

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
14 March 2002 (14.03.2002)

PCT

(10) International Publication Number  
WO 02/20319 A1

(51) International Patent Classification<sup>7</sup>: B60T 8/00,  
B60G 17/015

Drive, Ann Arbor, MI 48105 (US). **DOLL, Kenneth, A.** [US/US]; 2464 Cliffside Court, Ann Arbor, MI 48103 (US). **KEEN, Steven, Dale** [US/DE]; Emser Landstrasse 17D, 56112 Lahnstein (DE).

(21) International Application Number: PCT/US01/28201

(22) International Filing Date:  
7 September 2001 (07.09.2001)

(74) Agent: **MOLNAR, John, B.**; MacMillan, Sobanski & Todd, LLC, One Maritime Plaza, Fourth floor, 720 Water Street, Toledo, OH 43604 (US).

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
09/659,028 9 September 2000 (09.09.2000) US

(81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(71) Applicant (for all designated States except US): **KELSEY-HAYES COMPANY** [US/US]; 12000 Tech Center Drive, Livonia, MI 48150 (US).

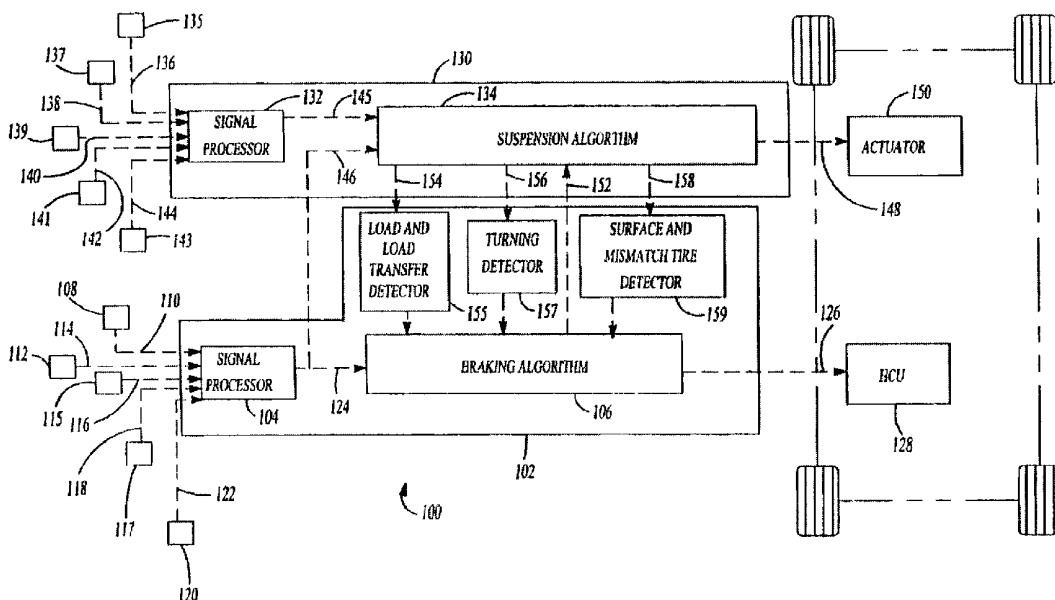
(84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF,

(72) Inventors; and

(75) Inventors/Applicants (for US only): **BARRON, Richard, J.** [GB/US]; 3407 Cromwell Court, Ann Arbor, MI 48105 (US). **MILOT, Danny, R.** [US/US]; 2366 Hickory Point

[Continued on next page]

(54) Title: ROUGH ROAD DETECTION USING SUSPENSION SYSTEM INFORMATION



(57) Abstract: Direct sensing of rough road conditions are used to modify operation of a wheel slip control system. At least one suspension sensor (139) senses an operating parameter of the suspension system. A road surface classifier is responsive to the suspension sensor (139) for generating a road surface signal representing a roughness of a road surface over which the vehicle travels. A braking system includes a wheel speed sensor and a brake actuator. An active braking control detector wheel slip in response to the wheel speed sensor (108) during at least one of braking or accelerating of the vehicle and modulates the brake actuator in response to the detected wheel slip. The active braking control is responsive to the road surface signal for modifying modulation of the brake actuator as a function of the road surface signal.

WO 02/20319 A1



CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

**Published:**

- *with international search report*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

## ROUGH ROAD DETECTION USING SUSPENSION SYSTEM INFORMATION

### BACKGROUND OF THE INVENTION

5           This invention relates in general to active vehicular braking and suspension systems. In particular, this invention is concerned with detection of rough road conditions using suspension information and then adjusting active braking control for improved performance for the current road surface conditions.

          Electronically-controlled active vehicular braking systems can include anti-  
10 lock braking (ABS), traction control (TC), and yaw stability control (YSC) functions. In such braking systems, sensors deliver input signals to an electronic control unit (ECU). The ECU sends output signals to electrically activated devices to apply, hold, and dump (relieve) pressure at wheel brakes of a vehicle. Electrically activated valves and pumps are used to control fluid pressure at the  
15 wheel brakes. Such valves and pumps can be mounted in a hydraulic control unit (HCU). The valves typically include two-state (on/off or off/on) solenoid valves and proportional valves.

          A basic function of active braking systems is to detect wheel slip (e.g., skidding or loss of traction) and actuate the brakes (or reduce torque from the  
20 engine) in a manner to reduce or control wheel slip. An individual wheel speed is measured and wheel slip is detected by comparing the individual wheel speed to a target speed determined for that wheel. Various control parameters of the active braking system are chosen to provide satisfactory performance over all conditions that are encountered during operation. For example, activation of the active control  
25 (e.g., abs or TC) to being to control slip does not occur until the difference between

actual wheel speed and target wheel speed exceeds a slip threshold. A base threshold is chosen that achieves best overall performance for all conditions.

Certain assumptions or tradeoffs are made in selecting a base threshold. For example, the flatness or roughness of the road surface influences the amount of slip that will achieve the highest overall vehicle acceleration or deceleration. Thus, to  
5 achieve a shortest stopping distance, there is an optimum slip threshold. Since characterization of road surface condition is not available to prior art systems, the base threshold is chosen for achieving best overall stopping distances.

It is known to dynamically vary this slip threshold in response to certain  
10 characteristics of the wheel speed signals (e.g., acceleration changes) to either increase or decrease the amount of slip that is controlled. For example, wheel speed signals have been analyzed in attempts to detect wheel hop, but this has not led to accurate road surface classification.

Electronically-controlled suspension systems typically include semi-active  
15 suspension systems and active suspension systems to provide active damping for a vehicle. In such suspension systems, sensors deliver input signals to an electronic control unit (ECU). The ECU sends output signals to electrically activated devices to control the damping rate of the vehicle. Such devices include actuators to control fluid flow and pressure. The actuators typically include electrically activated valves  
20 such as two-state digital valves and proportional valves.

## SUMMARY OF THE INVENTION

This invention employs information from a suspension sensor to classify a  
25 road surface condition (i.e., a rough road index) and modifies activation of an active

braking control system in response thereto, achieving advantages in the performance of slip control.

