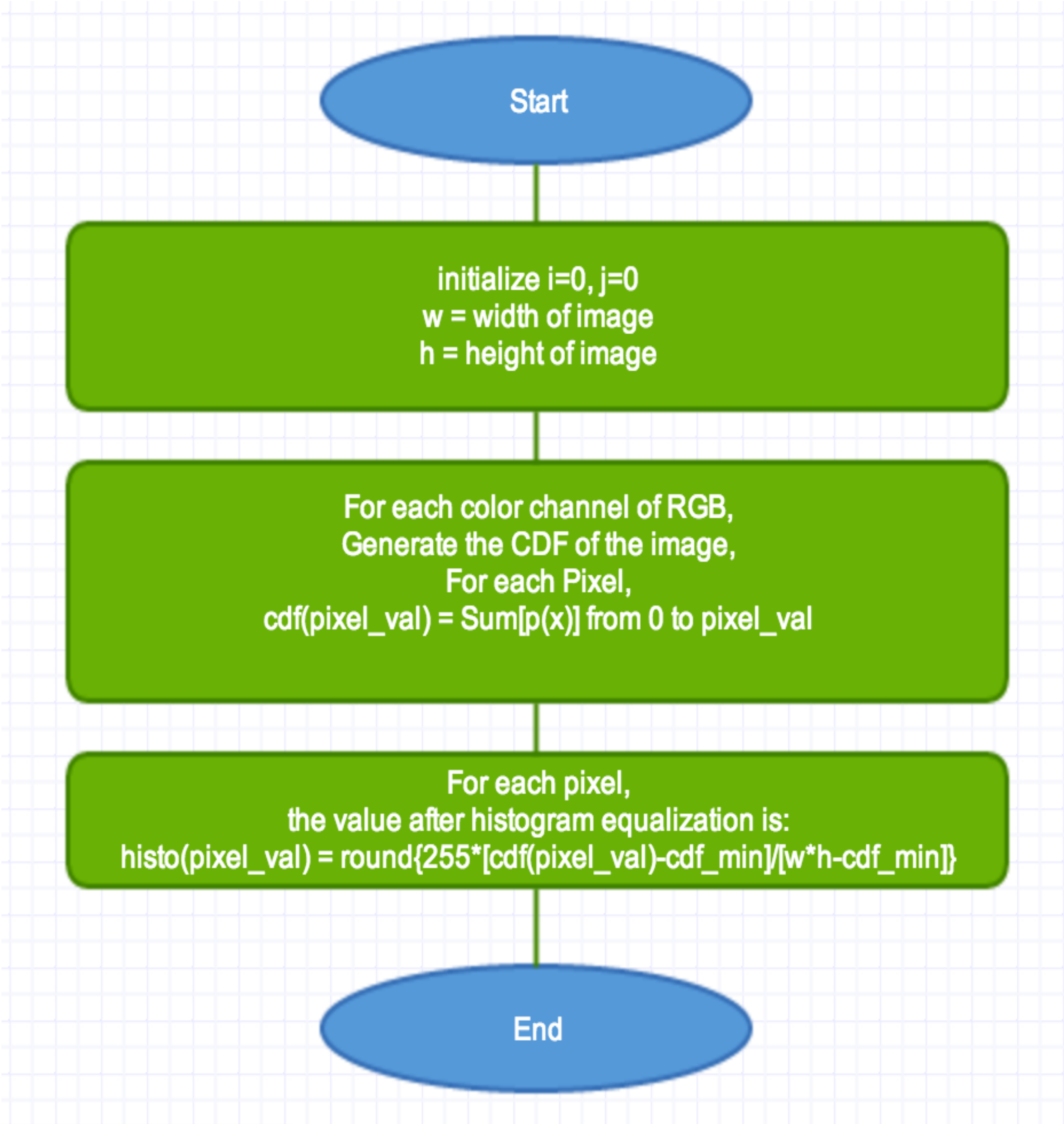

Figure 12. Flow chart for histogram equalization

2.3.2 Hardware components

Webcam

The Webcam is the input device used to monitoring the driver by capturing the face images. The images are then sent to the Beagle board for processing. The camera will be placed in front of the driver.

