Fuzzy Logic based Integrated Control of Anti-lock Brake System and Collision Avoidance System using CAN for Electric Vehicles

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Abstract- **This paper investigates the integrated control of Anti-lock Brake System (ABS) and Collision Avoidance System (CAS) in electric vehicle. Fuzzy logic techniques are applied for integral control of two subsystems. Control algorithm is implemented and tested in a prototype electric vehicle in laboratory environment using freescale HCS12 microcontroller. A high level network protocol CAN is applied to integrate all sensors, ABS and CAS. The results show that integrated control of ABS and CAS maintains the safe distance from obstacle without sacrificing the performance of either system.**

I. INTRODUCTION

Recently, various electronic control techniques and control systems, such as anti-lock braking system, traction control system, and so on are being developed greatly and applied widely to improve the ride comfort, safety and operation stability in vehicle. Many theories and design methods for anti-lock braking systems have been proposed several literatures for decades. Researchers have considered a lot of control strategies and methods of anti-lock braking systems, which have been demonstrated effective for ABS system. Georg.F.Mauer proposed Fuzzy technique for ABS in 1995 [1] and David E Nelson has implemented fuzzy logic based ABS for electric vehicle [2]. Now computers are increasingly in driving-related tasks in some commercial vehicles. As evident from literature, collision warning and avoidance systems are currently of prime interest in present automotive research and development. Fuzzy techniques are proposed for CAS by Jose E. Naranjo, Carlos Gonzalez [3] and Chan yet Wong [4]. However, none of these papers investigated regarding simultaneous control of ABS and CAS. In this paper we make an attempt to control both ABS and CAS together and control logic is fuzzy logic based. Moreover, this is implemented in HCS12 microcontroller using CAN protocol and important results are brought out.

When there are more electrical control devices in the modern cars, such as power train management system, anti-lock braking system (ABS), and acceleration skid control (ASC) system, etc, the functionality and wiring of these electric control units are getting more complicated. Therefore, it is of great concern to upgrade the traditional wire harness to a smart car network. In 198Os, a Germany car component provider Robert Bosch Co. introduced an in-car network; the controller area network (CAN) bus, to replace the complex and expensive traditional in-car wiring. [4][5].

In this paper specific focus of research is integral control for ABS with Front end Collision Avoidance System (CAS) using fuzzy logic techniques and its implementation in HCS12 Microcontroller. Control system of vehicle is a complicated system; the performances of vehicle depend on relationship with other subsystems strongly. The study of the integrated control of these subsystems is very important to improve the performances and advance the control efficiency. To have proper synchronization in functioning of both modules, data transfer between the sub modules should be proper and reliable. In this study, a high-level protocol CAN is adopted to interconnect the subsystems for reliable communications among ABS, CAS and sensors.

II. ANTI-LOCK BRAKE SYSTEM

The reason for the development of antilock brakes is in essence very simple. Under braking, if one or more of a vehicle's wheels lock (begins to skid) then this has number of consequences: a) braking distance increases b) steering control is lost c) tire wear will be abnormal. The obvious consequence is that an accident is far more likely to occur. The application of brakes generates a force that impedes a vehicles motion by applying a force in the opposite direction. During severe braking scenarios, a point is obtained in which the tangential velocity of the tire surface and the velocity road surface are not the same. This term is referred to as slip ratio and is the ratio between the tangential velocity of the tire and the true ground speed of the vehicle and is expressed as:

$$\lambda = \frac{V_g - V_t}{V_g} \quad \longrightarrow \quad (1)$$

V_g is circumferential velocity of braked wheel and Vt is vehicle road speed. 0% is slip of free rolling wheel and 100% for locked wheel. The braking force or the adhesion coefficient of braking force (µf) measured in the direction the wheel is turning is function of slip. µf depends on a number

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of factors, and the main ones are: a) road surface material condition b) tire material, inflation pressure, tread depth, tread pattern and construction.