In one aspect of the invention, an apparatus for a vehicle comprises a suspension system for connecting a vehicle body and vehicle wheels. The suspension system includes at least one suspension sensor for sensing an operating parameter of the suspension system and at least one suspension actuator for modifying a performance characteristic of the suspension system. An active suspension control controls the performance characteristic in response to the suspension sensor. A road surface classifier is responsive to the suspension sensor for generating a road surface signal representing a roughness of a road surface over which the vehicle travels. A braking system includes a wheel speed sensor and a brake actuator. An active braking control is coupled to the braking system and the road surface classifier for detecting wheel slip in response to the wheel speed sensor during at least one of braking or accelerating of the vehicle. The active braking control modulates actuation of the brake actuator in response to the detected wheel slip and is responsive to the road surface signal for modifying modulation of the brake actuator as a function of the road surface signal.

Various objects and advantages of this invention will become apparent to those skilled in the art from the following detailed description of the preferred embodiment, when read in light of the accompanying drawings.

### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram of a first embodiment of an integrated vehicular control system according to the present invention illustrating input signals

delivered to electronic control units, transfer of signals between the electronic control units, and output signals delivered from the electronic control units to electrically activated braking and suspension devices.

Figure 2 is a schematic diagram of a second embodiment of an integrated vehicular control system according to the present invention for controlling braking and suspension devices wherein an anti-lock braking/traction control algorithm and a vehicular stability control algorithm are provided.

Figure 3 is a schematic diagram of a third embodiment of an integrated vehicular control system according to the present invention for controlling braking and suspension devices wherein a single electronic control unit is utilized.

Figure 4 is

#### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

A first embodiment of a vehicular control system according to the present invention is indicated generally at 100 in Fig. 1. The control system 100 is particularly adapted to control fluid pressure in an electronically-controlled vehicular braking system and an electronically-controlled vehicular suspension system. The braking system can include anti-lock braking, traction control, and yaw stability control functions. The suspension system can include active damping functions.

The control system 100 includes a first electronic control unit (ECU) 102. The first ECU 102 includes a signal processor 104 and a braking algorithm 106. Various sensors 108 strategically placed in a vehicle deliver input signals 110 to the signal processor 104. Specifically, a lateral acceleration sensor 112 delivers an

input signal 114 to the signal processor 104. A longitudinal acceleration sensor 115 delivers an input signal 116 to the signal processor 104. A steering wheel sensor 117 delivers an input signal 118 to the signal processor 104. A yaw rate sensor 120 delivers an input signal 122 to the signal processor 104. Depending upon the  
5 braking functions of the braking system, some of the above-listed sensors and their associated input signals may be deleted and others may be added. For example, a braking system that provides only ABS and TC functions may not require some of the above-listed sensors.

The signal processor 104 delivers transfer signals 124 to the braking  
10 algorithm 106. The braking algorithm 106 delivers output signals 126 to a hydraulic control unit (HCU) 128. The HCU 128 can include electromechanical components such as digital and/or proportional valves and pumps (not illustrated). The HCU 128 is hydraulically connected to wheel brakes and a source of brake fluid, neither of which is illustrated.

15 The control system 100 also includes a second ECU 130. The second ECU 130 includes a signal processor 132 and a suspension algorithm 134. Various sensors 135 strategically placed in a vehicle deliver input signals 136 to the signal processor 132. Specifically, a suspension state sensor 137 delivers an input signal 138 to the signal processor 132. A suspension displacement sensor 139 delivers an  
20 input signal 140 to the signal processor 132. A relative velocity sensor 141 delivers an input signal 142 to the signal processor 132. An upsprung mass acceleration sensor 143 delivers an input signal 144 to the signal processor 132. Depending upon the performance requirements of suspension system, some of the above-listed sensors may be deleted and others may be included.

The second signal processor 132 delivers transfer signals 145 to the suspension algorithm 134. The first signal processor 104 delivers transfer signals 146 to the suspension algorithm 134. The suspension algorithm 134 delivers output signals 148 to suspension actuators 150, only one of which is illustrated. The actuators 150 are electrically controlled devices such as dampers that vary and control a damping rate of a vehicle. An actuator 150 can include electromechanical components such as digital and proportional valves.

Information from the vehicular braking system can be shared with the vehicular suspension system. For example, ECU 102 can direct information to ECU 130. One example of transferred information from the braking system to the suspension system is the transfer signal 146 from signal processor 104 to suspension algorithm 134. A second example of transferred information from the braking system to the suspension system is indicated by transfer signal 152, wherein information from the braking algorithm 106 is directed to the suspension algorithm 134.

Information from the suspension system can also be shared with the braking system. For example, ECU 130 can direct information to ECU 102. One example of transferred information from the suspension system to the braking system is a transfer signal 154 to a load and load transfer detector 155. Another example is a transfer signal 156 to a turning detector 157. Yet another example is a transfer signal 158 for surface and mismatch tire detector 159.

The control system 100 can be configured in various manners to share information from ECU 102 to ECU 130, and vice versa. In one example, an ECU 102 for the braking system that receives inputs signals 114, 116, 118 and 122, for lateral acceleration, longitudinal acceleration, steering wheel angle, and yaw rate,



respectively, can transfer these input signals to ECU 130 for the suspension system. The signal processor 104 of ECU 102 can send transfer signal 146 to the suspension algorithm 134.

In another example, if lateral acceleration and steering wheel angle signals 114 and 122 are not available to the braking system, a turning detector signal can be generated by ECU 130 and transmitted to ECU 102 to improve braking performance. If an electronically controlled suspension system is integrated with an electronically controlled ABS/TC braking system, turning of the vehicle can be detected by the suspension system, thereby generating a turning detector signal that is transmitted to a braking system that does not receive signals from lateral acceleration and steering wheel angle sensors. A turn detection signal to the braking system via ECU 102 can enhance braking performance, particularly during braking-in-turn and accelerating-in-turn.

A second embodiment of a control system for controlling vehicular braking and suspension functions is indicated generally at 200 in Fig. 2. Elements of control system 200 that are similar to elements of control system 100 are labeled with like reference numerals in the 200 series.

Control system 200 also includes an ABS/TC algorithm 206A and a YSC algorithm 206B in place of the braking algorithm 106 of control system 100. Signal processors 204 and 232 may be placed separately from their respective algorithms 206A, 206B, and 230, or they may be located in common ECU's (not illustrated in Fig. 2). Transfer signal 270 between ABS/TC algorithm 206A and VSC algorithm 206B is provided. Transfer signal 272 for load and load transfer is provided to the VSC algorithm 206B. Transfer signal 273 from the signal processor 204 is provided to the VSC algorithm 206B. Transfer signal 274 for the surface and mismatch tire

detector is provided to the YSC algorithm 206B. Transfer signal 275 is provided from the YSC algorithm 206B to the suspension algorithm 234. Output signal 276 is sent from the YSC algorithm 206B to the HCU 228.

Various calculations can be made for the suspension system. For example, relative velocity can be calculated from suspension displacement if it is not directly measured. A vehicle load and load transfer signal 154, 254 can also be calculated or enhanced from a lateral acceleration signal 114, a longitudinal acceleration signal 118, and a steering wheel angle signal 122 when these are available.

