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An Intelligent Embedded Diagnostic System on CAN Protocol to Avoid Rear-End Collision of Vehicles

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Abstract

Background/Objectives: In a modern day vehicle, the safety of drivers and passengers are of utmost significance. With increase of traffic on roads, there are increased cases of accidents and mishaps which call for a robust driver and passenger assisting systems that can overcome and handle these situations effectively. **Methods/Statistical Analysis:** The work proposes an intelligent embedded system that assists the driver in avoiding a rear end collision with its on board diagnostics. It is a mechanism that monitors the braking intensity of vehicle and depending upon its intensity alerts the other vehicles that are immediately following. The device on the following vehicle immediately is activated to take decisions to avoid the impending collision. An accelerometer interfaced to ARM Cortex M0 microcontroller is a part of the transmitter devices that calculates the rate of deceleration and notifies the device on following vehicle by displaying it on the rear LED arrays and transmitting messages through IR communication. The receiver device is responsible to decode the message and follow a control algorithm based on many other parameters to either decelerate or stop the vehicle notifying the driver immediately. The system also hosts an on board Diagnostic system over CAN protocol that assists the driver and the repair technician during servicing, thus reducing the debugging effort and facilitating easy. **Findings:** Literature survey states road accidents are very common in India due to human errors. Existing system are becoming advanced and they reached up to tracking the traffic by using GPS to avoid accidents. Various traffic managements systems are being developed. Proposed work introduces a new system which tells the intensity of braking in car, to the nearby cars in order to keep the driver alert, which helps in avoiding the accidents. **Conclusion/Improvements:** The proposed system has advantages over the other existing system in terms of response time and independency on external infrastructure. It is also cheap in terms of cost and reliable when tested in actual environment. The system does not intend to notify other running vehicles except the ones that are following it or is in the lambert Ian line of sight of the array of IR transmitter lined in the rear bumper. Hence it effectively helps in reducing the accidents due to human errors by alerting the driver in advance.

Keywords: Accelerometer, Collision Warning and Avoidance System, Embedded System, IR Communication, Rear-End Collision

1. Introduction

An analysis made by the National Institute of Disaster Management, in India postulates that there are road accidents occurring every 80 seconds and the major stake are of Human errors which amount to 93% of all accidents.[1]

Reducing such accidents with intelligent embedded system is one of the recent developments in automotive electronics. A mechanism that not only evaluates the braking intensity of the car but also actively notifies the following cars i.e establishing vehicle to vehicle communication will come handy in recent scenario of traffic. An active intelligent diagnostic system on the car that alerts warns and assists the driver in efficient driving and the technician with diagnosis among other available data is the need of the hour.

Researchers have been working on this important issue in recent times that has given rise to may development in this subject.

There are systems modeled for using Kamm's circle prediction algorithms on laser scanner to predict a collision[2]. Vehicle to infrastructure communication

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namely Vehicle Adhoc Network have also been implemented to manage traffic and avoid collisions[3]. The Global positioning systems that uses satellite communication to locate other vehicles has been used to evaluate the relative velocity to avoid an impending collision[4]. Various other WIFI, Zigbee based system and fuzzy based systems have also been deployed for the same purpose.

There is various cost metrics associated to the above mentioned methods and technologies such as complexities of algorithm, time delay in communication, cost of components, etc. The paper proposes an ARM Cortex-M0 controller based implementation to warn about a collision and overcome it effectively. It employs an accelerometer to measure the deceleration of leading car and send messages encoded in infrared signals to communicate with the trailing vehicle. It warns the driver and passengers on following vehicle with proper alert mechanism and avoids the collision with proper speed control according to the control program. It also logs the input and outputs of the decisions to storage file thus enabling diagnostic feature during the servicing.

2. Proposed System

The system is made of two sub-systems based on micro-controllers, one a Collision Warning System and other Collision Avoidance System as shown in Figure 1.