BeagleBoard

The Beagle Board would operate as the controller for all other components. First, it will send and collect information from the webcam. Then it would perform algorithms to determine the status of the driver to see whether his/her eyes are closed or not. Last it will send out 1.8V control signals to LED array and buzzer to control them. In order to collect information, analyze data, and send out feedback, we need to install Linux and openCV on the board and build corresponding drivers for other components. Even though power to BeagleBoard can be supplied via the USB OTG connector, the USB Host ports cannot supply power to our webcam. Therefore we used the DC power jack to supply power for BeagleBoard, using a Generic USB to 5.5 mm/2.1 mm 5 Volt DC Barrel Jack Power Cable that connected with the DXPOWER USB battery.

Our BeagleBoard will power and communicate with webcam using one of the four USB Host ports. We'll install Ubuntu on the board and use openCV library to support our algorithms. Most or the program is in C++ and compiled by g++, with a few bash commands to interact with the GPIO pins.

As for the input from buttons and output to alarming systems, we plan to use GPIO pins on the Beagleboard. Currently, we are using pin3(GPIO_139) and 5(GPIO_138), on the Expansion Header to control the LEDs, pin9(GPIO_136) for buzzer, and pin 7(GPIO_17) for the button. When the button is pressed, our system would continue running our program and record images of open and closed eyes. After the initialization is done, the board will run our algorithm to detect the driver's eyes, and notify the user by LED and buzzer when a dangerous signal appears.

Power Supply/Control Unit

For the final design, in order to make the overall system portable, the power source is provided by the car cigarette power outlet, which typically has 12V DC supply. Occasionally it also provides 24 V DC. The power supply unit can tolerate 8V to 24 V inputs and provide a filtered steady 5 V output to supply the USB battery which is used to power up the Beagle board and the camera. Also, it is used to power up the Buzzer and to illuminate the LED array by connecting appropriate resistors. One or Two USB receptor ports will be used to retrieve power and one USB outlet will connected to Beagle board. This module also provides one control signals to beagle board managed by the pushbutton. The pushbutton will control the beagle board and camera to take users' initial reference photos when it is pressed. The estimated working power consumption for the beagle board and camera is estimated to be 12 W, which is 2.4 A maximum current with output voltage of 5V. Additionally, a slide switch is installed in order to disable the alarming system when it is not needed.

Alarming system

Buzzer

The buzzer is chosen to work under 4V to 7V DC with 2.4 KHz alarming sound. It will directly connect to the power bus but not DC-DC converter output since it has a relatively large tolerance of functional voltage. Also, it can mitigate the load of the regulator.

Four through hole LED lights

There will be four LED on the PCB board in total. These LED are used for alarming purpose. There are three red LEDs put in series. In color selection is based on the minimum inference of driver by warm color light. The typical working voltage of these LEDs is 2.1 V. The power supply of LED will from the power bus connected from USB input. In order to limit the voltage, a series resistor is used to prevent LED from damage of over voltage. In order to achieve the adjustable frequency of the LED flashing, each LED is controlled by a NMOS switch, which is described as below.

NMOS switch

The control signal of the Gate for NMOS directly comes from Beagle board. The beagle board can provide a digital signal up to 1.837 V. Therefore, this voltage is able to drive the NMOS to implement on-off behavior to control the LED. The same design is used for buzzer. The only different for buzzer design is that resistor is not required for voltage limit purpose.