A load and load transfer signal 154, 254 is used by the braking algorithms to enhance braking torque proportioning and apply and dump pulse calculations.

A turning detector signal 156, 256 (roll moment distribution) can be used to optimize vehicle handling before YSC activation and enhance brake torque distribution calculation during YSC activation.

A road surface roughness and tire mismatching signal 158, 258 can be detected from suspension states and used by ABS/TC and YSC systems.

Braking/traction status information from the wheels can also be used to enhance braking algorithms by predicting pitch and roll motion in advance.

Suspension algorithms and braking algorithms can be embodied in separate ECU's 102 and 130 as illustrated in Fig. 1. In other embodiments, the suspension and braking algorithms can be integrated into a single electronic control unit.

If steering wheel angle signal 122, 222 and/or a lateral acceleration signal 114, 214 are available, then split mu detection in ABS and TC algorithms (for stand alone ABS and TC systems) can be improved.

In other examples, ECU 102 can only receive information from ECU 130. Thus, various input signals from the suspension system can be transferred to the braking system, but no signals are transferred from the braking system to the suspension system.

5 In yet other examples, ECU 130 can only receive information from ECU 102. Thus, various input signals from the braking system can be transferred to the suspension system, but no signals are transferred from the suspension system to the braking system.

A third embodiment of a control system for controlling vehicular braking and suspension functions is indicated generally at 300 in Fig 3. In control system 300, a  
10 single ECU 302 receives inputs signals 304 from various sensors 306 strategically placed in a vehicle. A signal processor 308 may be incorporated in the ECU 302 that delivers transfer signals 310 to an algorithm 312. The algorithm 312 delivers output signals 314 to a HCU 328 to provide a desired brake response. The  
15 algorithm 312 also delivers output signals 316 to actuators 350 to provide a desired suspension response. Control system 300 may be referred to as a totally integrated system for controlling vehicular braking and suspension.

The present invention employs a rough road index as a classification of the road surface for the purpose of enhancing ABS, TC and YSC functions. The  
20 generation of the rough road index will be described with reference to Figure 4. The intent of the rough road identification algorithm is to create a signal indicative of a rough surface terrain from suspension travel information. The signal is then used in ABS/TCS/YSC to modify activation thresholds and control targets.

The method of Figure 4 uses a relative suspension travel signal  $X_d$  from a  
25 suspension sensor 400. The relative travel is differentiated in derivative block 401

to give a relative velocity signal which is then filtered in a bandpass filter (BPF) 402. The direct detection of wheel hop is employed to classify the road surface in terms of roughness. In general, wheel hop frequency caused by rough road conditions is approximately 10 Hz. Thus, BPF 402 has a passband of about 10 Hz to 15 Hz to determine the amount of surface roughness being transmitted through the suspension. A 4<sup>th</sup> order Butterworth bandpass filter design can be used as follows:

$$G(s) = \frac{b_2 s^2}{s^4 + a_1 s^3 + a_2 s^2 + a_3 s + a_4}$$

10

$$b_2 = 1421$$

$$a_1 = 53.31$$

$$a_2 = 6415$$

$$a_3 = 1.331 \times 10^5$$

15

$$a_4 = 6.235 \times 10^6$$

The output of the bandpass filter represents the signal content of interest that is used to define the roughness of the road. If an active damping system is being used to control the relative wheel and body velocity, then the signal content in the wheel hop frequency range will be attenuated as measured through the relative suspension deflection, however, the road information is not removed by the damping change. Therefore, a gain 403 is inserted to change the signal content as a function of damping. The nominal value for the gain is one.

In block 404, the absolute value of the signal is taken to give a more energy-oriented parameter. The signal is then saturated in saturation block 405 to keep the

25

peak detection from artificially being pulled too high and then taking several seconds to decay. A peak detector 406 implements a peak detection algorithm to capture the peak of  $|\dot{x}_d|$  and to decay the index between peaks. Peak detector 406 generates the rough road index as an indication of the magnitude of the roughness of the road surface. The decay rate must be designed in accordance with the bandpass frequency. It is desired to exponentially decay (i.e.,  $e^{-t/\tau}$ ) between peaks.  $\lambda^k$  is the discrete implementation of  $e^{-t/\tau}$ , therefore, one must choose  $\lambda$  such that the desired decay rate ( $\tau$ ) is achieved. The following is a formulation for computing the appropriate  $\lambda$ :

10

Let  $f_{\text{avg}}$  = average frequency of the bandpass filter

$$\tau = 1/f_{\text{avg}}$$

15

$$\lambda^k = e^{-t/\tau}, \text{ at } t = \tau \Rightarrow k = \tau/T_s$$

$$\lambda^k = e^{-1}$$

20

$$k \ln(\lambda) = -1$$

$$\lambda = e^{-1/k} = e^{-T_s/\tau}$$

Choose actual  $\tau = 100/f_{\text{avg}}$

25 The actual peak detection is realized by the following:

```

    If  $|\dot{x}_d| > \lambda \cdot \text{Peak}$  Then
        Peak =  $|\dot{x}_d|$ 
    Else
        Peak =  $\lambda \cdot \text{Peak}(z^{-1})$ 
5      Endif

```

The output of the peak detect circuit can be appropriately scaled for use in the ABS, TCS, or YSC algorithms. The rough road index signal can be a continuous signal or can be quantized to provide a discrete level indication. Thus, there would be a

10 maximum peak velocity from the peak detect circuit which would be assigned to a maximum magnitude of the rough road index signal and a lower or minimum peak velocity which would be assigned to a zero value of the rough road index (i.e., a smooth road). The lower peak velocity is preferably greater than zero in order to reject noise. Thus, one preferred formula for the rough road index is:

$$15 \quad \text{RRID} = C \cdot (\text{Peak} - \text{Peak\_Min}) \div (\text{Peak\_Max} - \text{Peak\_Min}),$$

where RRID is the rough road index, C is a scaling factor for the maximum value of the RRID, Peak\_Min is the minimum peak velocity below which RRID is zero, and Peak\_Max is the maximum peak velocity corresponding to the roughest road.

The trimming of the algorithm takes into account the physical properties of

20 the suspension. For example, suspension properties such as spring stiffness, nominal damping rate, and sprung and unsprung masses help determine the specific implementations of the derivative and bandpass filters.

Using the rough road index from Figure 4, the performance of ABS, TCS, and YSC functions are enhanced during maneuvers where wheel hop due to surface

25 irregularities generally degrades performance. The enhancement in the manner in

which the slip control systems modify their modulation of brake actuation preferably comprises permitting an increased amount of wheel slip. Controlling to a greater amount of wheel slip generally improves performance in the case of a deformable surface such as snow or loose gravel where less tire rotation can  
5 promote digging into or plowing into the deformable surface to shorten stopping distance, for example.

Preferred methods of increasing the amount of wheel slip will be described with reference to Figure 5. This description is in the context of an ABS system where wheels are decelerating, although the concepts also apply in an analogous  
10 manner to a traction control system where wheels are accelerating.