The Collision warning system fixed on leading vehicle is responsible for notifying the alert Collision Avoidance System mounted on the following vehicle to warn its driver and effectively handle a crash due to an approaching rear-end collision. The desired mode of communication required is straight optical lambertian range of communication to notify only the vehicles following the leading vehicle. The warning system inputs data from an accelerometer and the avoidance system outputs signal to control the braking mechanism appropriately. The two individual modules also boast a diagnostic mechanism that notifies the vehicle user about its current state and error states that shall be logged on event occurrence basis along with the time stamp for efficient fault diagnosis.

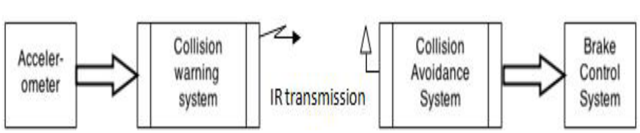


Figure 1. Block Diagram of Proposed System.

2.1 The Alert Collision Warning System

The warning system Figure 2 measures the rate of deceleration caused due to braking using an accelerometer and evaluates the threshold levels of deceleration. The warning system is CortexM0 controller with inbuilt 10 bit ADC that is used in digitizing the analog input signal at a very high rate. The input signal acceleration values are logged and dynamically slope of the signal is calculated at fixed interval of time. The control algorithm shown in Figure 3 is implemented in the ARM Cortex M0 Controller for prompt response. A decision drawn from the slopes is used to pulse width modulate a thirty kilohertz signal to be transmitted over Infrared to communicate with the Collision Avoidance system mounted on the vehicle following it.

The algorithm calculates the slope of the response of Accelerometer dynamically. The array of LED of distinct colors is blinked according to the level of deceleration as shown in Figure 4(a), (b), (c). The levels of deceleration corresponding to a braking is transmitted to the Collision Avoidance System to act upon a control algorithm and take a control action as can be seen in the functional block diagram in Figure 2.

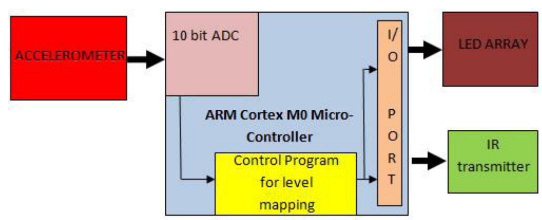


Figure 2. Block Diagram of the Collision Warning System.

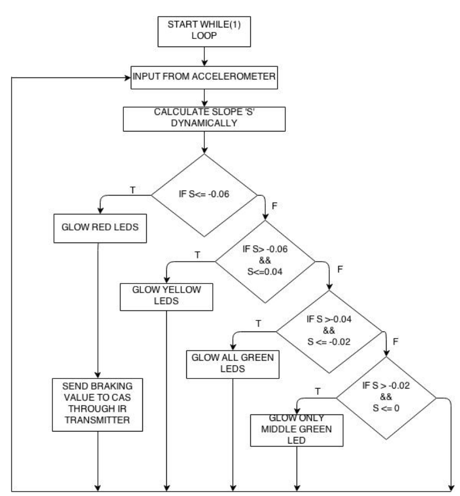


Figure 3. Flow Chart of the Collision Warning System.

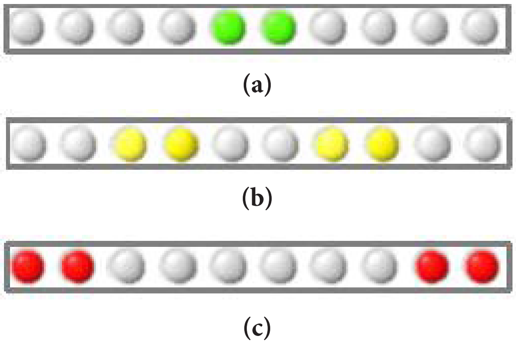


Figure 4. **(a)** Green led representing low braking intensity. **(b)** Yellow pair of penultimate led representing gradual braking and **(c)** RED led at ends representing sudden high braking intensity.

2.2 Accelerometer

The accelerometer is an electromechanical device that is used to measure static and dynamic acceleration of a moving vehicle. It employs quantum physics to draw an appropriate response to the acceleration; hence it is very quick in response time and is more reliable in measuring acceleration of any moving object. It is also very small in size that can be mounted anywhere on the surface of the vehicle.

