(12) UK Patent Application (19) GB (11) 2520493 (13) A

(43) Date of A Publication 27.05.2015

(21) Application No: 1320489.6

(22) Date of Filing: 20.11.2013

(71) Applicant(s):
Coventry University
(Incorporated in the United Kingdom)
Priory Street, COVENTRY, Warwickshire, CV1 5FB, United Kingdom

(72) Inventor(s):
James Trollope
Keith Burnham

(74) Agent and/or Address for Service:
Withers & Rogers LLP
4 More London Riverside, LONDON, SE1 2AU, United Kingdom

(51) INT CL:
B60R 21/0134 (2006.01) ***B62D 21/15*** (2006.01)

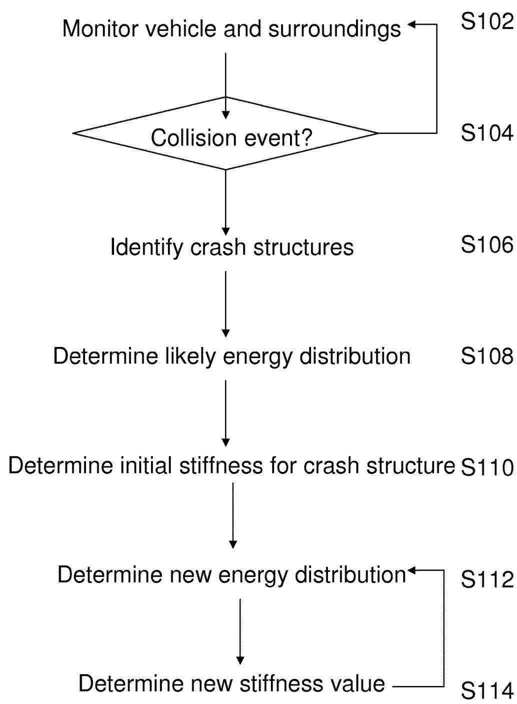
(56) Documents Cited:
US 7046167 B2
US 20040254729 A1
US 20040061598 A1
US 20020169533 A1
US 20020099485 A1

(58) Field of Search:
INT CL **B60R, B62D, G01S**
Other: **WPI, EPODOC**

(54) Title of the Invention: **Active buckling control**
Abstract Title: **A method of managing collisions between vehicles by actively stiffening vehicle crash structures**

(57) A method of managing collisions between a plurality of vehicles in an active collision management system, wherein one or more the of the vehicles has a crash structure whose stiffness can be adjusted, the method comprising the steps of: determining whether a collision between the plurality of vehicles is to occur based on data measured by one or more object detection sensors; and in the event that a collision is to occur, for each vehicle: identifying a first crash structure and determining an initial stiffness of said structure; determining the amount of energy which would be absorbed by each vehicle in the collision; and subsequently determining a level of aggressivity of the collision based on said predicted energy absorption; determining a subsequent stiffness value for the crash structure based on the determined amount of energy to be absorbed by each of the vehicles such that the energy absorbed by the crash structure is changed and the level of aggressivity is reduced; and stiffening the first crash structure to the determined stiffness value. A vehicle provided with such an active collision management system is also claimed.

Figure 3



GB 2520493 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

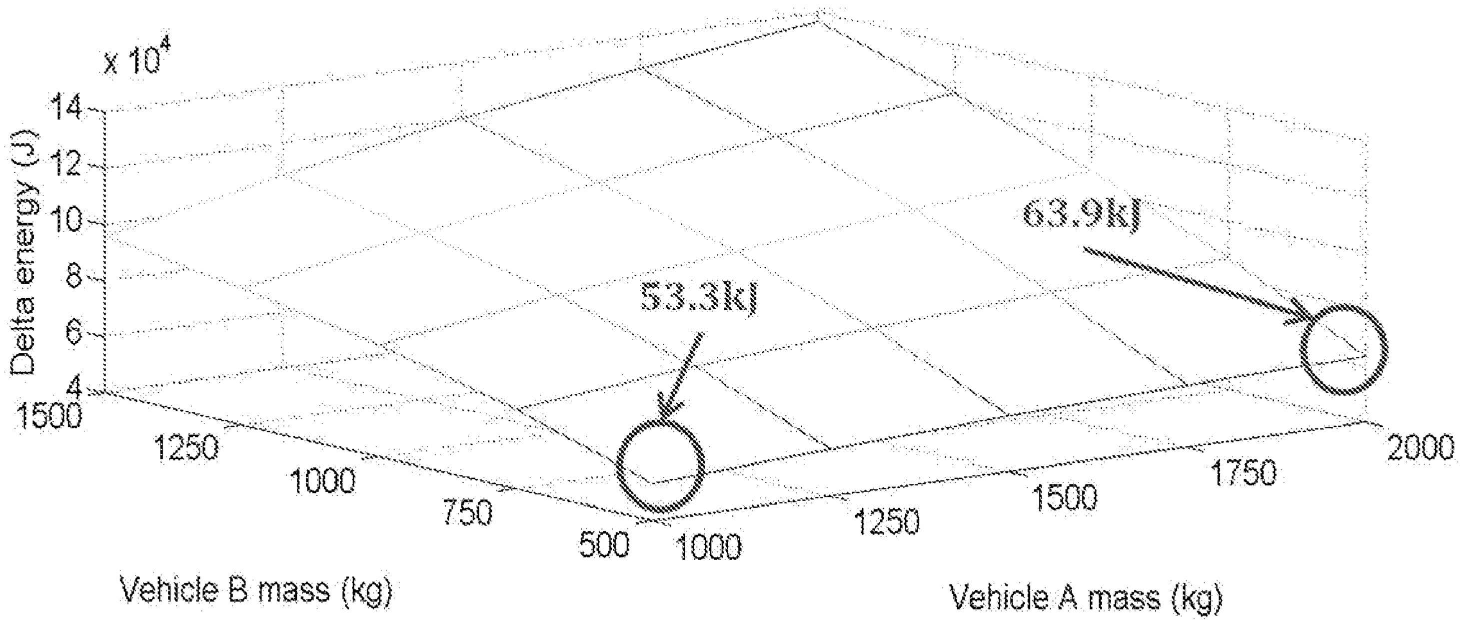

x 10^4
14
12
10
8
6
4
Delta energy (J)
1500
1250
1000
750
500
Vehicle B mass (kg)
1000
1250
1500
1750
2000
Vehicle A mass (kg)
53.3kJ
63.9kJ