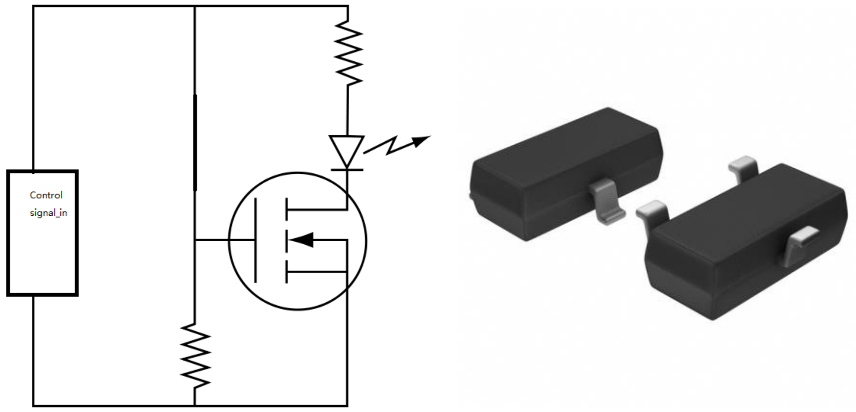

Figure 13. The LED –NMOS control circuit implementation and NMOS image

Mechanical switches

Two types of mechanical switches would be used in the design. As the figure 8 show on the left, the slide switch is used to control the power of whole system. It serves the power on-off button. Two push buttons are used in order to send commend signals to Beagle board for information acquisition purpose. The system power switch has current limit up to 6A and the signal buttons have the limit of 100 mA (Off-MOM). The resistor is needed to limit the current flow for the signal buttons.

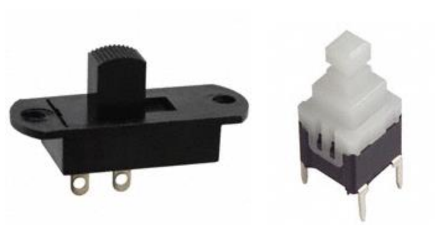

Figure 14. Slide switch (left) and push button switch (right)

2.4. Schematics with components

PCB schematic and layout design

The PCB design tool used is Cadence Orcad and Allegro. The reason why I don’t choose Eagle is because in most industrial design, Allegro Cadence is recommended.

Critical inductor and 1uF capacitor are surface mount components. Due to the price of the components, major capacitors are through hole devices. The figure 9 demonstrates the first draft schematic design of the PCB board. The communication ports with Beagle board are also shown below. The pin connection with Bealge board pin is illustrated in Figure 16.

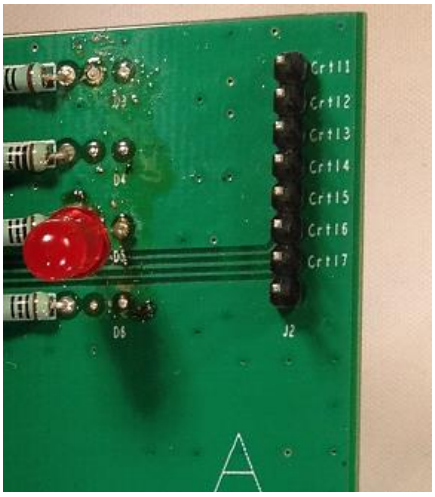

Figure 14. Communication pins of PCB

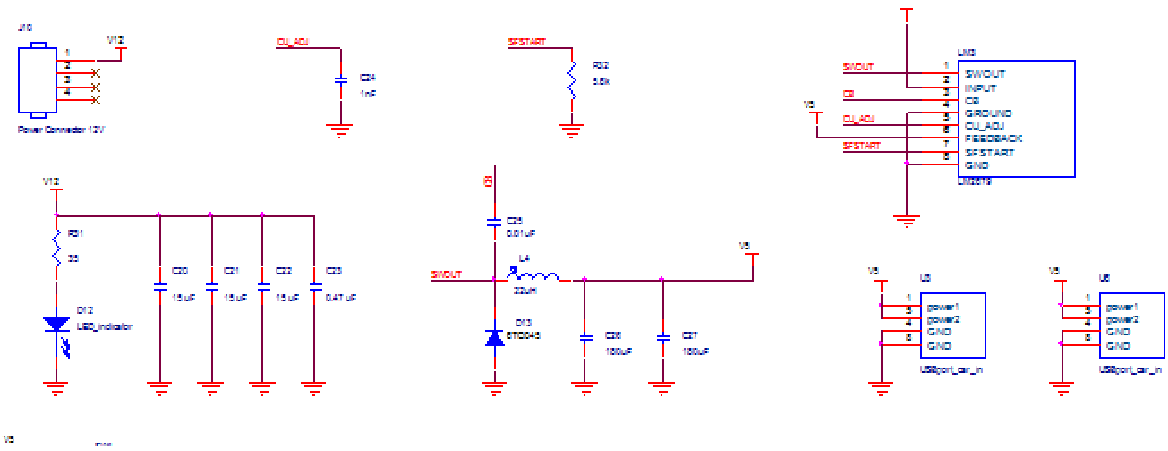

Figure 15. PCB schematic design (OrCad)