An ADXL335 Figure 5 accelerometer is an analog device which has to be interfaced to the microcontroller's Analog to digital convertor to get the values in digital form for processing. This module is a small and low power module that measures acceleration in three axes within the range of ±3g.[5]

To get the actual response of accelerometer for vehicle acceleration, it was experimented on a car with actual road trials. The value of the accelerometer was logged in a file using a serial terminal. Analysis was made on the data available which are described below in Figure 6.

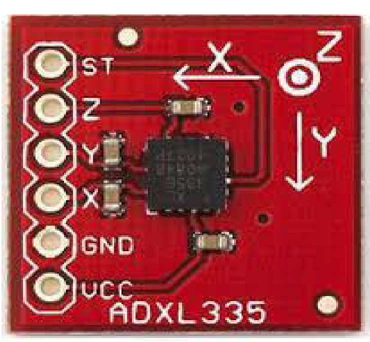


Figure 5. An ADXL335 accelerometer.

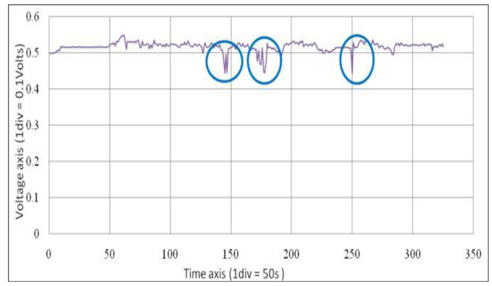


Figure 6. Accelerometer response graph for braking intensity of a vehicle.

The real-time response plotted gives information about the intensity of brakes. The sharp dips indicate deceleration and hence symbolize the braking action. The slopes of these dips that are to be calculated distinguish it for the different level of braking. Gradual slope indicate gradual braking as seen around time-sample 175 and steep slope indicate hard braking as observed around time-sample 250 (refer Figure 7(a), (b)).

2.3 Evaluation of Deceleration Levels

The slope of the response has to be calculated dynamically on real-time by programming the microcontroller unit

It can be inferred from the plot that for the given vehicle brake system, deceleration values above −0.04 represent safe braking represented inside green circle while deceleration values lower than it represent further levels of gradual and hard braking. This is evident around time-sample 175 and 250 represented by yellow and green circle respectively in Figure 8. It is red level that is to be taken care of by alerting and activating the warning and collision avoidance system.

Figure 7. Snippet from response of accelerometer differentiating gradual and high braking intensity, (a) Gradual slope and (b) Steep Slope.

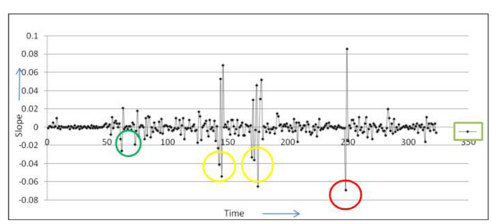


Figure 8. Plot of slope against time.

2.4 Braking Display LED Array

The various slope levels mapped on to level of braking from the above graph need to be conveyed to the driver and the vehicle following. There is an arrangement LED arrays that represents the tail light of leading vehicle. It blinks with particular color to indicate the level of blinking thus making the following car give a visual signal about the leading cars braking level. Based on the level of braking the leds glow green, yellow and red color .The window level for glowing green led that represent low intensity braking is more than –0.04. Similarly, while yellow led glow in window period from –0.04 to –0.06 representing gradual braking, red led glow in window period more than –0.06 representing sudden hard braking as shown in below Figures.

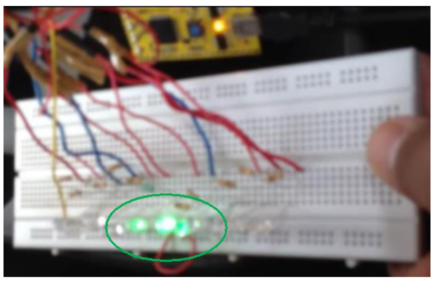


Figure 9. Centre LEDs (Green) in the array glowing indicating safe or low intensity of braking.