Figure 1

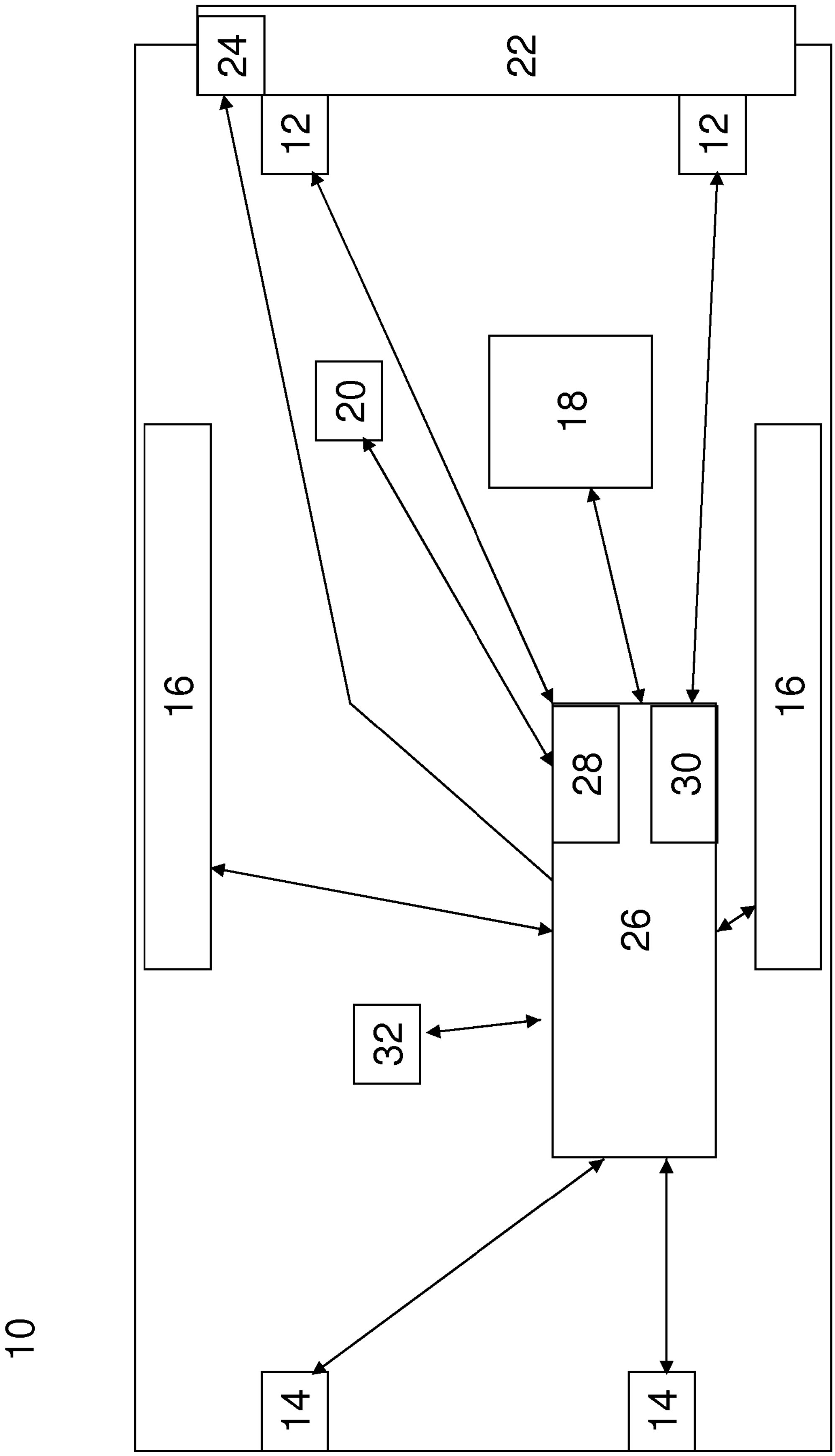


Figure 2

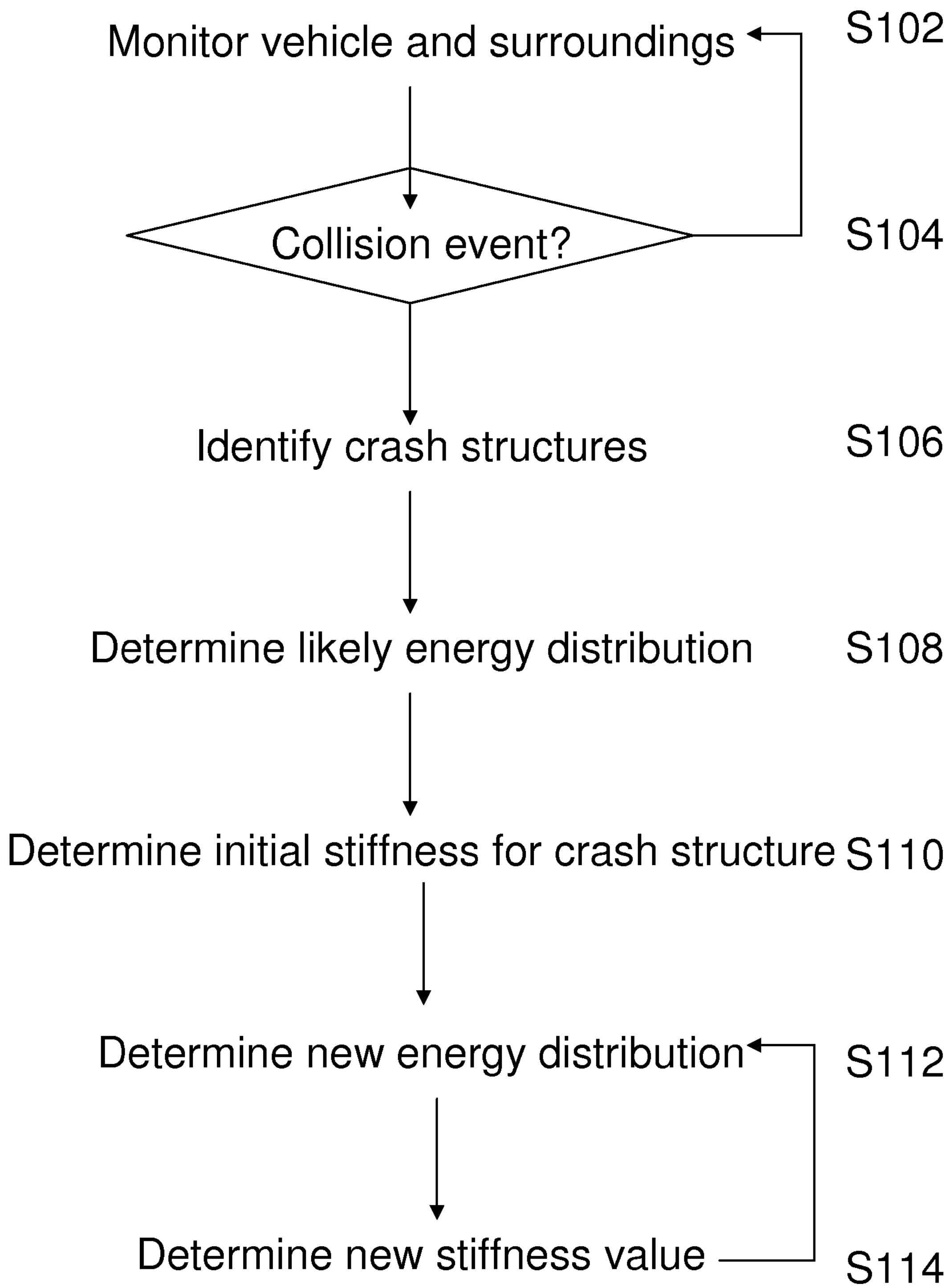

Monitor vehicle and surroundings
S102
Collision event?
S104
Identify crash structures
S106
Determine likely energy distribution