During braking, a vehicle generally decelerates. Curve 410 shows the slowing deceleration of the vehicle. A curve 411 is an actual wheel speed as measured at a wheel as the vehicle is braking. As the wheel begins to slip or skid, the wheel speed drops faster than the vehicle speed. In order to maximize brake  
15 performance, the wheel speed should be controlled to a target wheel speed 412 which corresponds to an amount of wheel slip where maximum braking force is obtained. Assuming the wheel is slipping, then the actual wheel speed cannot be used to establish the target speed. Instead, a target speed is maintained by decaying a previous value of the wheel speed according to a predetermined gradient. The  
20 gradient can be determined in response to overall vehicle deceleration and/or deceleration of the wheel prior to the onset of slipping, for example.

The difference between target speed 412 and actual speed 411 is monitored. When the difference equals a predetermined threshold, then an ABS activation decision is made and the ABS system begins to modulate the braking to control the  
25 slip. A nominal threshold  $\Delta_1$  corresponds to a base threshold as used in the prior

art. The difference exceeds threshold  $\Delta_1$  at a time  $t_1$  resulting in an ABS activation event. In order to increase the amount of slip permitted when a rough road is indicated, one preferred embodiment of the present invention uses an increased slip threshold  $\Delta_2$ . This delays an activation decision until  $t_2$  when the difference  
5 between target speed 412 and actual speed 411 exceeds  $\Delta_2$ .

Figure 6 shows actual wheel speed 411 after the onset of slip. A target wheel speed is determined based on a predetermined gradient or decay 414 (which would instead be an increase during acceleration in a traction control system). Based on following the predetermined gradient from the previous target wheel speed value, a  
10 current target wheel speed value 415 is generated. In a second preferred embodiment of the present invention, the increased slip desired when the rough road index is high is obtained using an increased gradient 416. Following increased gradient 416 generates a current target wheel speed value 417 which is less than target speed 415.

15 Referring to Figure 7, using an increased gradient results in a target wheel speed curve 417 which decays more quickly than prior art target curve 412. Consequently, at time  $t_2$  the difference between the target wheel speed and the actual wheel speed is less than the nominal threshold  $\Delta_1$ . Due to the faster decay of the target wheel speed, the difference does not exceed nominal threshold  $\Delta_1$  until  
20 time  $t_2$ . Slip is thereafter controlled to a lower target wheel speed curve 417 so that an increased slip level is maintained.

The rough road index signal can be generated in either the active braking control or the active suspension control system. When generated in the active suspension system, the value of the rough road index signal can be transmitted to



the active braking control system via a multiplex communication network, such as CAN, for example.

Figure 8 shows apparatus with several separate improvements for making the modified activation decision according to Figures 5 and 7. A base threshold 500 is typically determined as a fixed percentage of current vehicle speed (e.g., 10%). The base threshold is coupled to one input of a summer 501. The prior art has included various additions to and subtractions from the base threshold. For example, US patent 5,627,755 shows a desensitizer computation 502 based on acceleration and slip duration which increases the final threshold. Patent 5,627,755 is hereby incorporated by reference. This desensitizer addition may be added to the base threshold in summer 501. The final threshold is multiplied by actual wheel speed in a multiplier 505 and the product is compared to a target wheel speed in a comparator 506 which generates an activation signal.

Figure 8 shows modifications in both the determination of the final threshold value and the determination of decay rate for determining target wheel speed, although both modifications would not usually be used together.

To adjust the activation threshold, the rough road index is coupled to a scaling block 504 to provide a desired transfer function as appropriate for the relative values used in the control system. Scaling takes into account any differences in relative magnitude for maximum roughness, and matches the general phasing of the signal (i.e., the circuit providing the rough road index signal may have more lead depending on the equations used). The scaling block may also provide filtering to smooth out fast changes in the rough road index so that signal dynamics do not cause significant digital noise downstream. This filtering works as follows:

```

    If road_id_in >= ABS_road_id_filt
        ABS_road_id_filt = road_id_in
        road_id_timer = 0
5      Else
        road_id_timer = road_id_timer + 1
      Endif

    If road_id_timer >= 200 msec
10     road_id_timer = 0
        If ABS_road_id_filt > 0
            ABS_road_id_filt = ABS_road_id_filt - 1
        Endif
    Endif

```

15 Where road\_id\_in is the rough road signal from Figure 4 and ABS\_road\_id\_filt is the filtered rough road signal. This filter allows positive changes in the road ID to pass through and then requires 200 milliseconds to pass before allowing the signal to reduce.

In a preferred embodiment, the scaled/filtered rough road index is provided  
20 to one input of a multiplier 503, the other input of which receives the desensitizer factor from desensitizer computation 502. The rough road index is scaled such that increasing surface roughness increases the amount of desensitization by preselected proportions. This preferred embodiment is particularly advantageous in the interplay with the prior art desensitization computation. Increased slip is primarily  
25 beneficial when a deformable road condition is present. It has been found that

instances when both the prior art desensitization and the present rough road index are relatively large is a good indicator of deformable road conditions. Thus, using the product of the two results in enhanced performance.

In an alternative embodiment, the rough road index is scaled for additive  
5 affect upon the final threshold value. Thus, the scaled rough road index is provided to an input of summer 501. This input to the summer is an alternative to the use of multiplier 503.

In another alternative embodiment, the decay rate used in determining target wheel speed is adjusted in response to the rough road index. Thus, the rough road  
10 index signal is provided to a decay rate generator 510. The selected decay rate is provided to a decay block 511 that receives the previous target wheel speed from a unit delay block 513. The decayed target wheel speed is provided from decay block 511 to one input of a maximum selector block 512 which also receives the current actual wheel speed measurement. Maximum selector block provides the greater of  
15 the current wheel speed or the decayed previous target speed to the noninverting input of comparator 506 and to the input of unit delay block 513.

the general phasing of the signal (i.e. one design may have more lead than another depending on the equations used).

A more specific example of the “reference decay increase” modification will  
20 now be described. The rough road ID signal is quantized to values of 0, 1, 2, or 3 for each wheel and depending on the overall vehicle average. The reference gradient for updating target wheel speed is decayed for ABS and increased for TCS. Definition of variables is as follows:

Name	Description	Units	Resolution
ABS_road_id_filt	Filtered road ID input for use in ABS and TCS functions	---	1
Ax	Estimated vehicle acceleration input	m/sec <sup>2</sup>	1/256
Temp	Temporary value that is added to the previous reference value in order to decay or increase the control reference	km/h/ loop	1/256

The following pseudo code illustrates a preferred implementation.

```

If sum(ABS_road_id_filt(1:4))/4 = 0
5
    Temp = max(-ax,REF_DECAY_RATE_MIN)·REF_OVER_DK/
        ABS_LOOPS_PER_SEC/16384
Endif

10 If sum(ABS_road_id_filt(1:4))/4 = 1
    Temp = max(-ax,REF_DECAY_RATE_MIN)·REF_OVER_DK01/
        ABS_LOOPS_PER_SEC/16384
Endif

15 If sum(ABS_road_id_filt(1:4))/4 = 2
    Temp = max(-ax,REF_DECAY_RATE_MIN)·REF_OVER_DK02/

```

ABS\_LOOPS\_PER\_SEC/16384

Endif

If sum(ABS\_road\_id\_filt(1:4))/4 = 3

5

Temp = max(-ax,REF\_DECAY\_RATE\_MIN)\*REF\_OVER\_DK03/  
ABS\_LOOPS\_PER\_SEC/16384

Endif

- 10 REF\_DECAY\_RATE\_MIN is the minimum of the reference gradient. Temp  
modifies the reference gradient used in the ABS algorithm. One of four different  
gain values (i.e., REF\_OVER\_DK) are selected in response to the average level of  
the road identification signals in order to modify Temp. A similar algorithm is used  
for traction control gradient modifications, however, the incremental change is  
15 increasing instead of decreasing.