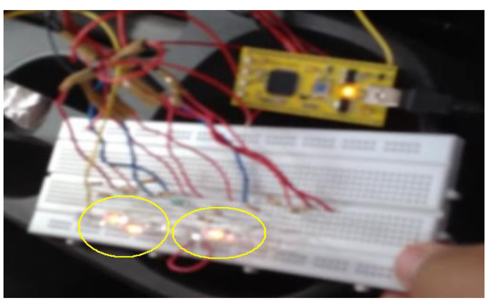


Figure 10. Penultimate LED (Yellow) in the array glowing indicating Gradual Braking Levels.

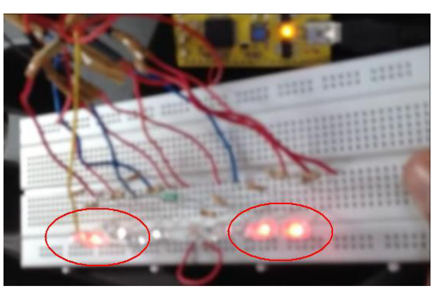


Figure 11. Extreme LEDs (Red) in the array glowing indicating high intensity of braking.

2.5 Infrared Communication

The braking levels one calculated must also be communicated. A pulse width modulated IR signal is used to represent the levels. The duty cycle of the pulse width modulated signal is proportionate to the deceleration levels. The Figure 12 shows us a rectangular pulse on the Cathode Ray Oscilloscope (CRO) and IR led glowing in dark sending the signal modulated by the controller according to the calculated deceleration level. PWM of a 50% duty cycle represent normal braking of above –0.04 deceleration and hence no action is expected from the avoidance controller. PWM of different duty cycle lesser than 50% represent the slope levels of –0.05 to –0.06 and –0.06 and below.

2.6 The Alert Collision Avoidance System

The IR signal transmitted by the Collision Warning System (CWS) is received by the Collision Avoidance System (CAS) to draw a proper control decision from the control program. The control program calculates the time to collision and thus decisions are made on its pre decided values. Figure 14 represents the control flow of the CAS.

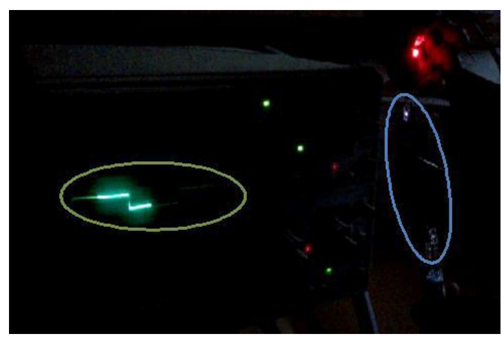


Figure 12. IR LEDs (Blue) communicating via pulse width modulated wave (Green) seen in a CRO.

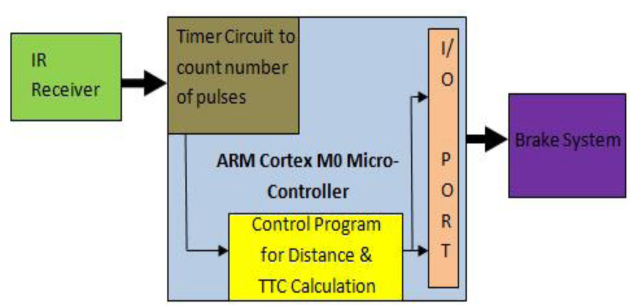


Figure 13. Block Diagram of the Collision Avoidance System.

2.7 IR Receiver

An IR photo diode along with the signal conditioning circuitry is used as the PWM generator modulated proportional to the intensity of the brake levels. These IR rays incident on the following car are to be received and demodulated to decode the information of brake level applied in the leading car. This information is prime input to the control algorithm of the CAS to make decision on control action.