S108
Determine initial stiffness for crash structure
S110
Determine new energy distribution
S112
Determine new stiffness value
S114

Figure 3

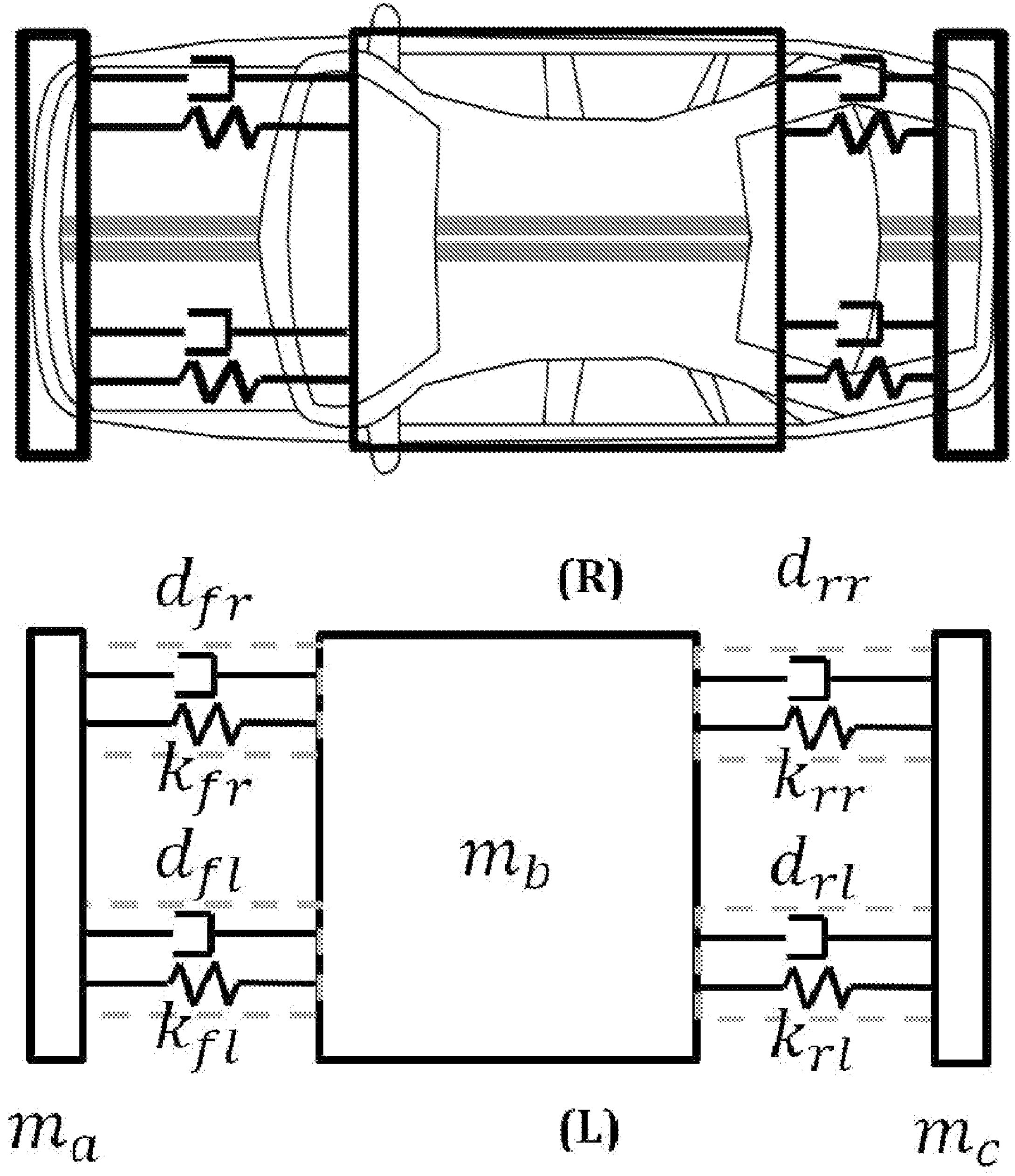
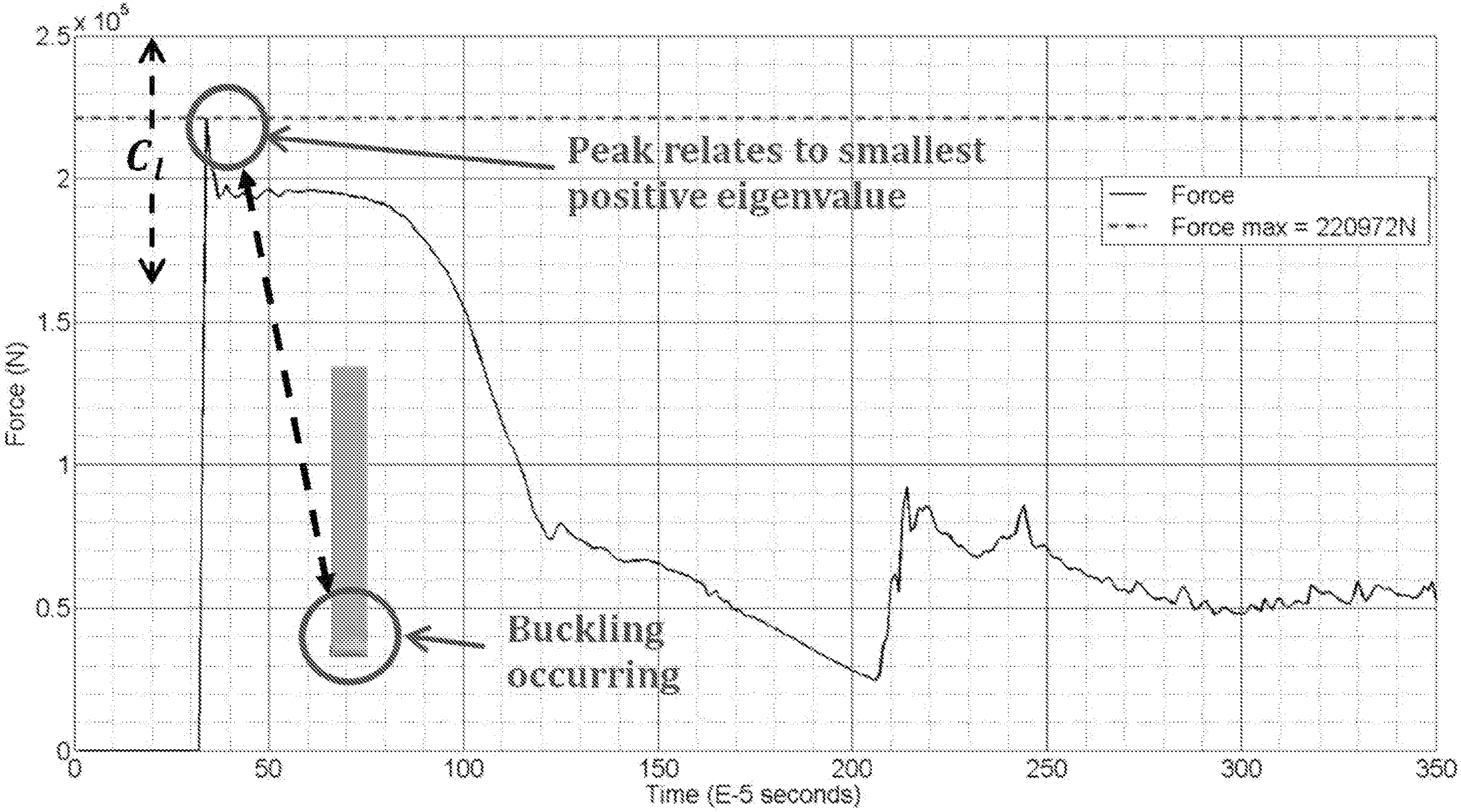