A more specific example of the “slip threshold increase” modification of the  
present invention will now be described. The rough road ID signal is used to  
increase the slip threshold by multiple integers of 5% of vehicle speed. An  
additional variable for this pseudo-code implementation is ABS\_sthr\_final\_abslt  
20 which is the ABS slip threshold for each wheel in km/h with a resolution of 1/256:

Surface\_id\_rear = min(max(front\_road\_id[1:2]),rear\_road\_id[1:2])

/\* Select lowest value between maximum of front and smallest of rears as the  
25 modifier \*/

```
ABS_sthr_final_abslt *= (1 + ABS_road_id_filt(Surface_id_rears)*0.12 (0.08 for  
rears))
```

```
5 /* Increasing the final slip threshold by multiple integers of 12% (8% for rears) */
```

```
T = 5*ABS_road_id_filt*filtered wheel speed/100
```

```
/* Adding integer values of 5 % of vehicle speed to slip threshold */
```

```
10
```

```
If T < 3 km/h
```

```
    T = 3 km/h
```

```
Endif
```

```
15 /* Minimize to 3 km/h unless road_id = 0 */
```

```
If ABS_road_id_filt (Surface_id_rear[1:2]) = 0
```

```
    T = 0
```

```
Endif
```

```
20
```

```
ABS_sthr_final_abslt += T
```

The ABS slip threshold is then used for activation detection and cyclical wheel control modes. The increase in the threshold for activation inherently will increase  
25 the level of slip to which the wheel is being controlled.

An analogous implementation is performed for the slip thresholds for TC, thus increasing the amount of spin on the driven wheels.

In accordance with the provisions of the patent statutes, the principle and  
5 mode of operation of this invention have been explained and illustrated in its preferred embodiment. However, it must be understood that this invention may be practiced otherwise than as specifically explained and illustrated without departing from its spirit or scope.

What is claimed is:

1. Apparatus for a vehicle, comprising:

5 a suspension system for connecting a vehicle body and vehicle wheels, said suspension system including at least one suspension sensor for sensing an operating parameter of said suspension system and at least one suspension actuator for modifying a performance characteristic of said suspension system;

an active suspension control for controlling said performance characteristic in response to said suspension sensor;

10 a road surface classifier responsive to said suspension sensor for generating a road surface signal representing a roughness of a road surface over which said vehicle travels;

a braking system including a wheel speed sensor and a brake actuator; and

15 an active braking control for detecting wheel slip in response to said wheel speed sensor during at least one of braking or accelerating of said vehicle and for modulating actuation of said brake actuator in response to said detected wheel slip, said active braking control being responsive to said road surface signal for modifying modulation of said brake actuator as a function of said road surface signal.

20

2. The apparatus of claim 1 wherein said modification of brake actuator modulation is comprised of permitting an increased amount of wheel slip.

3. The apparatus of claim 2 wherein said active braking control determines  
25 an actual wheel speed in response to signals from said wheel speed sensor, wherein



said active braking control determines a target wheel speed in response to a predetermined gradient from previously determined actual wheel speed, wherein said active braking control compares said actual wheel speed and said target wheel speed to determine said modulation, and wherein said increased amount of wheel slip is obtained by increasing said predetermined gradient in response to said road surface signal.

4. The apparatus of claim 2 wherein said active braking control determines an actual wheel speed in response to signals from said wheel speed sensor, wherein said active braking control determines a target wheel speed in response to a predetermined gradient from previously determined actual wheel speed, wherein said active braking control compares a difference between said actual wheel speed and said target wheel speed with a threshold in order to determine said modulation, and wherein said increased amount of wheel slip is obtained by increasing said threshold in response to said road surface signal.

5. A method of making an activation decision in a wheel slip control system installed in a vehicle, said vehicle including a suspension system, said method comprising the steps of:

- determining an actual wheel speed for a wheel of said vehicle;
- generating a rough road index in response to a measured operating parameter of said suspension system;
- determining a predetermined gradient in response to said rough road index;
- determining a target wheel speed for said wheel from a previously determined target wheel speed modified by said predetermined gradient;

determining a difference between said target wheel speed and said actual wheel speed; and

comparing said difference with a threshold and activating said wheel slip control system if said difference exceeds said threshold.

5

6. The method of claim 5 wherein said activation decision is an anti-lock braking decision and wherein said predetermined gradient is a speed decay.

7. The method of claim 5 wherein said activation decision is a traction control decision and wherein said predetermined gradient is a speed increase.

10

8. A method of making an activation decision in a wheel slip control system installed in a vehicle, said vehicle including a suspension system, said method comprising the steps of:

15

determining an actual wheel speed for a wheel of said vehicle;

generating a rough road index in response to a measured operating parameter of said suspension system;

determining a threshold in response to said rough road index;

determining a target wheel speed for said wheel from a previously

determined target wheel speed;

20

determining a difference between said target wheel speed and said actual wheel speed; and

comparing said difference with said threshold and activating said wheel slip control system if said difference exceeds said threshold.