2.8 Time Gap Calculation

Pulse width modulation used for the communication of braking level are nothing but rectangular pulses of 40 KHz frequency. A concept of Doppler shift is applied which relates the shift in frequency to the distance travelled by the signal. The Figure 15 shows the spread in pulses with the distance travelled. This spread of pulse is the change in frequency which is to be detected and measured by the Collision avoidance microcontroller. A timer and counter are employed for calculation of number of pulses in a particular duration of time. This is mapped to the distance between the two vehicles. The distance for collision will be proportional to the change in the number of pulses.

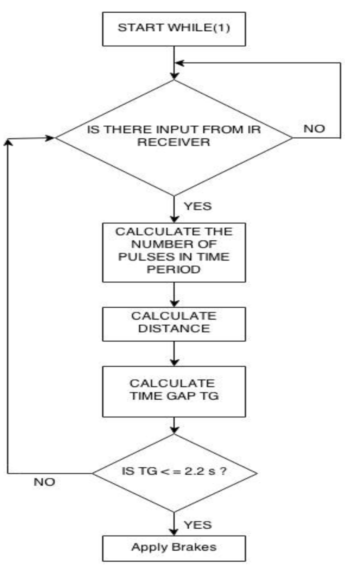


Figure 14. Flow Chart of the Collision Avoidance system.

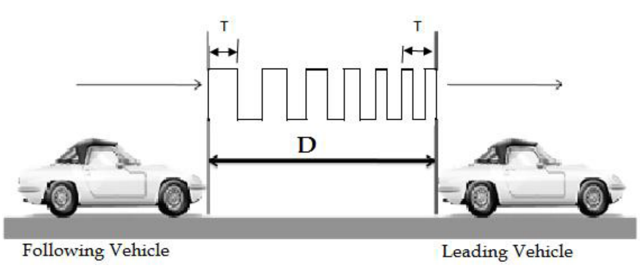


Figure 15. Distance proportional to spread in pulse width.

2.9 Control System

An interrupt driven control program is written that starts the timer of the controller to count the number of pulses that are being received by the IR receiver. A reference frequency value is already stored in the controller against which the new frequency will be compared to map to the corresponding distance. Once the distance is measured, along with the inputs from the vehicle velocity, the time gap is calculated as shown in equation (1).

$$TG = \frac{Distance}{Velocity\ of\ Following\ car} \quad (1)$$

The Honda Algorithm is used as the reference algorithm which is dependent on the time to collision parameter and hence the time gap for collision avoidance in Honda Cars. According to it, it is very critical to apply brakes and stop the following vehicle if the Time Gap (TG) is detected to be less than 2.2 seconds[6]. Thus a control action of reducing the speed and stopping the vehicle can be emulated with a prototype shown in Figure 17. A DC motor resembling the wheel of the vehicle is used to demonstrate the control action. In reality, other active and passive safety mechanisms can be activated like the Antilock braking, Electronic stability program, Traction control, Seat belt tightener and the Air bag inflation according to their need at the situation.

2.10 CAS-ECU CAN Communication

The CWS and the CAS devices mounted on the vehicles need to communicate of their states and actions with other Electronic control Units of the car over an internal communication network, normally a Controller Area Network (CAN) network. This communication is important for activation and deactivation of other mechanisms of the vehicle related to the safety of the driver and passenger. In the prototype we use the on board CAN controller following CAN2.0 B protocol specification of Nuvoton Nuc140 Development board to simulate an environment of communication between the Device and other Electronic control unit. This is demonstrated by the DC motor control by the ECU on trigger from the device as seen in Figure 17.

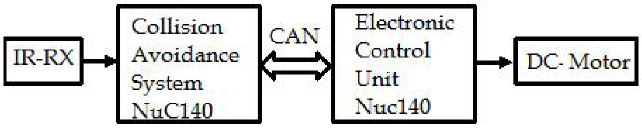


Figure 16. Communication flow of the CAS.

An interrupt driven control program is used that generates CAN message as a part of the interrupt subroutine to generate the appropriate control action on detection of the appropriate braking level and time gap. These messages are handled internally by storing them in Message Objects. This message object is then checked in accordance to Message Handler's acceptance filtering for their correctness according to the CAN protocol. Once the objects clear the filtering they are stored in the CAN controller's

Message RAM. The message handler finite state machine handles the data in transmit and receive registers of the controller,

The Trans-receiver then places the data on the CAN bus with its appropriate frame format that can be read by other CAN controller of other electronic control unit which are a part of the CAN network. The CAN message is decoded to get the information and then control the DC motor according to it as the response of the Collision Avoidance system (Refer Figure 17).