Figure 4



Peak relates to smallest
positive eigenvalue
Buckling
occurring
C_l
Force
Force max = 220972N
Force (N)
Time (E-5 seconds)
x 10^5
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
300
350

Figure 5

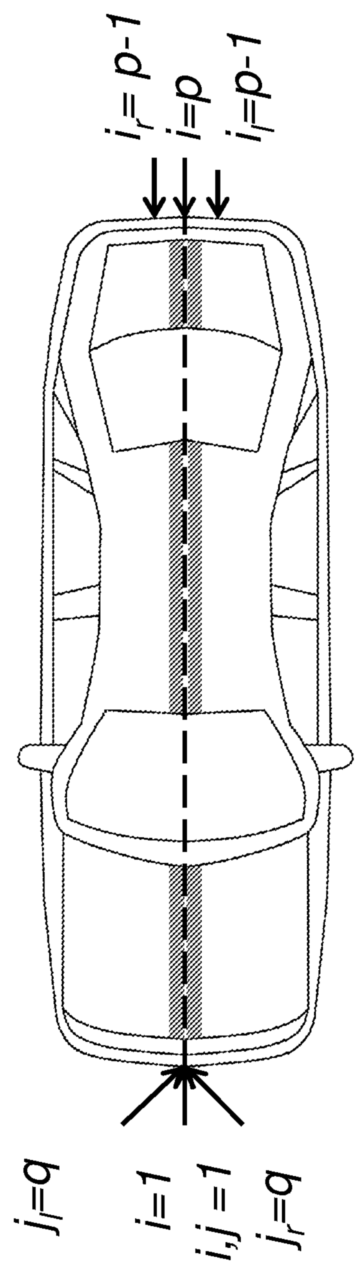


Figure 6

Active buckling control

Field of invention

The invention relates to active crash management systems. In particular an active crash management system in which the stiffness of a crash structure is varied so as to reduce the level of aggressivity in a collision involving two or more vehicles.

Background to the invention

Crash management systems and crash structures form a significant part of modern vehicle design. Typically the trend for modern vehicle design is to provide body structures which are stiffer to resist torsion and buckling. Such structural stiffness may be achieved by introducing structural reinforcements or increasing the gauge of the material, which typically results in a heavier vehicle structure.

