Chapter 7. Microcontroller Implementation Consideration

The overall performance of wheel slip control systems have been limited in the past primarily by the unavailability of low cost, flexible, high-speed electronic technology. The application of high speed digital microcontrollers in anti-lock brake systems allows increased computational capabilities and control performance. In this section, a Motorola 68HC11 microcontroller is evaluated for its suitability for the anti-lock brake control application. This family of microcontroller have been used in FLASH lab, Virginia Tech Center for Transportation Research for evaluation of the automatic highway system concepts and technologies (Kachroo, 1995). Due to the unavailability of the small-size electromagnetic brakes, we have not implemented the electromagnetic brakes and its control system on the small-scale vehicle in FLASH lab. But the digital control algorithm of the possible ABS system is evaluated and features of 68HC11 and alternative families of microcontrollers are evaluated to estimate their suitability for ABS application.

For regular friction brakes, modulated brake torque can be calculated and applied to every individual wheel because there is a possibility that different wheels are on different road surfaces. On the other hand, due to the location of electromagnetic brakes, its output torque must be applied to all four wheels in an overall base. The anti-lock brake system discussed in this section takes both situations into consideration.

7.1. Motorola 68HC11 Microcontroller (Motorola, 1991)

The high-density complementary metal-oxide semiconductor (HCMOS) 68HC11 is an advanced 8-bit microcontroller with sophisticated on-chip peripheral capabilities. The HCMOS technology combines smaller size and higher speeds with the lower power and high noise immunity of CMOS. There are plenty of peripheral functions provided on chip. There is an eight-channel analog-to-digital (A/D) converter included with eight bits of resolution. An asynchronous serial communications interface (SCI) and a synchronous serial peripheral interface (SPI) are also included. The 16-bit free-running timer system has three input-capture lines, five output-compare lines, and a real-time interrupt function. An 8-bit pulse accumulator subsystem can count external events and measure external periods. All these features allow interfacing to various sensors and actuators. Communication with other on-board computer systems, and additional wheel slip control functions (e.g. traction control) are also possible.

Two software-controlled power-saving modes, WAIT and STOP, are available to conserve additional power. These modes make the 68HC11 attractive for automotive application. A 68HC11 controlled small-scale vehicle was constructed in the FLASH lab, Virginia Tech Center for Transportation Research for evaluation of the automatic highway system concepts and technologies (Kachroo,1995).

7.2. Evaluation of the Motorola 68HC11 microcontroller designs for wheel slip feedback control systems

Many issues needed to be evaluated regarding the suitability and performance of the microcontroller in wheel slip feedback control system. Three major issues are:

1. I/O requirement
    - four wheel slip speed inputs (sensor inputs)
    - multiple solenoid driver/outputs
    - additional digital I/O ports for expandability
    - serial communication for diagnostics
    - watchdog timer
2. CPU and instruction set flexibility
    - Real time computational capability
    - amount of available RAM
    - high level instruction set for shorter software develop time
3. Expandability and adaptability to other wheel slip control applications such as traction control.

7.2.1. I/O requirement

The Motorola 68HC11A8 has only three input-capture lines, so it requires extra additional hardware to handle four wheel speed sensors. Among the 68HC11 family of microcontrollers, the 68HC11E9 uses pin PA3 as either output or input. By configuring the PA3 as an input capture pin, it fulfills the requirement of 4 input-capture lines. The sensors on the wheels generate an analog signal the frequency of which is proportional to the equivalent wheel transitional speed (Spasov, 1993). The input capture function is able to measure the frequency by recording the times when falling edges or rising edges occur. The software then calculates the period by calculating time difference between two consecutive edges. Based on this information, software can determine the actual wheel speed.

Vehicle speed can be measured by different methods in ABS system today. One approach is to make use of the Doppler principle. Another approach is to use the propeller shaft sensor that senses the mean rotational speed of rear and front wheels (this method does not work when the wheel is locked). The use of magnetic markers for vehicle speed detection is also a feasible method. None of these ABS methods of measuring the vehicle speed is perfect; an analytical observer may provide a better system performance and act as a backup system during sensor failure (e.g. the failure of the magnetic marker system) (Unsal, 1996).

Altogether the 68HC11 can have 40 output pins which can be used to drive the solenoids or other possible driver/switch units. It should be able to handle the requirements of the application. Manual control of the elctromagnetic brakes would need only four solenoids to increase the braking power in 4 consecutive stages (see Chapter 2). New control switches, solenoid contactors and more groups of coil circuits can be designed to fulfill a much more precise control of brake power.