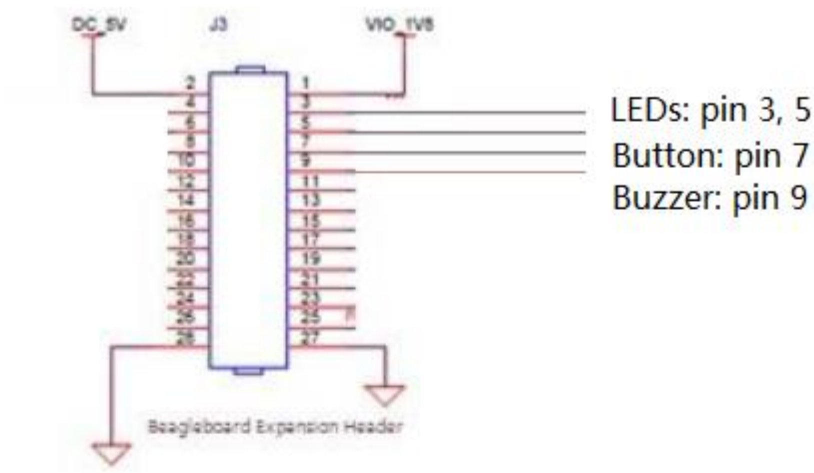

Figure 16. GPIO pins for input/output control signals

3. Verifications

3.1 Testing procedure

Software:

The test was initially executed on the computer and then on the Beagloboard. To verify the eye portion algorithm, the tester stood 0.2 to 0.3 away from the Webcam which was located in front of the tester at an angle with ±15°. The image of the eye section was extracted successfully and was highlighted by a red rectangle.

To test the daytime detection, we controlled the environment light intensity to be 80W and the tester stood at the same detection position as above. When the tester closed the eye for more than two seconds, the program showed “eye closed” at terminal as required. In addition, when the tester blinked the eye, nothing happened as expected. To test the night detection, the only difference is that we controlled the surrounding light intensity to be 20W. We successfully got the same detection result as daytime.

Beagleboard:

We compiled our code on the Beagleboard and ran with webcam connected. For each of our main loop we tried to capture an image and analyze it, a timer is used to record the time for each loop. The average time is within 0.33 second as satisfied our requirement. For the GPIO pin output, we were able to send out a control signal varying from 1.788V to 1.835V which satisfied our requirement(1.8V ±5%). These control signals were able to drive LEDs and buzzer successfully. For the GPIO pin output, we fed a control signal of 0V to the pin and our program is able to identify that the pin is set to low, which meets our requirement.

Power supply and alarming system:

Requirements	Testing procedure and result
Power/Control Unit: I. Able to receive control signals from BeagleBoard via GPIO. II. Able to supply an output via USB port with 5V voltage with 5% tolerance when input of the Power supply unit varies ±3V. High frequency signal noise in the supply voltage should be suppressed by the regulator into 10% of its magnitude. III. The LED are able to illuminate normally with 57 lm ~ 62 lm under typical voltage 3 V and the buzzer can make sound 88dB under 5V supply voltage.. IV. Able to turn off the alarming system by switch. V. Able to send GND control signal	I. Tested by the precise control of LED and Buzzer behavior by sending signal from Beagle board. II. The output terminals is connected to the oscilloscope. The output wave form is obtained with certain load. Verified by waveform measurement. III. When the signal sent from Beagle board become high, the LED and buzzer can behave as requirements described. It is verified by the functionality of the system during the demo and regular tests. IV. Tested and verified by sliding the switch off, the LED warning system can be turned off.

to Beagle board in order to take initial pictures for driver for reference.	V. Tested and verified by pressing the button to see the response from Beagle board. The beagle board successfully receives the GND signal.
Alarming devices I. LEDs are able to flash at same frequency in different sequences. The frequencies include 1Hz, 2Hz, and 4Hz. (4 LED in total). II. Under 5V input voltage, the buzzer sound can be heard from users who are within 0.5m	The Led and buzzer functionalities are tested and verified by proper behavior when control signal is high from send from Beagle Board.