2.11 The Diagnostic System

On-board diagnostics present for devices use the telematics of vehicle to assist safe driving, monitor vehicle climate, measure speed of wheels, alignment, engine health, monitor tyre pressure, fuel level, check emission efficiency and also connect over internet to log data related to the current health of the vehicle. They also help with the fault diagnostics during the servicing of the vehicle by logging data and managing them to draw quick conclusions. Recent advancement in automotive technology market demands on board or on chip intelligence in every device that is compatible to the existing technology yet boasts additional comforts to assist the driver, passenger and the technicians during fault diagnosis.

Figure 17. DC motor control action by CAS-ECU CAN communication.

Primitive version of Diagnostic only included lighting a lamp or a light indicating malfunctioning of the device and did not provide any information to the driver, passenger and technicians about the state of the device and cause of the problem or the state.

To provide a diagnostic, all the conditions and state of the device need to be considered and appropriate diagnostic signal and handling messages needed to be logged in the device itself. Diagnostics primarily include detection of condition or error, then draw conclusion and send control signal, log the real time data in the storage space and display output message over display or speakers. The Collision warning and avoidance system simulated certain predefined conditions and errors of the device that would aid the vehicle users in handling it. They are as discussed with the obtained results over the CAN protocol.

The Various Device's states are as follows

- Object (Vehicle) detection state for the IR communication:

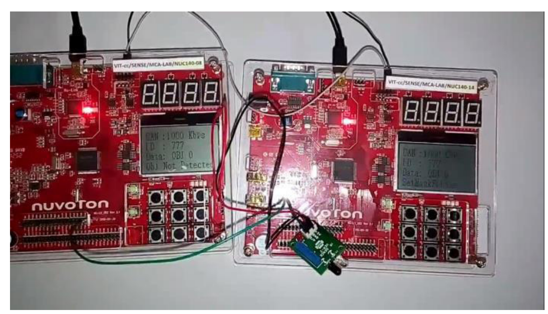


Figure 18. Representation of No Object (Vehicle) detection.

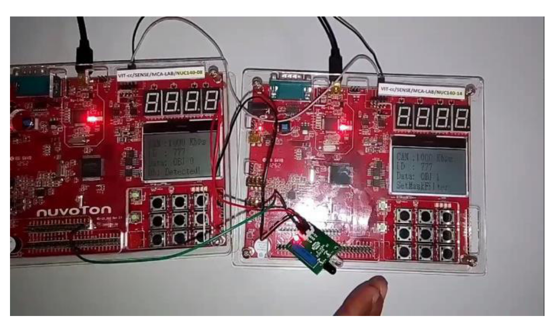


Figure 19. Representation of Object (Vehicle) detected.

The Device on detection of vehicles in range has to log the event and start the operation of devices. Figure 18 represents the no object detection with the display of message and no led and buzzer on while Figure 19 represents Object detection with displaying message, glowing LED and buzzing the buzzer thus alerting the driver. Thus control signal to transmit appropriate pulse width can be initiated according to conditions.

- Normal Level Braking state of the Vehicle
- Medium Level Braking state of the Vehicle
- Dangerous level braking state of the Vehicle

There are various error confinement state that a CAN node unit can go into depending on the various error that occur during CAN message transfer are as follows

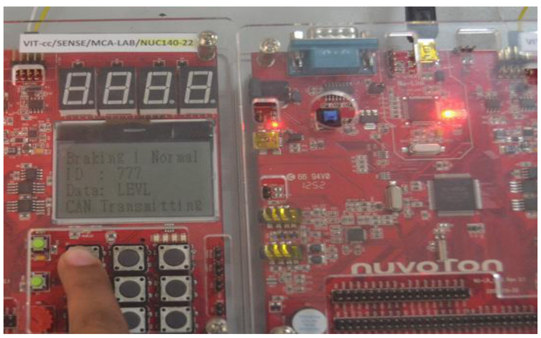


Figure 20. Diagnostic Message for Normal Braking.