For the future I/O expansion, the 68HC11 has enough output ports for extra application demand, but not enough input ports. That would require a dual processor or off-chip circuitry. But additional circuitry would add hardware complexity and degrade the calculation resolution by introducing interference. Usually in automobile applications, multiple processors are used. Every processor controls a different system, such as ABS, instrument panel and engine control. Different controllers can communicate with one another using communication ports. The 68HC11 has a double buffer serial communication interface (SCI) which can be configured to select the baud rate of the communication, communication word length, enable/disable interrupts, transmit, and receive as required. Both SCI and SPI (synchronous serial input/output) can be used for diagnostics and monitoring purposes.

The 68HC11 has watchdog timer system which is intended to detect software processing errors by keeping a free-running watchdog timer from timing out. If the watchdog timer times out, it is an indication that the software is no longer being executed in the intended sequence. Caution would be given and appropriate action could be activated, such as to initiate a system reset or activating backup units.

7.2.2. CPU and instruction set flexibility

The digital algorithm design is limited in control ability by the architecture and instruction set of the microcontroller used. In this section, we consider the suitability of the architecture and instruction set of Motorola 68HC11.

The fastest rate of system clock of the 68HC11 family is 2MHz. A programmable prescaler allows the user to select one of four clock rates. The default fastest rate is 500 ns per cycle. For the system simulated in Chapter 5 which has satisfactory performance, the time between every integration step is 1 ms. That means that we can have 2000 clock cycles between every time step to fulfill the computational requirement. The calculation requirements for the controlled brake torque calculation are listed in Table 7.1.:

Table 7.1. Computational Requirement for controlled brake torque calculation.

Memory/operations Requirements	Numbers of using memory/operation	Maximum Clock Cycles every operation
Variables/Parameters	17	N/A
Addition/Subtraction	35	7
Production	50	10
Division	14	41
Square Root	2	10

Absolute Value	2	3
Sign function	1	3
Comparison (if-else loop)	1	3

The maximum clock cycles needed to fulfill the control torque calculation (see Appendix line 35-57) is:
$(35\times 7)+(50\times 10)+(14\times 41)+(2\times 10)+(2\times 3)+(1\times 3)+(1\times 3)=1351$ clock cycles. So the 68HC11 has sufficient real-time computational capability for our application. On the other hand, it does not leave enough capability for us to implement analytical observers (state estimators) that may improve the system performance by giving more precise vehicle velocity and wheel slip values (Unsal, 1996). So it is recommended that the possible observer implementation be done on a separate microcontroller and the results be sent to the brake torque calculation microcontroller for further calculation.

There are 256 bytes of RAM and 512 bytes of EEPROM available on the 68HC11. This should be sufficient for the application. If not, off-board RAM with an address/data decoder can be used. But the off-board RAM will result in longer access time and complex hardware.

Software design and development time for the Motorola 68HC11 is regarded as short, due to its popularity in the automobile industry and its efficient instruction set and I/O architecture.

7.2.3. Expandability and adaptability to other wheel slip control applications

The possible expansion of the system for other applications such as traction control is considered here. One possible bottleneck is the limited number of input ports available. Dual processor or off-chip circuitry solutions could degrade the calculation accuracy of the system and make it less cost-effective. So it is recommended that the amount of inter-processor communication should be kept as less as possible. Algorithms of different modules could be designed to work as independently as possible.

7.3. Algorithm Design Consideration

This section outlines the software algorithm issues associated with the control loop of the system. The flow diagram is shown in Figure 7.1. The description of the major modules are as follows:

RESET: After power-up or initialization by the watchdog timer system, the RAM is cleared, the stack pointer is initialized, and the I/O ports and registers are configured by setting/resetting relevant bits. The internal watchdog timer is initiated, and interrupts are enabled.

START: Various wheel slip control software modules and subroutines are initialized, control flags are reset, and addresses and parameters are configured.

FAILSAFE: This module detects system failure and initiates a system shutdown and driver warning mechanism.

MODE SELECT: This module determines if anti-lock action should be allowed based on the failure status and/or low vehicle speed cut-off considerations. The module should have vehicle velocity, wheel speed and system failure status as inputs.

ANTI-LOCK MODE OFF: This module should shut down the modulator dependent on system failure status (system failure mode or normal system condition).

ANTI-LOCK MODE ON: This module activates the anti-lock brake system. For regular brakes, the module should treat each wheel sequentially, while this is not necessary for electromagnetic brakes. Three major subroutines should be included in this critical module:

1. Wheel speed and deceleration calculation

The sensors on the wheels generate an analog signal with frequency proportional to the wheel rotational speed. The input capture ports on the microprocessor can capture the value of the free-running timer on every transition of the sensor signal pulse. In that way, wheel speed can be obtained. By combining both past and present speed values, the wheel deceleration can be calculated.