3.2. Quantitative Results and Measurements

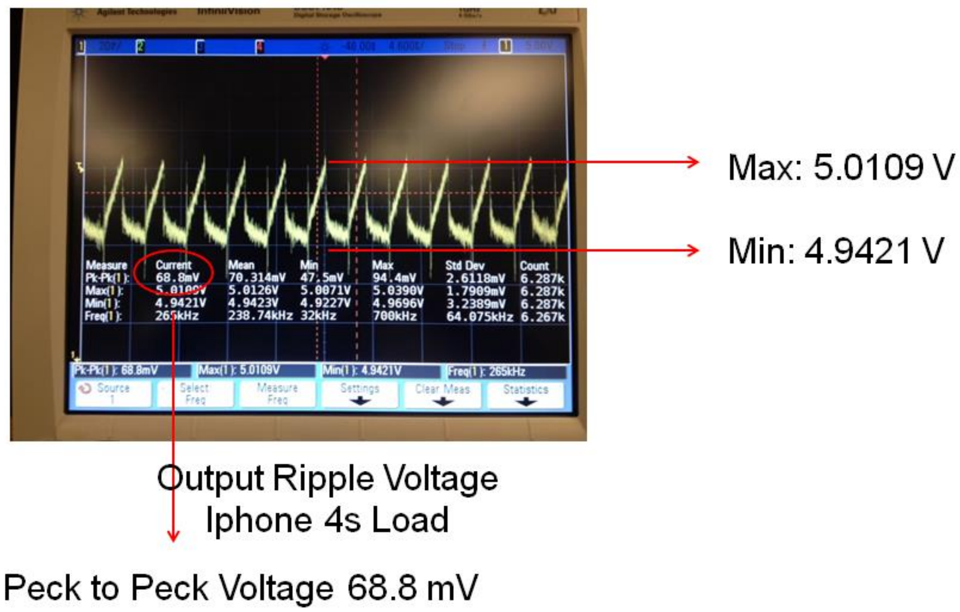

Figure 17. Power supply output voltage ripple with Iphone 4s load

The figure 17 shows the voltage ripple measurement of dc-dc converter output while charging a Iphone 4S device. The maximum and minimum values indicate that ripple variance is within 10% range. The current draw is 0.43A.

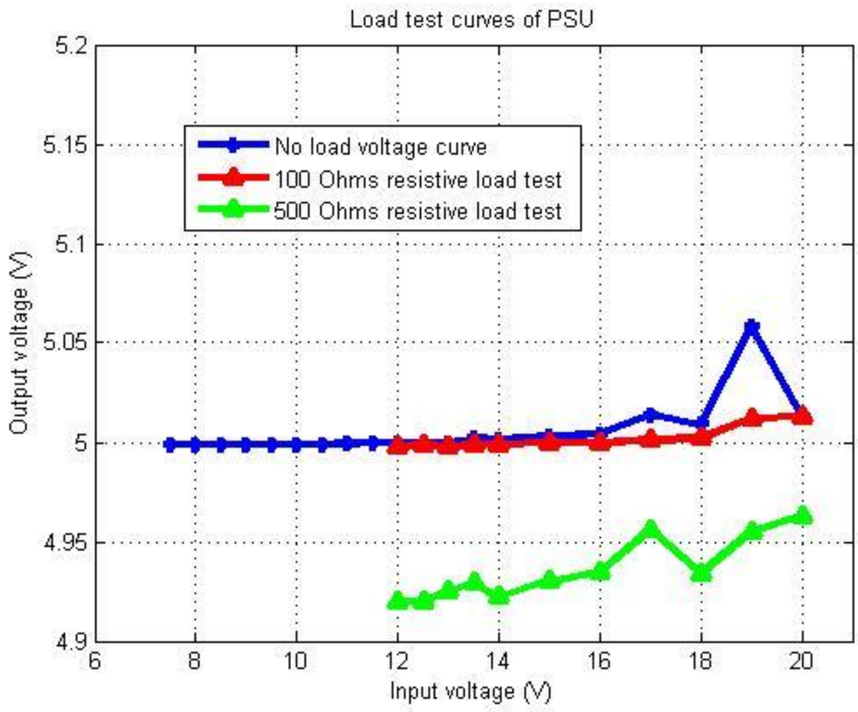

Figure 18 : Power supply output voltage (V) vs input voltage (V) for different resistive load

A series load tests have been performed for the dc-dc converter. The plot indicates that under no load and light load (100 ohms) conditions, the output voltage is very resilient at 5V. With the relative heavy load (500 ohms), the output drops to 4.95V slightly, which is in tolerance range. The current source load tests has been performed. However, due to the permanent damage caused by overcurrent during the test, the result does not shown in the report.