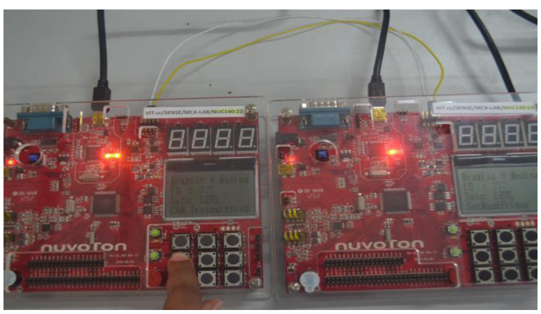


Figure 21. Diagnostic Message for Medium Braking.

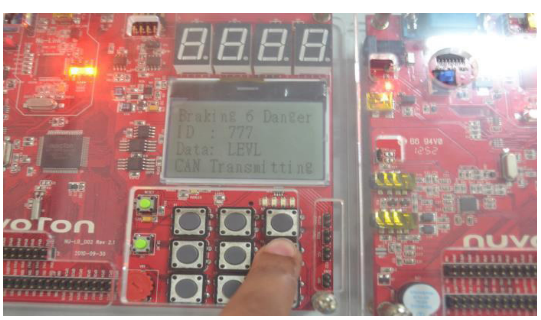


Figure 22. Diagnostic Message for Dangerous Braking along with buzzer ON.

- Error Passive mode

When the Transmit Error Counter and the Receive Error Counter exceed value 128, the node goes into Error Passive state depicting high level disturbance in the CAN node as depicted in the Figure 23.

- Error Active mode

When the Transmit Error Counter and the Receive Error Counter is within the value 128, the node is in Error Passive state depicting low level disturbance in the CAN node as depicted in the Figure 23. The node a still transmits and receives messages.

- Bus Off Error

When the Transmit Error Counter and the Receive Error Counter reaches the value 256, the node is pushed into Bus Off state. In this state the node cannot interact with the bus.

These error and states need to be logged as per the activity of the Bus and the controller. The snippet of the error log of the diagnostic system that will help the technician detect the issue with ease is as shown in Figure 26.

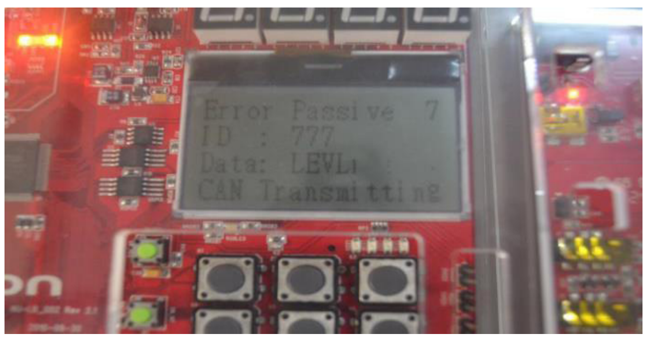


Figure 23. Diagnostic Error Message showing Error Passive state.

Figure 24. Diagnostic Error Message showing Error Active state.

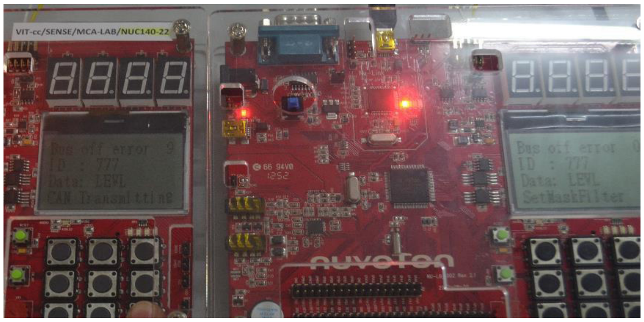
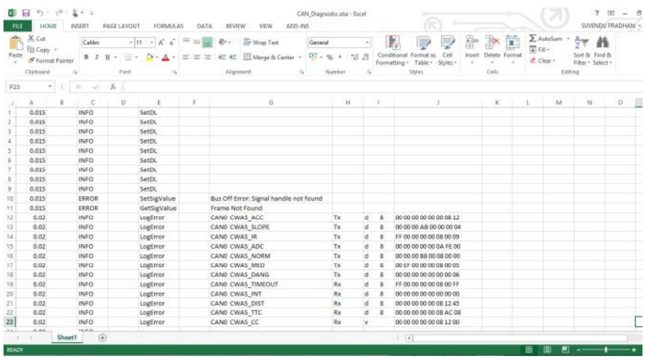