Relevant safety standards typically require a vehicle body to be able to withstand an impact with a stationary structure. However, many collisions occur between two or vehicles. Furthermore, such vehicles may be of different mass, for example in a collision between a small car and a SUV the difference in mass between the two vehicles may be over 2 tonnes. The difference in vehicle mass in a collision may lead to the larger vehicle absorbing less energy than a smaller vehicle, which is known as vehicle aggressivity.

A further consideration in vehicle design is to increase fuel economy in a vehicle. Such economy may be obtained as a combination of more efficient engine management or by reducing the weight of the vehicle.

It is known that certain materials, such as magnetorheological materials, piezoelectric polymers, shape memory alloys etc., can adjust their stiffness. The timescales in which the adjustment occurs is of the order of 50ms or less. Such materials can therefore be used in vehicle crash structures (such as front end crumple zone) where the stiffness of the structure is varied in the event that a collision is to occur. For example US 7,046,167 in the name of Ford Global Technologies describes a system in which the stiffness of a vehicle changes in the event a collision is predicted to occur. Such systems however do not consider the other vehicles involved in the collision.

Accordingly to mitigate some of the above problems there is provided a method of managing collisions between a plurality of vehicles in a active collision management system, wherein one or more the of the vehicles has a crash structure whose stiffness can be adjusted and one or more object detection sensors, the method comprising the steps of: determining whether a collision event between the plurality of vehicles is to occur based on data measured by one or more object detection sensors; and in the event that a collision event is to occur, for a first vehicle involved in the collision event: identifying a first crash structure and determining an initial stiffness of the crash structure; and subsequently determining a level of aggressivity of the collision based on a predicted energy absorption as result of the collision for each of the plurality of vehicles; determining a subsequent stiffness value for the first crash structure based on the predicted energy absorption and level of aggressivity of the collision such that the energy absorbed by the crash structure is changed and the level of aggressivity of the collision is reduced; and stiffening the first crash structure to the subsequently determined stiffness value.

Such a system therefore allows for one or more vehicles involved in a crash to compensate for the differences in vehicle masses and reduce the aggressivity of the collision. By predicting the amount of energy to be absorbed by each crash structure in advance of the collision, the stiffness of the crash structure can be varied so the energy absorption may be distributed more evenly between the vehicles in the collision.

Other aspects of the invention will become apparent from the appended claim set.

Brief description of the drawings

Preferred embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic representation of illustrates a surface which represents typical collision events between two vehicles of different mass;

Figure 2 is a schematic representation of a vehicle having an active buckling control system installed thereon according to an aspect of the invention;

Figure 3 is a flow chart of the process of active buckling control according to an aspect of the invention;

Figure 4 is a schematic representation of a vehicle and the modal structure of the vehicle according to an aspect of the invention;

Figure 5 is a plot of energy absorption in a typical collision; and

Figure 6 is a representation of a vehicle and its impact zones.

Summary of the invention

According to an aspect of the invention, there is provided a system which actively manages collisions between one or more vehicles. In particular an aspect of the invention is to actively vary the stiffness of one or more crash structures in a vehicle in the event of a collision. By varying the stiffness of a crash structure the point at which buckling of the structure occurs will vary and hence the level of energy absorption for the vehicle will vary. Therefore the invention is able to control the amount of energy absorbed by each vehicle in the collision by varying the stiffness of the crash structures before the point of collision. By controlling the amount of energy absorbed by each vehicle, the aggressivity of the crash can be managed.

By considering the following example the need to actively manage a collision may be illustrated.

Consider two vehicles, denoted Vehicle A and Vehicle B, of dissimilar mass but of similar geometry and stiffness, where the conservation of momentum and energy are considered. For this example, vehicles of mass m_a and m_b and are given by 1000kg and 500kg, respectively, with the final velocity of the combined masses being denoted as V_f. Prior to the collision the individual vehicle velocities are given by V_a and V_b respectively. It is well known that the conservation of momentum can be expressed as:

$$(m_a V_a + m_b V_b) = m_{a+b} V_f$$

Equation 1

where,

$$m_{a+b} = m_a + m_b$$

Equation 2

is the combined mass.

Consider Vehicle A travelling at 17.88m/s (40mph) and Vehicle B being stationary. It can be deduced from equation 1 that the final velocity of the combined mass of the two vehicles is 11.92m/s (26.7mph). Further, the principle of conservation of energy states that the kinetic energy before and after the collision must be equal, given by:

$$\frac{1}{2} m_a V_a^2 + \frac{1}{2} m_b V_b^2 = \frac{1}{2} m_a V_f^2 + \frac{1}{2} m_b V_f^2 + \Delta E$$

Equation 3

where ΔE is the collision energy dissipated within the vehicle body structures; in this case it amounts to 53.3kJ.

It is known that the ratio of absorption of energy from a collision is proportional to the change in the vehicle velocities, denoted ΔV_a and ΔV_b, where:

$$\Delta V_a = |V_f - V_a|$$

Equation 4

and similarly for vehicle b.

It can be deduced that the ratio of ΔV_a:ΔV_b is the same as m_b:m_a, so that in the event of a collision, the smaller vehicle becomes the more vulnerable of the two, and will absorb the larger proportion of the collision energy. The difference in mass, and accordingly the amount of collision energy absorbed is known as aggressivity.

Figure 1 illustrates a surface which represents typical collision events of two arbitrary vehicles, Vehicle *A* and Vehicle *B*, with in the range of 1000-2000kg and in the range of 500-1500kg, corresponding to Vehicle *A* travelling at 17.88m/s (40mph) and Vehicle *B* being stationary (as per the above example). Vehicle *A* and vehicle *B* are of similar stiffness and geometry. The resulting delta energy absorbed in the collision is plotted vertically.

As can be seen where the mass ratio is 2:1 the smaller vehicle of 500kg would absorb 35.5kJ of energy and the larger vehicle of 1000kg would absorb only 17.8kJ.

In further examples where the ratio of masses is 4:1, the smaller vehicle of 500kg would absorb 51.1kJ compared to the larger vehicle of 2000kg absorbing only 12.8kJ.