The table 2 shows the frame taking frequency when the eye detection algorithm is operated on the Beagleboard Linux platform.

Table 2. Average time for a main loop in program

Loop	1	2	3	4	5	Average
Time/s	0.342	0.322	0.325	0.319	0.321	0.326

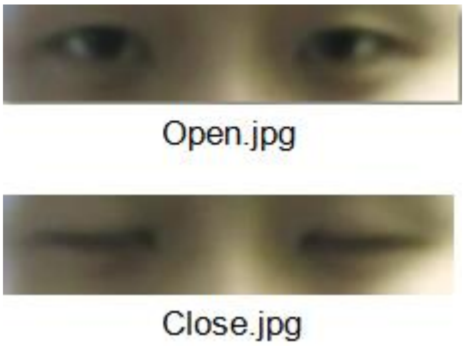

Figure 19. Recorded image for eye open/close detection done by Beagle Board

The figure 19 shows the regional eye detection algorithm identifies the eye open/close status during the running process.

3.3. Discussion of results and performance

The software detection algorithm part is implemented successfully. The performance is fast, efficient and very accurate. The program can run smoothly on the computer in real time with no delays. In addition, we tested the algorithm for 200 times, the accuracy achieves 93% in daytime and 82% at night, which is very high compared with the products sold on the market, for which the highest accuracy is 90%.

As for the Beagle board, most of our requirements are satisfied. The Average time of a main loop is less than 0.33 second, which give us an image capturing frequency of 3Hz. GPIO pins are able to output a signal of 1.788V to 1.835V. Button press is able to send a ground signal through GPIO pin to start the process of image taking.

Besides, we made a few changes regarding the original description. First, Kinect is replaced by a webcam, which is much less expensive but has almost the same amount of image quality. And we are still able to achieve the 3Hz image capturing rate as in the requirement. Second, we made button press to send ground signal instead of a 1.8V signal because we later found out that the GPIO pin is active-low. And we are still able to identify a button press and record images correctly.

4. Cost

4.1. Labor cost

Name	Rate/hour ($)	Hrs/week	Weeks	Total (Rate×2.5×Hrs/week×Weeks) ($)
Chenyang Xu	40	15	12	18000
Xiangyu Chen	40	15	12	18000
Yixiao Nie	40	15	12	18000
Total				54000

4.2. Components and device cost

Table 3. Components purchase list for hardware section

Index	Quantity	Part Number	Description	Customer Reference	Available Quantity	Backorder Quantity	Unit Price	Extended Price
1	2	OR1070-ND	CONN USB 1A 30VAC R/A BLACK		2 Immediate	0	2.35000	$4.70
2	2	P12345S-ND	SWITCH PUSH SPST-NO 0.1A 14V		2 Immediate	0	1.49000	$2.98
3	1	CKN10054-ND	SWITCH SLIDE SPST 6A PNL MNT SLV		1 Immediate	0	2.01000	$2.01
4	1	6TQ045SPBF-ND	DIODE SCHOTTKY 45V 6A D2PAK		2 Immediate	0	2.37000	$4.74
5	5	P15845CT-ND	CAP ALUM 15UF 50V		5 Immediate	0	0.48000	$2.40

Index	Quantity	Part Number	Description	Customer Reference	Available Quantity	Backorder Quantity	Unit Price	Extended Price
			20% RADIAL					
6	3	493-4025-1-ND	CAP ALUM 180UF 16V 20% RADIAL		3 Immediate	0	0.88000	$2.64
7	2	P990-ND	CAP ALUM 0.47UF 50V 20% RADIAL		2 Immediate	0	0.26000	$0.52
8	1	P990-ND	CAP ALUM 0.47UF 50V 20% RADIAL		1 Immediate	0	0.26000	$0.26
9	2	PCF1340CT-ND	CAP FILM 10000PF 50VDC 1206		2 Immediate	0	0.70000	$1.40
10	2	495-4402-1-ND	CAP FILM 4700PF 100VDC RADIAL		2 Immediate	0	0.32000	$0.64
11	2	495-4402-1-ND	CAP FILM 4700PF 100VDC RADIAL		2 Immediate	0	0.32000	$0.64
12	1	308-1335-1-ND	INDUCTOR 22UH 4.7A SHIELD		1 Immediate	0	1.35000	$1.35