25

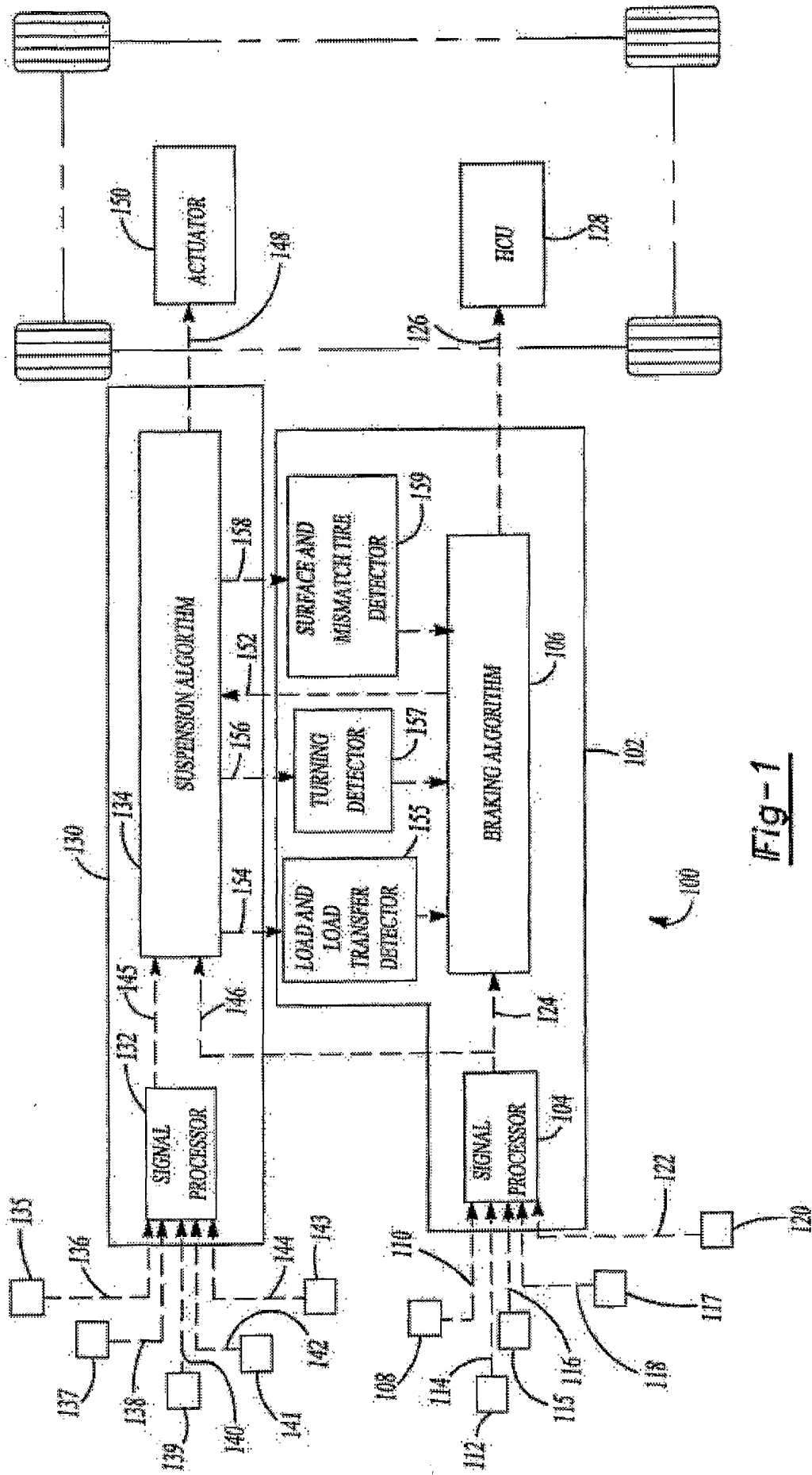


Fig-1

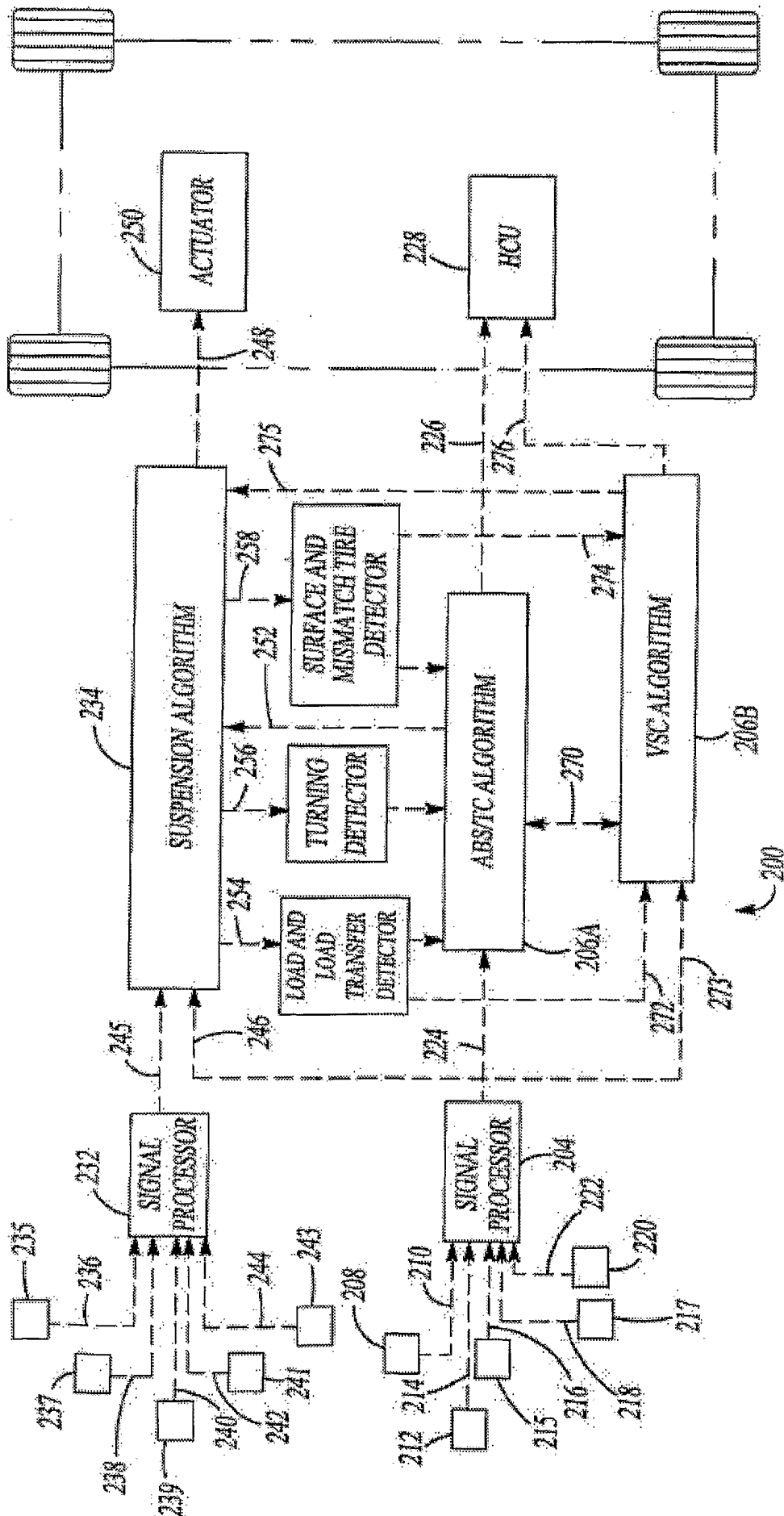


Fig-2

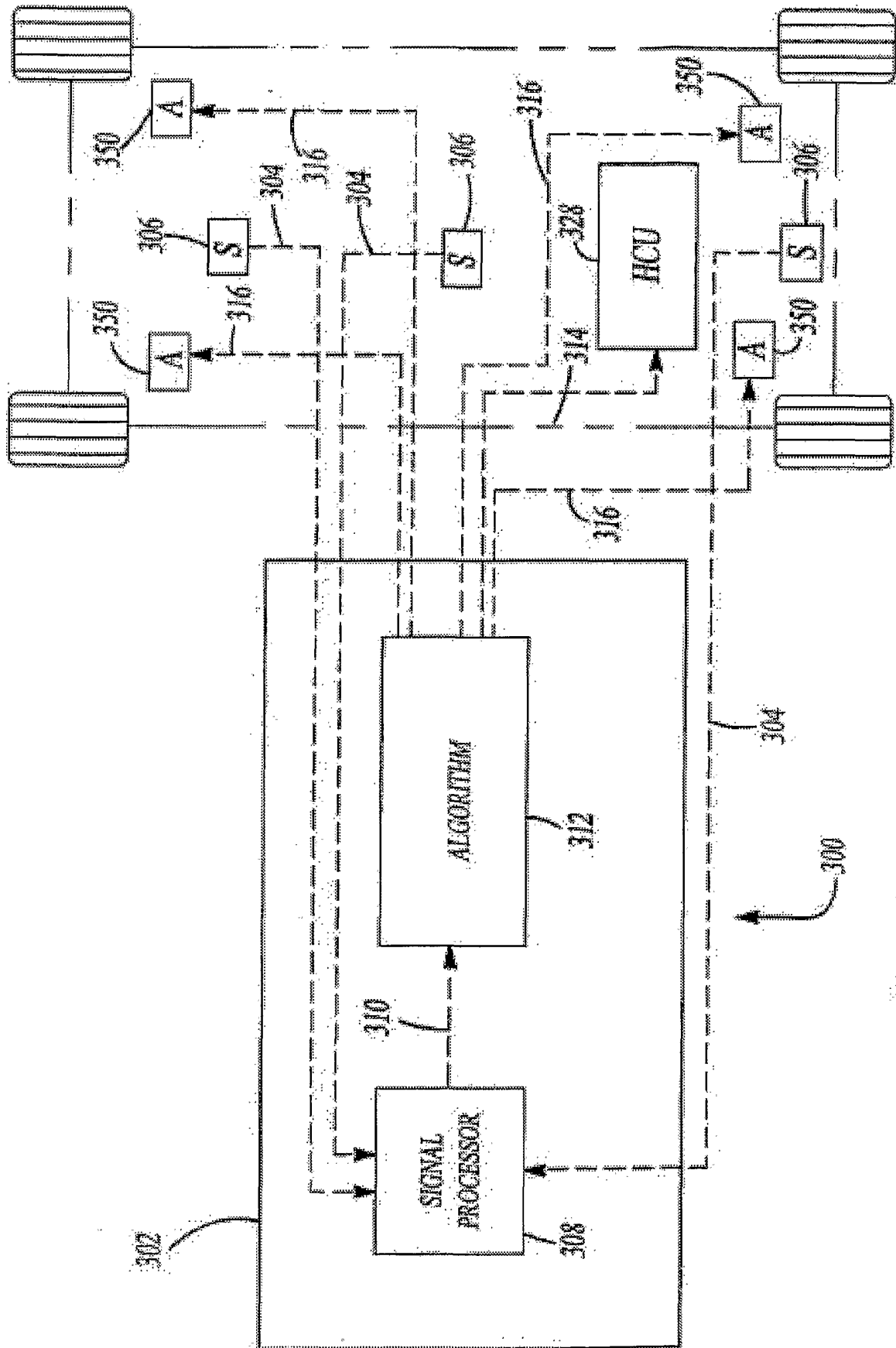


Fig-3

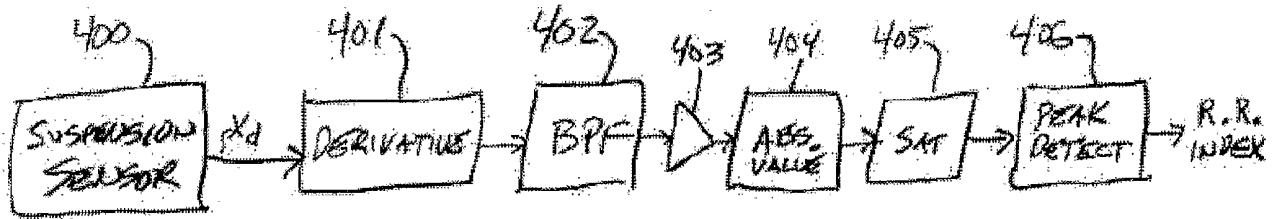


Fig. 4

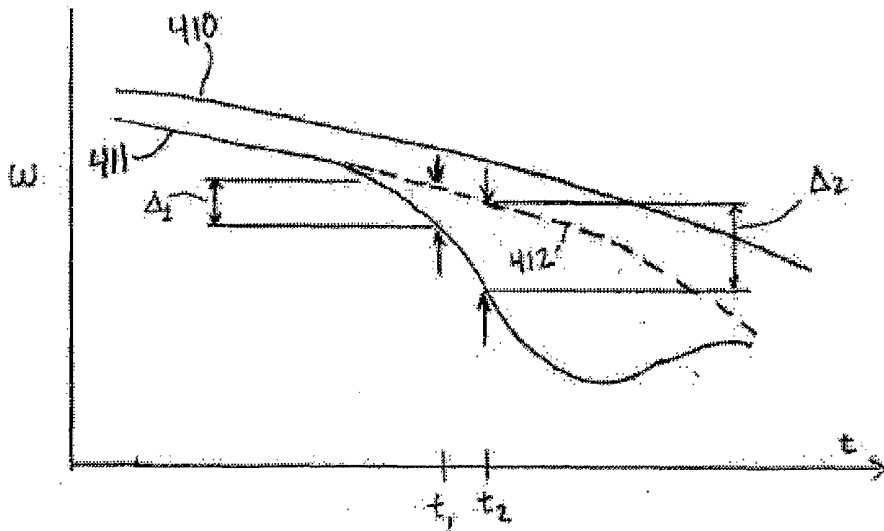


Fig. 5

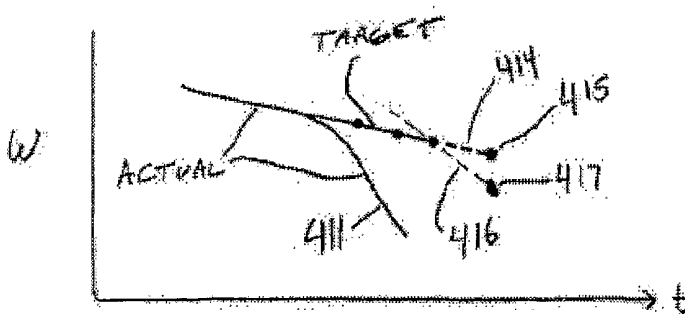


Fig. 6

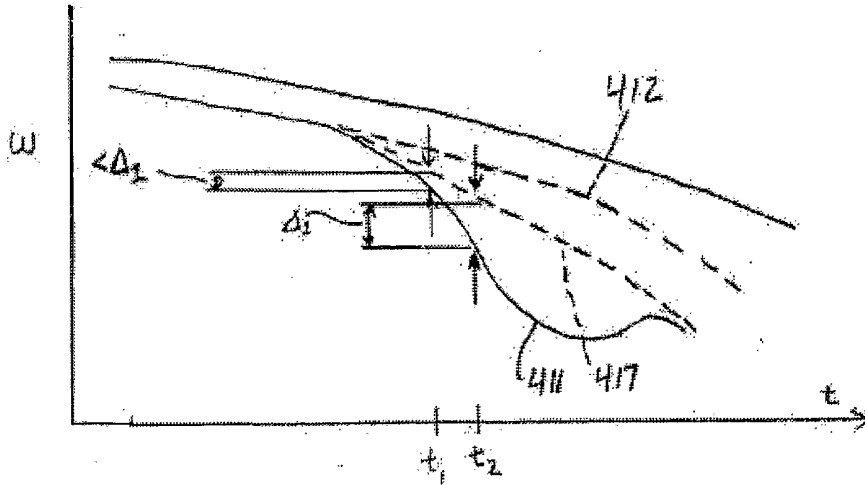


Fig. 7

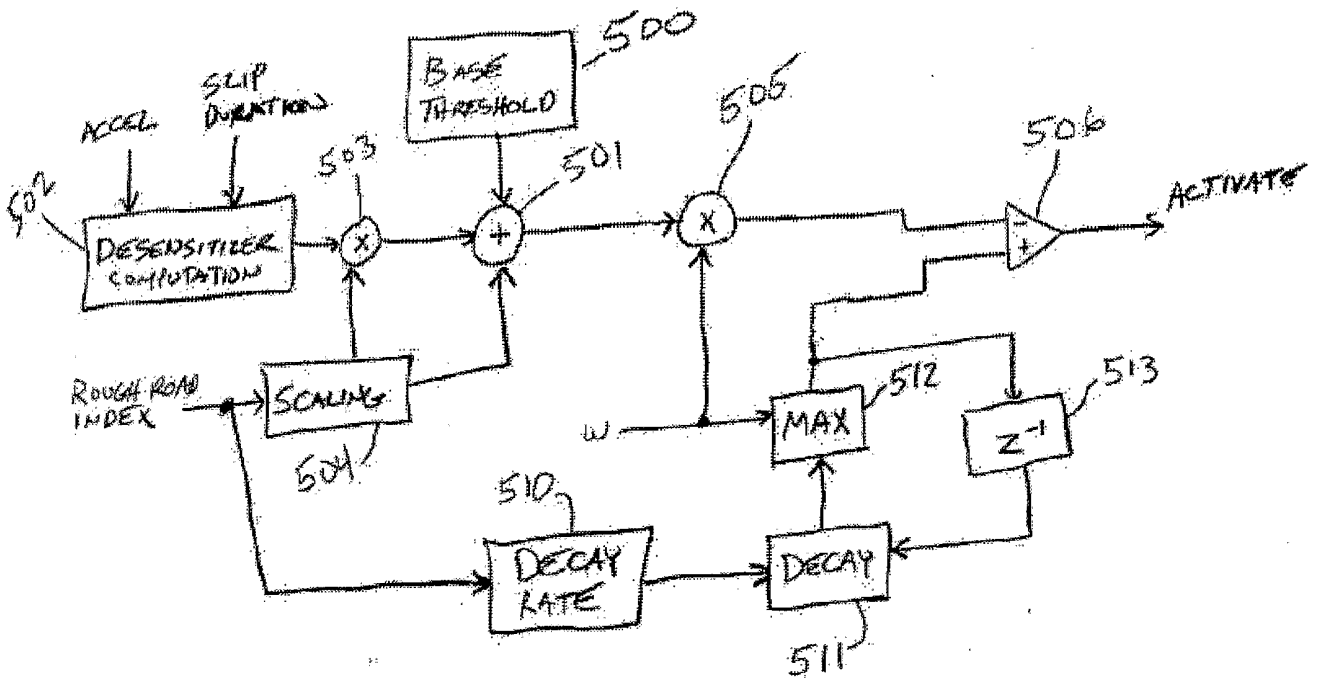


Fig. 8

INTERNATIONAL SEARCH REPORT

Inter I Application No  
PC1/US 01/28201

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 B60T8/00 B60G17/015

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 7 B60T B60G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 00 06433 A (CONTINENTAL TEVES AG & CO OHG ;BAITER ULRICH (DE); FUEHRER JOCHEN) 10 February 2000 (2000-02-10) page 4, line 24 -page 9, last line; figures 1-4	1-8
A	EP 0 449 118 A (MAZDA MOTOR) 2 October 1991 (1991-10-02) column 8, line 19 -column 14, line 5; figures 1-4	1-3,5-8
A	DE 41 33 238 A- (BOSCH GMBH ROBERT) 8 April 1993 (1993-04-08) the whole document	1-8
P,A	DE 199 46 463 C (BAYERISCHE MOTOREN WERKE AG) 5 April 2001 (2001-04-05) column 4, line 5 - line 11	1-8
	-/--	

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