Therefore in such collisions, the lighter vehicle would absorb more energy than the heavier, more aggressive, vehicle. In collisions where the mass ratio is high, due to the aggressivity of the collision the level of energy absorbed by the smaller vehicle may be higher than the standard to which the vehicle has been tested.

A vehicle structure is typically made up of two zones, the crumple zones and the passenger compartment/cell. The crumple zones are typically located at the front and rear of the vehicle for energy absorption in the event of a frontal or rear collision. Whilst the passenger compartment is the area whereby the passengers are located, with this designed to remain rigid/stiff, preventing intrusion of other vehicles into the passenger compartment. The zones of the vehicle are herein referred to as crash structures. The term crash structure refers to both regions of a vehicle such as the crumple zone and passenger cell, as well as the components of these regions which absorb collisional energy.

In the present invention one or more crash structures in a vehicle are constructed of actively controlled materials (ACM) such as piezoelectric polymers, shape memory alloys, magnetorheological material etc.. Such ACM have the ability to bring about desirable changes to the mechanical properties of a structure, in particular they are able to vary their stiffness over a period of 50ms. Therefore in the event of a collision between two or more vehicles the stiffness of the material used in the crash structure (e.g. the crumple zone) is varied to a desired stiffness so as to change the point of buckling of the material and consequently the energy absorbed by each vehicle. Therefore the invention utilises an active buckling control methodology in order to manage, and reduce the aggressivity of a collision.

Figure 2 is a schematic representation of a vehicle having an active buckling control (ABC) system installed thereon according to an aspect of the invention.

In the event that a collision event is detected to occur the ABC system varies the stiffness of one or more crash structures in one or more of the vehicles so as to manage the energy absorption in a manner so as to reduce the aggressivity of the collision.

In Figure 2 there is shown a vehicle 10 having installed thereon active buckling control system according an aspect of the invention. For clarity purposes only a single vehicle is shown.

There is shown vehicle 10 having a front object detection sensor 12, a rear object detection sensor 14, and side object detection sensor 16. The number of, and position of, the object detection sensors (12, 14, 16) may vary according to the specifics of the installation of the invention, however for clarity purposes only, a single front, rear and side sensors are shown. There is also shown an object recognition camera 18 and a speed determining means 20. The vehicle 10 has a first crash structure 22 which is made of at least in part an actively controlled material (ACM). The front crash structure 22 has attached thereon a stiffness controller 24 which is configured to actively change the stiffness of the ACM. The vehicle 10 further comprises a processor having an advanced driver assisted system (ADAS) 28. An active safety system (ASS) 30, and a vehicle-to-vehicle communicator 32. The vehicle 10 further comprises an on-board processor 26 configured to monitor and receive information from the object detection sensors (12, 14, 16), object recognition camera 18 and a speed determining means 20. The processor 26 is further configured to control the stiffness controller 24.

The on board processor 26 monitors information from the object detection sensors (12, 14, 16) and preferably the object recognition camera 18 in a manner which is known in ADAS systems 28. In such systems the object detection sensors and object recognition camera are used in order to identify any other vehicles, street furniture, pedestrians etc., which are in the vicinity of the vehicle 10 and to determine the likelihood of collision with any of the identified features. Such object detection and ADAS is known in the art. Preferably, the processor 26 communicates with one or more further vehicles (not shown in Figure 2) using the vehicle-to-vehicle communicator 32. Information regarding the velocity of the vehicle as measured by the speed determining means 20, as well as further information identifying the one or more vehicles (such as make, model etc) is transmitted using the vehicle-to-vehicle communicator 32. Such communication occurs using a standard handshake protocol in which vehicles in the vicinity of the vehicle 10 are identified, and one a connection is established bi-directional communication begins. Accordingly, using the vehicle to vehicle communicator 32 information regarding the vehicles within the vicinity of the main vehicle 10 may be easily determined. Such vehicle-to-vehicle communication occurs in a manner known in the art.

When vehicles in the vicinity of the host vehicle 10 are not equipped with vehicle-to-vehicle communication 32, the processor 26 uses the object recognition camera 18 in order to determine characteristics of the vehicle. The object recognition camera 18 and processor 26 are configured to identify, using known object detection techniques based on the shape and size of the object, characteristic, such as the likely make and model, mass etc., of the vehicle. Furthermore, using the object detection sensors (12, 14, 16) the processor 26 is also able to determine a relative velocity of the neighbouring vehicle using the information regarding the main vehicle 10 using the speed determining means 20 and the relative approach velocity as determined using the object detection sensor(s).

The processor 26 is further configured to control one or more stiffness controllers 24 of the crash structure 22. The crash structure is in part, or wholly, constructed using ACM. For clarity purposes only a first front crash structure 22 has been shown in Figure 2, though a vehicle would typically have several such crash structures, each having a stiffness controller configured to vary the stiffness of any ACM within the crash structure 22. The processor 26 is therefore configured to adjust the stiffness of the crash structure 22 via the stiffness controller 24. In embodiments where the ACM is a piezoelectric polymer, the stiffness controller 24 has an electrical terminal and is configured to apply the appropriate voltage in order to achieve the desired stiffness of the ACM.

In a preferred embodiment, the processor 26 is also equipped with a memory (not shown) which contains information regarding a number of vehicle images and characteristics. Each vehicle identified by the object recognition camera 18 is then compared with the vehicles held in the database, using known shape matching algorithms or image comparison techniques. The database preferably also contains characteristics of the vehicle such as mass, as well as information regarding the vehicle construction e.g. stiffness of various crash structures.

In use, the processor 26 therefore obtains information regarding the vehicle 10 (such as speed as determined by the determining means 20) the current stiffness of the crash structure 22 as well as information regarding the vehicles within the vicinity as identified by the object detection sensors 12, 14 and 16 and preferably the object recognition camera 18. Furthermore, information regarding the other vehicles may be determined using the vehicle-to-vehicle communicator 32, though this is dependent on the other vehicles within the vicinity of the vehicle 10 having such functionality.