2. Control output calculation

In this subroutine, wheel characteristics obtained from the above subroutine are used to calculate the appropriate control command to adjust the brake pressure modulator (for regular friction brakes) and exciting current modulator (for electromagnetic brakes).

3. Action on modulator

The calculated results are used in this module to activate the pressure modulator solenoid valves. The output commands of the valves for regular friction brakes can be as follows:

- “Off”: the vehicle and the wheels are not in anti-lock brake mode
- “Hold”: the pressure is neither increasing nor decreasing
- “Decay”: the pressure is decreasing
- “Build”: the pressure is increasing

The output commands of the solenoids for electromagnetic brakes can be as follows:

- "Off": the vehicle and the wheels are not in anti-lock brake mode
- "Turn on": the solenoid connector controlling a specific group of exciting coils turns on to increase the braking torque (power)
- "Turn off": the solenoid connector controlling a specific group of exciting coils turns off to decrease the braking torque (power)

VEHICLE CALCULATION: If the vehicle speed is detected by sensor technologies (e.g. Doppler effect devices or magnetic markers), this module can be simplified. Otherwise, the vehicle velocity is calculated from the four wheel speeds. If the vehicle is in acceleration, the lowest of all wheel speeds is used for calculating the vehicle velocity. If the vehicle is in deceleration or if the anti-lock brake system is activated, then the highest of all wheel speeds is used for the vehicle velocity calculation. This variable is referred to as vehicle "raw" speed. The actual speed can be calculated by combining the "raw" speed and knowledge of speed at the previous scan time (Kalman filter can be used as an estimator here). The vehicle deceleration is calculated based on the slope of the vehicle speed. The above information is then used to determine overall wheel slip and road friction coefficient.

STORAGE: At the end of the loop, various parameters like wheel speeds, acceleration or deceleration of the wheels, vehicle velocity, etc; are stored in RAM for future reference.

7.4 Alternative microcontrollers

There is a wide variety of microcontrollers available on the market, ranging from 8-bit to 16-bit CPU's, and an assortment of on-board peripherals with differing architectures and instruction sets. In this section, Motorola 68HC12 (16-bit CPU processor) and MCS 296 (16-bit CPU processor) are compared with 68HC11 to show alternative (and better) candidate for ABS system (see comparison chart on Table 7.1).

MCS 296 can be operated in 50mhz which gives much higher performance than 68HC11. MCS 296 is an ideal candidate for real time feedback control application based on its pipelined architecture and 40-bit accumulator. There are 512 bytes register Ram which make fast data manipulation possible and save a great deal of time. The MCS 296 is complemented by a complete set of hradware and software developed by third party development tool vendors. Compared with 68HC11, MCS 296 has better processing speed, better high-speed I/O subsystem and more I/O driver pins.

The Motorola 68HC12 is migrated from 68HC11 and all 68HC11 codes are compatible on 68HC12 processors. The 68HC12 adds features like on-board Flash EEPROM, 64 new instructions, 20-bit ALU, instruction queue, larger program and data space on the ALU, faster math capabilities to support real-time requirement. Another feature of the 68HC12 is that it supports the modular design methodology, enabling the CPU to connect to existing, proven Motorola peripheral modules.

All these new generations of 16-bit microcontrollers have better performance over Motorola 68HC11 because of their real-time processing speed capability, larger memory space and better I/O subsystem.

Table 7.1. Comparison chart for different microcontrollers.

Considerations	MCS 296 (Intel)	68HC11 (Motorola)	68HC12 (Motorola)
Multiple solenoid drivers	48	40	40
Watchdog timer	Available	Available	Available
Powerdown RAM, EEPROM	Powerdown RAM OTPROM	EEPROM Powerdown RAM	Powerdown RAM EEPROM/FLASH

			EEPROM
Serial Communication	Available	Available	Available
Real-time computational capability	Very high (40 bit accumulator) (232 registers)	High (16 bit accumulator)	Very high (20 bit accumulator)
CPU architecture for real-time I/O	Very high (specific high-speed I/O subsystem)	High	Very High
Available RAM	2K	256	1-4K
EEPROM/OTPROM	Available	Not Available	Available (Flash EEPROM)
System clock rate	50MHz	2MHz	8MHz
Software design and development	Available	Available	Available

For serial communication networks in vehicles, the controller area network, or CAN, protocol is usually used. The CAN specification addresses the lowest two layers of the ISO's Open Systems Interconnect (OSI) Reference model for communication protocals, the data link layer and the physical layer. Motorola HC05 chips are used to support the CAN devices (such as built-in CANBus Interface). That makes HC05 a candidate for our application for its compatiability with the CAN bus devices.