° Special categories of cited documents :

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
- \*E\* earlier document but published on or after the international filing date
- \*L\* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- \*O\* document referring to an oral disclosure, use, exhibition or other means
- \*P\* document published prior to the international filing date but later than the priority date claimed

- \*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- \*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- \*Y\* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- \*G\* document member of the same patent family

Date of the actual completion of the international search

8 January 2002

Date of mailing of the international search report

15/01/2002

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

Authorized officer

Blurton, M



## INTERNATIONAL SEARCH REPORT

Interr: Application No  
PCT/US 01/28201

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 655 362 A (MAZDA MOTOR) 31 May 1995 (1995-05-31) column 21, line 57 -column 25, line 48; figures 11-15 -----	1-8

## INTERNATIONAL SEARCH REPORT

nation on patent family members

Inter Application No  
PCT/US 01/28201

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
WO 0006433	A	10-02-2000	DE 19933389 A1 WO 0006433 A1	03-02-2000 10-02-2000
EP 0449118	A	02-10-1991	JP 2818900 B2 JP 3273967 A JP 2856828 B2 JP 3279065 A JP 2818902 B2 JP 3281468 A JP 2917039 B2 JP 3281469 A DE 69112247 D1 DE 69112247 T2 DE 69129502 D1 DE 69129502 T2 EP 0449118 A2 EP 0655362 A2 KR 9502933 B1 US 5117934 A	30-10-1998 05-12-1991 10-02-1999 10-12-1991 30-10-1998 12-12-1991 12-07-1999 12-12-1991 28-09-1995 25-01-1996 02-07-1998 17-09-1998 02-10-1991 31-05-1995 28-03-1995 02-06-1992
DE 4133238	A	08-04-1993	DE 4133238 A1 FR 2683776 A1 JP 5201230 A	08-04-1993 21-05-1993 10-08-1993
DE 19946463	C	05-04-2001	DE 19946463 C1 EP 1088724 A2 JP 2001114086 A US 6321155 B1	05-04-2001 04-04-2001 24-04-2001 20-11-2001
EP 0655362	A	31-05-1995	JP 2818900 B2 JP 3273967 A JP 2856828 B2 JP 3279065 A JP 2818902 B2 JP 3281468 A JP 2917039 B2 JP 3281469 A EP 0655362 A2 DE 69112247 D1 DE 69112247 T2 DE 69129502 D1 DE 69129502 T2 EP 0449118 A2 KR 9502933 B1 US 5117934 A	30-10-1998 05-12-1991 10-02-1999 10-12-1991 30-10-1998 12-12-1991 12-07-1999 12-12-1991 31-05-1995 28-09-1995 25-01-1996 02-07-1998 17-09-1998 02-10-1991 28-03-1995 02-06-1992