As described in further detail below, in the event that collision event is identified the processor 26 determines an initial optimal stiffness for the first crash structure 22 so as to more effectively apportion the energy absorption between the two or more vehicles involved in the collision. As is known in existing ADAS systems and ASS systems the processor 26 updates such information every 50ms. Therefore, the processor 26 has a constantly updating awareness of the potential dangers posed to the host vehicle

10. This information is used to refine the initially determined stiffness for the crash structures, so as to compensate for any changes in the collision (e.g. changes in velocity of the vehicles involved etc.).

Figure 3 is a flowchart of the process of the adaptive buckling control system varying the stiffness of a crash structure in the event that a collision is determined to occur.

At step S102 the onboard ADAS or similar, monitors the vehicle 10 and its surroundings. Such monitoring is known in modern car technologies and occurs in a known manner.

At step S104 it is determined whether a collision event is to occur based on the data as collected at step S102. In the event that no collision event is to believed to occur the process returns to step S102 and monitoring continues in the known manner. If at step S104 a collision event is determined to occur the process continues to step S106. Known ADAS systems have collision mitigation functionalities (such as automatic emergency braking) and preferably such known steps occur at step S104 in order to prevent, or reduce the effect of, a collision.

If a collision event is then confirmed despite the mitigation actions taken, at step S106 the onboard processor determines the likely crash structures in the vehicle which will be impacted as a result of the collision. Depending on the circumstances of the collision event (speed, number of vehicles involved, direction of travel etc.) one or more crash structures may be impacted. At step S106 for each of the one or more crash structures identified, the current stiffness level of the structure is determined. In an embodiment of the invention, during normal operation of the vehicle (i.e. when not involved in a collision) the crash structures have standard stiffness which remains unchanged. In such embodiments the stiffness is stored in the memory of the vehicle. In further embodiments the stiffness of various structures may be actively varied during normal use. For example, the stiffness of the chassis of the vehicle may be adjusted according to driving conditions or style. In such embodiments the current stiffness of the crash structure is measured (for example based on the level of current passed through the piezoelectric polymer) and this value is used.

At step S108 the processor determines the likely distribution of collisional energy between each vehicle as a result of the collision.

In order to determine the likely distribution of collisional energy, the current velocity of the vehicle, its mass and the stiffness of the crash structures as identified at step S106 are all inputted. Using the data collected at step S102, information regarding the other vehicles in the collision may also be ascertained.

Preferably, the monitoring at step S102 occurs via vehicle-to-vehicle communication and the mass, velocity and stiffness of the likely crash structures of the second vehicle are transmitted directly to the primary vehicle using the vehicle-to-vehicle communicator. In the event that the secondary vehicle is not equipped with vehicle-to-vehicle communication functionality, at step S108 a determination of the velocity, likely mass and likely stiffness of the secondary vehicle is determined. The velocity in an embodiment is measured directly using one or more object detection sensors which are placed on the vehicle (see Figure 1). The likely mass of the secondary vehicle is determined using the object recognition camera 18 and the processor which are configured to identify the make and model of the secondary vehicle using known objection detection, or shape detection, techniques. Using a look up table, the likely mass of the vehicle is then subsequently used in the calculation of the likely collision energy distribution at step S108.

Other methods of estimating the secondary vehicle mass and velocity made in further embodiments are used. Therefore, at step S108 the aggressivity of the collision is determined. As described above the aggressivity of the collision will determine the proportion of the collisional energy as absorbed by each of the vehicles involved in the collision. The energy distribution calculation is based on equations 1 to 4.

The active buckling control (ABC) system thereby enables the management of the distribution of the collision energy such that the individual vehicles involved in the collision event absorb a different amount of energy than would occur if no active buckling control were to occur. In a preferred embodiment the stiffness of the crash structures is varied such that the amount of energy absorbed by each vehicle is similar. In further embodiments the amount of energy absorbed by each vehicle is proportional to the masses of the vehicles involved, and/or the ability of the crash structure to absorb the energy. Therefore depending on the requirements of the collision and the intended management of the collision the percentage of energy absorbed by each vehicle may be varied.

Therefore, in further embodiments of the invention, the management of the collision event and subsequent stiffening of the crash structures will vary depending on how the aggressivity is managed. At step S110 the initial stiffness value (set as an eigenvalue of the material, described below in further details) is determined. Once the stiffness of the crash structure to be impacted has been determined, the processor 26 emits a control signal in such that the stiffness controller 24 stiffens the crash structure 22 to the determined stiffness. Typically, such stiffening of the crash structure will occur over a time scale of 50ms.

Therefore at step S110 the ABC system has begun to reduce the aggressivity of the crash by actively varying the stiffness of the crash structure according to the parameters of the vehicles involved in the crash.

Beneficially, the invention continually monitors the collision event in order to ensure an optimal distribution of collision energy between the vehicles. Accordingly, at step S112 the likely collision energy distribution between the two vehicles is updated using the new stiffness values of the crash structure as well as the new values of the velocity of the vehicles involved. Preferably, at step S112 if both vehicles in the collision are equipped with vehicle to vehicle communication ability, the updated stiffness values of the crash structure is transmitted to the other vehicles involved in the collision. Accordingly, a more accurate determination of the likely energy distribution at the point of impact can be made.

In an embodiment where both vehicles are equipped with vehicle-to-vehicle communication ability, one of the vehicles is assigned to be a "master" vehicle, and performs the calculation for the ABC system so as to reduce aggressivity. The second vehicle awaits the results of the calculation which is subsequently transmitted as step S112 via the vehicle to vehicle communicator and acts accordingly so as to stiffen the crash structure at the value given. This ensures that conflicting calculations are not performed by the processor on each vehicle such that the subsequently calculated adapted stiffness values for each crash structure are sub-optimal.

If upon calculating the updated likely collision energy distribution the aggressivity of the impact may be further reduced, new stiffness values are determined using the multi dimensional look up table and at step S114 the value of the stiffness value of the crash structures is adjusted as appropriate.

Steps S112 and S114 may be iteratively repeated as often as possible before the collision event.

Figure 4 is a mechanical representation of two interconnected crash structures. A substructure represented by a two degrees of freedom, mass, spring and damper system, hence two structural modes, is illustrated in Figure 4, where m_1 and m_2 denote the two masses, with corresponding displacements q_1 and q_2, the three spring stiffnesses are denoted k_1, k_2, and k_3 and denote d_1, d_2, d_3 the three damping factors.