Figure 1 shows the relationship between the braking effort (μf) and the amount of slip. Graph is divided into two areas: stable and unstable. In the stable zone, balance exists between the braking effort applied and the adhesion of the road surface. Non-slip braking is possible. In unstable zone when the critical slip (l) is passed, no balance exists and the wheel will lock, unless the braking force is reduced. The value of critical slip can vary from 8% to 30% depending on road conditions. As the slip ratio increases, the adhesion, will peak and then decline. After the peak, the rotating tire can then lock up abruptly thus resulting in even less adhesion. Asphalt (wet or dry) has a peak braking efficiency at approximately 20% slip ratio. Derivation of a mathematical model for such a complex system would be a tedious task if not impossible due the nonlinear and nondeterministic characteristics of all of the involved components. Since fuzzy logic is ideally suited to handle non lineararities, a fuzzy system was chosen to control the ABS system. [3]

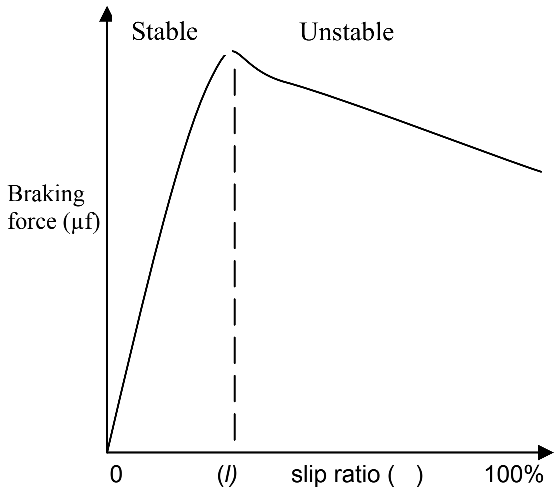

Fig 1: Relationship between braking force and slip

III. COLLISION AVOIDANCE SYSTEM

Driver errors cause a majority of all car accidents. Forward collision avoidance systems aim at avoiding, or at least mitigating, host vehicle frontal collisions, of which rear-end collisions are one of the most common. This is done by either warning the driver or braking or steering away, respectively, where each action requires its own considerations and design. We here focus on forward collision by braking; a brake maneuver is activated to mitigate the accident when the probability of collision is one.

We present a multisensor system for traffic monitoring and collision warning. The vehicle was equipped with obstacle sensors. Adaptive cruise control (ACC) has been implemented in the market these days where the ECU can maintain the distance between the car in front and the host car. Same ACC sensors can be used for forward collision avoidance system.

Traffic situations remain complex and difficult to manage, particularly in urban settings. The driving task belongs to a class of problems that depend on underlying systems for logical reasoning and dealing with uncertainty. So, to move vehicle computers beyond monitoring and into tasks related to environment perception or driving, we must integrate aspects of human intelligence and behaviors so that vehicles can manage driving actuators in a way similar to humans. Fuzzy logic controllers serve the purpose. Collision avoidance system (CAS) presented in this paper is based on a fuzzy estimation techniques. Measurements from sensors are used to estimate distance between vehicles. The estimated distance is then used to predict possibility of collision with the vehicle in the headway. [7] [8]

IV. INTEGRATED CONTROL OF ABS WITH CAS

The slip ratio is inferred from the comparison of the deceleration of all four wheels and sometimes also by comparison with an on-vehicle accelerometer. The road condition (coefficient of friction between tire and road) can be inferred by observing the slip ratio resulting from a given braking force. Wheel speed sensors are employed to detect the circumferential velocity of braked wheel and vehicle road speed. Slip ratio is calculated using equation (1). To determine the actual road conditions, reference values of slip ratio at different brake torques for different road conditions like wet, dry and ice are stored. Detected slip ratio and braking torque is compared with stored reference values. Slip ratio is not constant for different road surfaces such as dry, wet or icy asphalt. Based on brake force and slip ratio, type of road is detected. The table I consists of references to identify the road condition is given below, by comparison, type of road is detected. [1] [6]

TABLE I

Brake force(%)	Slip ratio(%)	Type of Road
10	20	Icy
20	50	Icy Wet
50	95	Wet
80	50	Wet-dry
90	20	Dry