Index	Quantity	Part Number	Description	Customer Reference	Available Quantity	Backorder Quantity	Unit Price	Extended Price
			SMD					
13	1	308-1335-1-ND	INDUCTOR 22UH 4.7A SHIELD SMD		1 Immediate	0	1.35000	$1.35
14	2	67-1080-ND	LED 3MM 5V SHORT LENS YEL DIFF		2 Immediate	0	0.66000	$1.32
15	3	67-1106-ND	LED 5MM 5V RED DIFFUSED		3 Immediate	0	0.54000	$1.62
16	2	458-1049-ND	BUZZER MAGNETIC 4-7VDC 12MM SMT		2 Immediate	0	2.84000	$5.68
17	1	PCB	Advanced circuit		1	0	50.00	$50.00
18	1	Webcam	Amazon		1	0	6.59	$6.59
19	1	Beagle Board (Provided by Class)	Texas Instruments		1	0	130	$130

4.3 Grand Total

Labor Cost ($)	Parts Cost ($)	Grand Total ($)
54000	266.35	54266.35

5. Conclusion

5.1. Accomplishments

As for the software part, we fulfilled our goal successfully. The detection algorithm could not only work effectively and accurately at daytime, but also at night. The Eye portion extraction is smooth and in real time with no delays on the computer. In addition, there is a bonus function in the software part – detection with glasses.

For the Beagleboard, we achieved two major difficulties. First, we were not able to power up the board with any commercial chargers initially, including the ones for Iphone, for Samsume, or the USB charger on car. But later we added DXPOWER battery to power our board and used the power supply we designed to charge the battery to solve the problem. Second, we experienced a few difficulties while installing the OpenCV library on Beagleboard, but were able to solve it by changing flags in makefiles to the one corresponding to ARM board architecture. The power supply unit basically completes all its design requirements. By adding the extra USB battery stage, the problem of powering the entire microcontroller and alarming system has been solved. Moreover, the alarming system works as we supposed. The voltage ripple of the power supply unit can be mitigated by applying more resilient capacitor components.

It is apparent that the overall project success is not derived from one team member’s mind but the keen coloration within our group. Each part is indispensable and every team member made the great dedication on the completion of this design project. The pace is intense, the learning, immense.

5.2 Ethnical consideration

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 [5];

By using our Driver Sleep Detection and Alarming System, customers would be warned when his/her physical condition is not good enough for driving and thus prevents dangerous behaviors from happening. It is consistent with the safety and welfare of the public.

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

By using openCV and related libraries, we try to develop and improve algorithm for eye closeness detecting. We then apply this technology to our application in order to help drivers achieve a better and safer driving condition.

7. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;

We consult Professor and TAs for review advices and improve, seek online resources to help correcting errors, and properly cite the contributions of other people.

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

We design our product using qualified components and follow proper safety rules, avoid wrong actions happening to other people.

5.3. Future work

1. Use OpenGL to control the frame rate more accurately
2. To achieve a higher accuracy at night
3. Use parallel programming such as CUDA to make code faster and more efficient
4. Use bash script to enable our program to auto start after booting.
5. Use parallel programming and multi thread to handle image capturing, sending control signal, and running algorithm separately.
6. Design hardware enclosure for PCB , microcontroller and USB battery
7. Use more advanced components in out/in capacitors to reduce the voltage

ripple of the output voltage

5.4. Uncertainty

The precision of night vision detection has some spaces to improve due to the algorithm and hardware ability limitation. The accuracy of the algorithm needs further optimization for the night condition.

6. References

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[3] "TPS61032 (ACTIVE) 5-V Output, 1-A, 96% Efficient Boost Converter." Texas Instruments, Jan 2012. <http://www.ti.com/lit/ds/slus534e/slus534e.pdf>.

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7. Appendix

- Overall system PCB view