7.5. Summary and Conclusions

The software structure and algorithms for wheel slip control system design are described in this chapter. Motorola 68HC11 microcontroller is evaluated to be sufficient for this application based on its architecture, instruction set, available on-board RAM, I/O pins, watchdog timer, communication and A/D conversion capabilities. New families of 16-bit microcontroller such as Motorola 68HC12 and MCS 296 could be a better candidate for ABS system because they have better speed and accuracy performance.

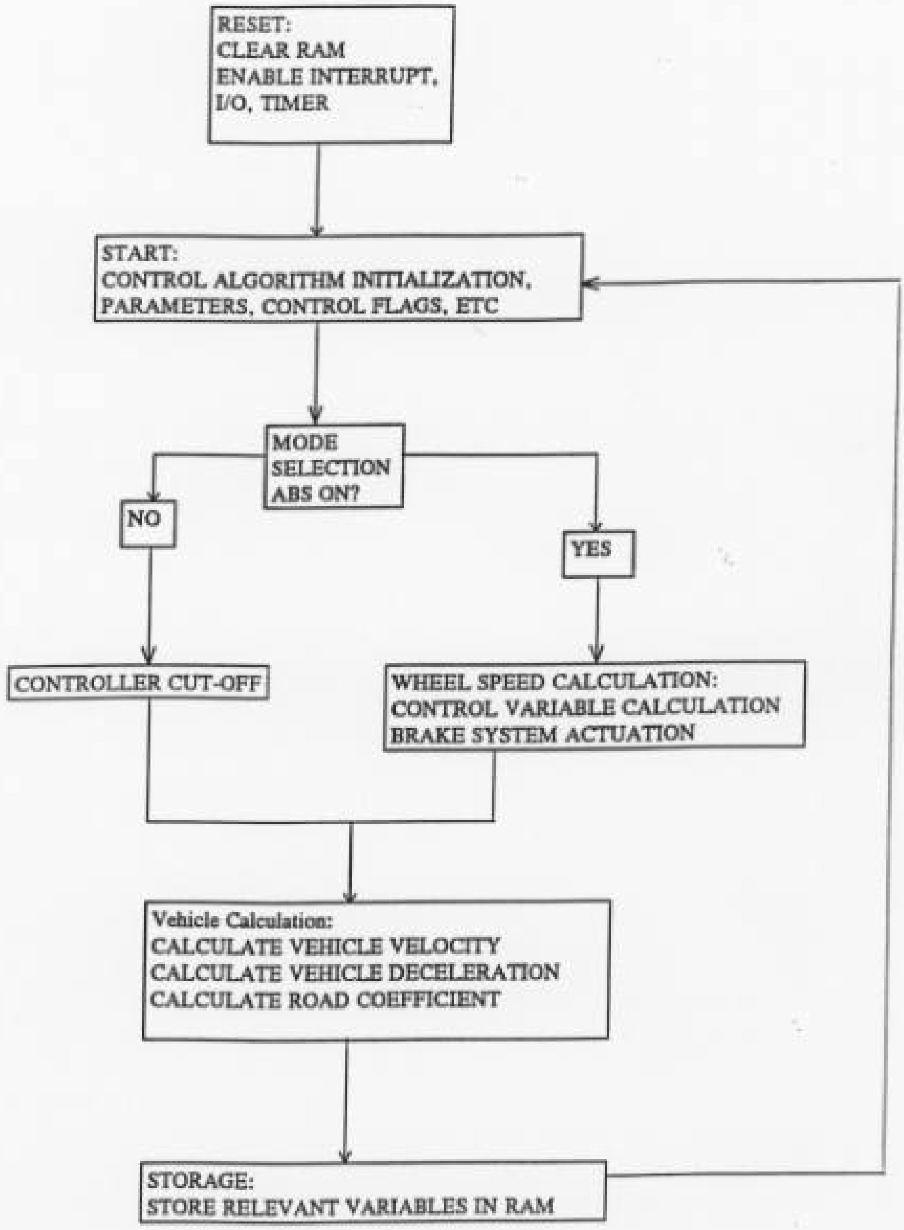

Figure 7.1. Flow Diagram of the Sofytware Structure for ABS System