The fuzzy system consisted of three inputs: brake force, obstacle distance and slip ratio and one output PWM factor, which is input signal to ABS driving circuit. Fuzzy operation basically includes three steps, fuzzification, rule evaluation, and defuzzification. The fuzzification operation converts the crisp input to fuzzy values. The microcontroller uses an instruction MEM to do fuzzification. After fuzzification we will get fuzzy output in RAM locations for each label. We have used instruction REV for rule evaluation, which is an unweighted rule evaluation scheme supported by the microcontroller. Last operation of the fuzzy engine is to generate a crisp output from the fuzzy output stored in its output RAM location. A singleton output membership function, which already stored in the ROM location of the microcontroller, is used by the WAV instruction to find the crisp output. The output duty cycle of PWM generated is controlled by output membership. Figures 3, 4, and 5 show the definitions, respectively. The fuzzy rule base used for the integrated control of ABS with CAS is: [2]

IF Obstacle IS Very Near AND Applied Brake force is high AND Slip Ratio is Unsafe THEN PWM is Minimum

IF Obstacle IS Very Near AND Applied Brake force is high AND Slip Ratio is Critical THEN PWM is Medium

IF Obstacle IS Very Near AND Applied Brake force is high AND Slip Ratio is Safe THEN PWM is Maximum.

IF Obstacle IS Near AND Applied Brake force is High AND Slip Ratio is Unsafe THEN PWM is Minimum

IF Obstacle IS Near AND Applied Brake force is High AND Slip Ratio is Critical THEN PWM is Medium

IF Obstacle IS Near AND Applied Brake force is High AND Slip Ratio is Safe THEN PWM is Maximum.

IF Obstacle IS Near AND Applied Brake force is Low AND Slip Ratio is Safe THEN PWM is Maximum.

IF Obstacle IS Near AND Applied Brake force is Low AND Slip Ratio is Critical THEN PWM is Medium

IF No Obstacle IS Near AND Applied Brake force is Low AND Slip Ratio is Safe THEN PWM is Maximum

IF No Obstacle IS Near AND Applied Brake force is High AND Slip Ratio is Critical THEN PWM is Medium

IF No Obstacle IS Near AND Applied Brake force is High AND Slip Ratio is Unsafe THEN PWM is Minimum

IF No Obstacle IS Near AND Applied Brake force is Low AND Slip Ratio is Unsafe THEN PWM is Minimum

IF No Obstacle IS Near AND Applied Brake force is Low AND Slip Ratio is Critical THEN PWM is Medium