Figure 25. Diagnostic Error Message showing Bus Off Error state.



CAN_Diagnostic.xlsx - Excel

	A	B	C	D	E	F	G	H	I	J
1	0.015		INFO		SetDL					
2	0.015		INFO		SetDL					
3	0.015		INFO		SetDL					
4	0.015		INFO		SetDL					
5	0.015		INFO		SetDL					
6	0.015		INFO		SetDL					
7	0.015		INFO		SetDL					
8	0.015		INFO		SetDL					
9	0.015		INFO		SetDL					
10	0.015		ERROR		SetSigValue		Bus Off Error: Signal handle not found			
11	0.015		ERROR		GetSigValue		Frame Not Found			
12	0.02		INFO		LogError		CAN0 CWAS_ACC	Tx	d 8	00 00 00 00 00 00 08 12
13	0.02		INFO		LogError		CAN0 CWAS_SLOPE	Tx	d 8	00 00 00 AB 00 00 00 04
14	0.02		INFO		LogError		CAN0 CWAS_IR	Tx	d 8	FF 00 00 00 00 08 00 09
15	0.02		INFO		LogError		CAN0 CWAS_ADC	Tx	d 8	00 00 00 00 00 0A FE 00
16	0.02		INFO		LogError		CAN0 CWAS_NORM	Tx	d 8	00 00 00 B8 00 08 00 00
17	0.02		INFO		LogError		CAN0 CWAS_MED	Tx	d 8	00 EF 00 00 00 08 00 05
18	0.02		INFO		LogError		CAN0 CWAS_DANG	Tx	d 8	00 00 00 00 00 00 00 06
19	0.02		INFO		LogError		CAN0 CWAS_TIMEOUT	Rx	d 8	FF 00 00 00 00 08 00 FF
20	0.02		INFO		LogError		CAN0 CWAS_INT	Rx	d 8	00 00 00 00 00 00 00 00
21	0.02		INFO		LogError		CAN0 CWAS_DIST	Rx	d 8	00 00 00 00 00 08 12 45
22	0.02		INFO		LogError		CAN0 CWAS_TTC	Rx	d 8	00 00 00 00 00 08 AC 08
23	0.02		INFO		LogError		CAN0 CWAS_CC	Rx	v	00 00 00 00 00 08 12 00

Figure 26. Diagnostic Log sheet showing Buss of Error Log.

3. Conclusion and Future Scope

The proposed system uses an ARM Cortex M0 processor known for quick response time and effective and efficient control response. The system has advantages over the other available system in terms of response time and independency on external infrastructure. It is also cheap in terms of cost and reliable when tested in actual environment. The system does not intend to notify other running vehicles except the ones that are following it or is in the lambertian line of sight of the array of IR transmitter lined in the rear bumper. These following vehicles are the most probable cause of rear end collision. Hence IR was chosen over other radiation technologies like RF, ZigBee and Bluetooth for its straight line of sight capabilities. Omnidirectional broadcasting of message was found to be undesirable in rear end collision avoidance of vehicles.

The integration of system with the CAN network makes it possible to achieve robust control action to avoid a rear-end Collision along with its diagnostics. Advanced algorithms as steering the vehicle to change lane and advanced cruise control can be incorporated as the future features. An embedded Diagnostic system that can improve the Driver and passenger safety with its diagnostics and help its own service during repair time is proposed. It can be further sophisticated with autoregressive tests with on- road test conditions.

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