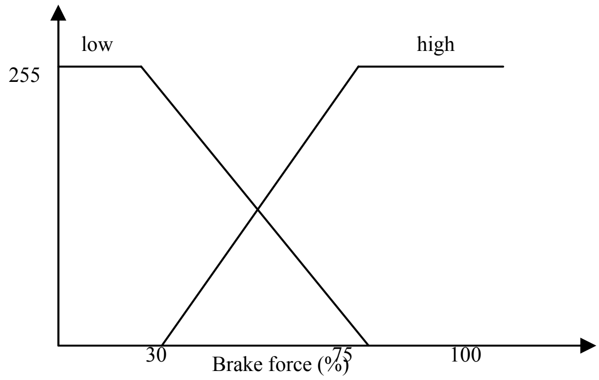

Fig 2: Applied brake force fuzzy set

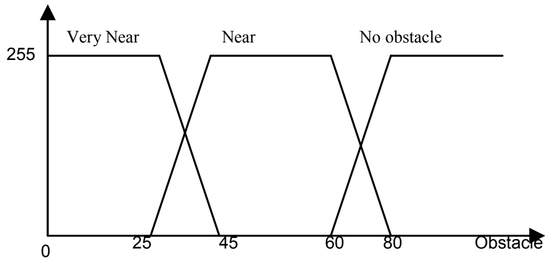

Fig 3: Obstacle fuzzy set

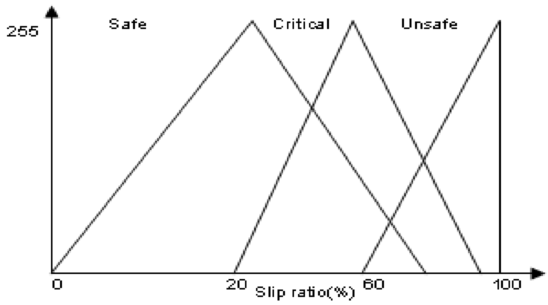

Fig 4: Slip Ratio fuzzy set

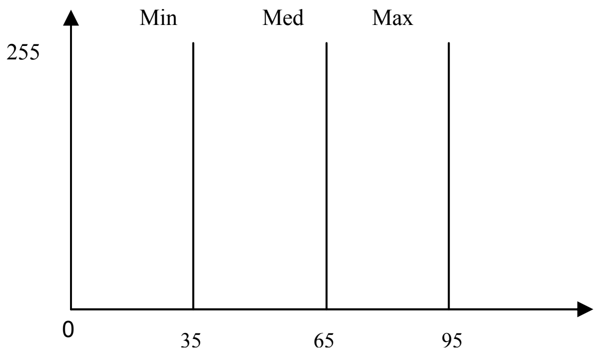

Fig 5: PWM fuzzy set

V. IN-CAR NETWORK ARCHITECTURE

With the automotive technology progress, the safety of driving is enhanced and the number of in-car electronics modules also greatly increases in modern high-class cars.

However, if all in-car devices (such as switch, actuator, sensors, etc) are still wired by traditional wiring harnesses, the weight of wiring becomes a dominant load. Also, the cost of electric components and systems takes 20% of the total cost and the percentage is still increasing. As there are more electronics in future cars, the wiring certainly becomes more complicated and linking the in-car devices by a high performance network is thus required. Controller Area Network (CAN) is highly suitable communication technique which satisfies the purpose. To integrate all the sensors and subsystems in this study, the proposed integrated control system for ABS and CAS is connected through the CAN bus and experimental setup is shown in figure 9. The CAN protocol is adopted because of its easy management of network monitor and error detection abilities. [7][8].

The controller is implemented using Freescale HCS12 microcontroller. The controller was initially chosen not only because of its ease of use, popularity, and configurability but also because freescale provides a fuzzy engine written in assembly for the HCS12 line of microcontrollers. This microcontroller also supports automotive industry standard communication protocol Controller Area Network (CAN), which is required to transfer the data between subsystems like ABS, CAS and ACC. Wheel speed sensors are inductance sensors and wheel speed is calculated by Electronic Control Unit (ECU) by sensing the frequency of signal generated by wheel speed sensors. The block diagram of the setup is shown in figure 6.

Two HCS12 microcontrollers are used, one acts like master, where integrated control algorithm will execute and other forms an interface for front end CAS sensors. Another HCS12 microcontroller will control the electric motor driving system of ABS. All the modules are connected with CAN protocol. CAS sensor controller will generate value according to input from sensor and send the message to ABS, which will act on brake module according to fuzzy control algorithm.

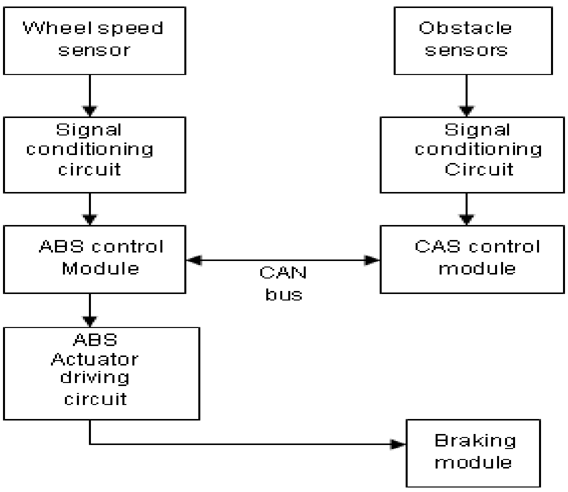

Fig 6: Block diagram of setup

VI. RESULTS

This section shows the Data Frames which got in the Logic Analyzer and verified. The message frames from CAS is transferred to ABS module through CAN bus. ABS module takes the decisions based on messages which it has received from CAS. CAS has to send three different messages: Very near is represented by $DF; near is represented $D2 and no Obstacle is $88. CAN frames of above frames are shown in figure 7 & 8.

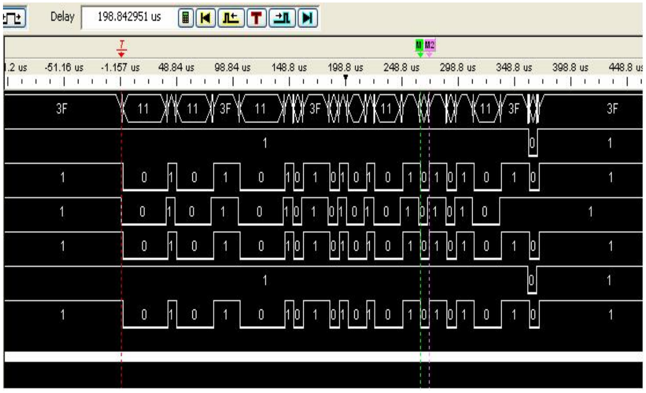

Fig 7: frame represents $DF

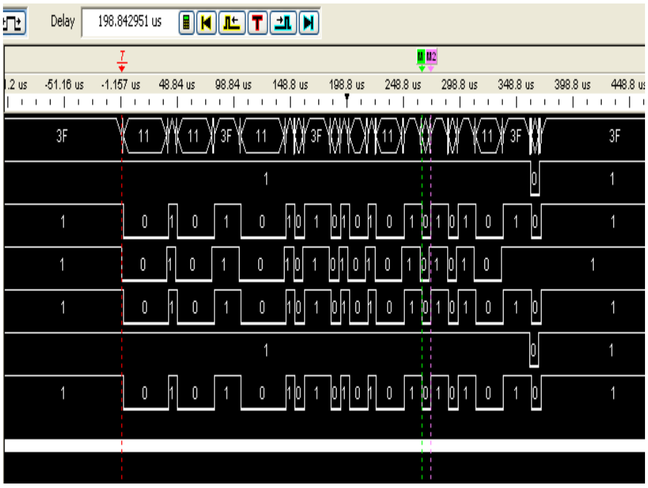

Fig 8: frame represents $DF

Figure 9 and figure 10 show the photographs of Electronic Control Unit and Prototype of Electric Vehicle. A smooth surface (tiled floor) was chosen as a test surface. And again comparatively rough surface was chosen (rough card board) to test the vehicle prototype. Stopping distances for ABS and performance of collision avoidance system is tested. We are unable to check the system for all road conditions in laboratory environment.

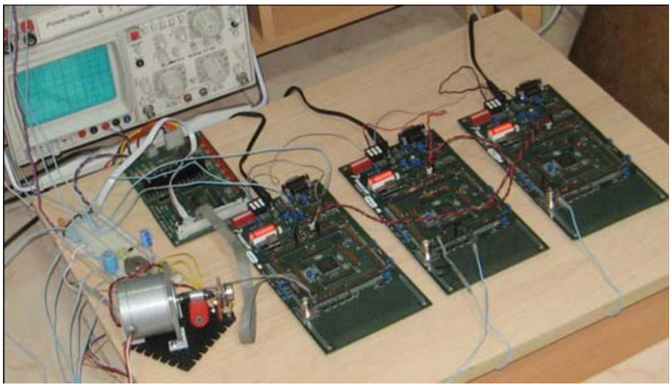

Fig 9: Electronic Control Unit setup

VII. Conclusions

Using a HCS12 microcontroller setup and a fuzzy engine written in assembly programming language, an integrated control for antilock braking system with collision avoidance system was successfully developed and tested on electric vehicle prototype in laboratory environment. The results clear indicate that fuzzy based integrated control of ABS and CAS maintains the safe distance from obstacle without sacrificing the performance of either system.

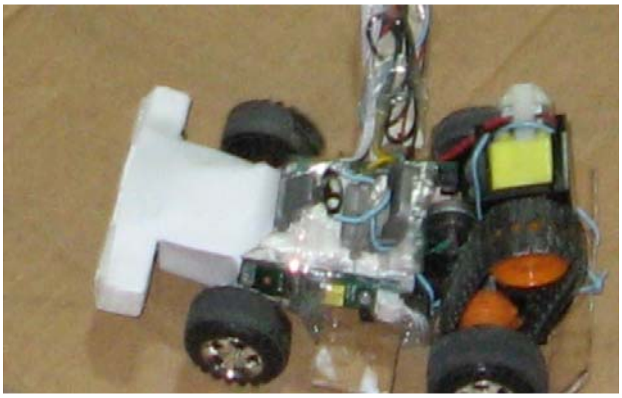

Fig 10: Prototype of Electric Vehicle

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