Such mechanical properties are modelled using a modal approach based on the spectral properties of the system i.e. the eigenvectors and eigenvalues. The stiffness and dissipative damping may be actively controlled in the members of the structure. As the level of force required to trigger buckling is to be varied depending on the desired level of energy absorption arising from a collision, the following equation is derived, based around the generalised eigenvalue problem

$$(K - \lambda K\sigma)v = 0 \quad for\ v \neq 0$$

Equation 5

where (λ,v) are the eigenvalues and eigenvectors, related to the modes and mode shapes, respectively, and K and $K\sigma$ are the stiffness and initial stress matrices, of the structures of interest, respectively. A given eigenvalue λ is proportional to the buckling load of a given member, and changing the eigenvalue can be achieved by controlling the stiffness of the material through the use of ACM. At the point where buckling of the structure commences, λ becomes zero, corresponding to the system becoming unstable and the stiffness matrix becoming non-positive definite. Effectively, the problem reduces to specifying the smallest positive eigenvalue, i.e. the point beyond which the structure begins to buckle.

Figure 5 is a plot of a typical force versus time curve obtained from the buckling of a frontal longitudinal member of a vehicle. In this case the peak force before buckling is 221kN.

The peak force before buckling therefore is the smallest positive eigenvalue λ for equation 7.

In effect the buckling eigenvalue λ must be greater than some pre-defined load factor, denoted C_l, i.e. $\lambda > C_l$. Therefore by specifying the buckling eigenvalue, the load factor is an adjustable quantity being modified by making use of ACM, i.e. effectively forcing the vehicle body structure to commence buckling, via ABC, at a desired point so that energy absorption is more appropriately apportioned between the two vehicles.

At step S110 the initial stiffness is selected as the initial smallest positive eigenvalue λ. Preferably this is obtained from a pre-calculated multi-dimensional look up table. As such calculations are inherently complex and involve a large number of factors, in order to ensure an effective determination of the initial positive eigenvalue for stiffness the values are pre-calculated and stored as an indexed multi-dimensional lookup table. Therefore the required stiffness values can be quickly determined based on the information as determined at steps S106.

As described at step S114 and S116 the process repeats iteratively in order to determine an optimal stiffness at the point of collision. An aspect of the invention is the ability to refine the stiffness values after the initial calculation of the stiffness value at step S110. The value determined at step S110 represents an initial selection made at the time a collision event is predicted to occur. The subsequent refinement of the eigenvalue of the stiffness of the structure is time limited up to the point of impact, denoted Δt, during which time further information regarding the collision may be collected - and subseqnetly used to refine the eigenvalue of the crash structure.

As described above, the energy absorption in a collision is inversely proportional to to the vehicle body structure (VBS) stiffness ratio, which relates to the ratio of the buckling eigenvalues. Thus controlling the ratio of the buckling eigenvalues will affect the apportionment of the collision energy of two or more colliding vehicles. Estimates of the colliding vehicle masses and collision velocity provide estimates of the magnitude of the collision energy, hence the ratios and magnitudes of the smallest positive eigenvalues.

The relative masses determine the ratio of the buckling eigenvalues and the collision velocity determines their magnitude. There are further considerations which need to be taken into account, such as high velocity collisions require structures to be stiffened to protect the occupants, and low velocity collisions require stiffening for self-protection. In both cases energy absorption distribution will be dependent on the controllable stiffness ratios. Therefore at step S114 the refinement of the stiffness of the crash structure ensures an optimal distribution of energy in a collision.

The ABC initially selects the ratio and magnitude via an initial first guess as described at step S110. For a collision involving *n* vehicles will select *n* buckling eigenvalues. Whilst the procedure generalises to *n* vehicles the following detailed description is restricted to *n*=2 for ease of understanding.

The refinement process has two separate considerations, 1) optimising the ratios of the eigenvalues of the affect crash structures, 2) optimising the magnitudes of the determined eigenvalues. Due to the nature of collisions involving a plurality of vehicles there are a number of unknown parameters which need to be estimated. The value of some of these parameters will also change during the course of Δt (for example the velocity of one or more vehicles). Preferably the present invention utilises fuzzy logic to determine optimal crash parameters.

The optimisation of the eigenvalues may be broadly described as using a "fuzzy Min operation" to fine tune the eigenvalues via nonlinear interpolation and Centre of Gravity defuzzification. The latter is used in conjunction with an on-board state and parameter estimation scheme, e.g. Kalman filter prediction-correction approach, which provides updated values of the vehicle masses, which is used to fine tune the ratios.

The optimisation of the magnitude of the eigenvalues makes use of an on-board state and parameter estimation scheme, e.g. Kalman filter prediction-correction approach, which, in conjunction with available information from on-board ADAS, e.g. object detection sensors and the object detection camera. This information is continually provided to the system during time Δt, and thus provides the processor with updated values of the estimated collision velocity, which is used to fine tune the magnitudes of the eigenvalues.

The preferred embodiment utilises multi-dimensional look up tables (MDLT) to perform these optimisation operations.

For each defined crash structure or overlapping contact frontal, side and rear $i_l = 1 \ldots p$, $i_r = 1 \ldots p$ (l and r denote left and right respectively) and for each defined angle of impact $j_l = 1 \ldots q, j_r = 1 \ldots q$, ($l$ and r denote the left and right respectively) of a host vehicle, denoted Vehicle A, and a partner vehicle, denoted Vehicle B, there exists a set comprising $2(pq - p - 1)$ MDLTs, noting the symmetry about perpendicular axes when $j = 1$ for $i = 1 \ldots p$ and the duplication of the central longitudinal axis, where $i = 1$ and $i = p$, see Figure 6.

Each MDLT contains pre-calculated values of collision energy corresponding to host and partner vehicle mass, denoted m_a and m_b, respectively, and collision velocity, denoted V_c, where

$$m_0 < m_a \leq m_\infty$$
$$m_0 < m_b \leq m_\infty$$

in which m_∞ and m_0 are upper and lower limits of mass, respectively, and

$$V_0 < V_c \leq V_\infty$$

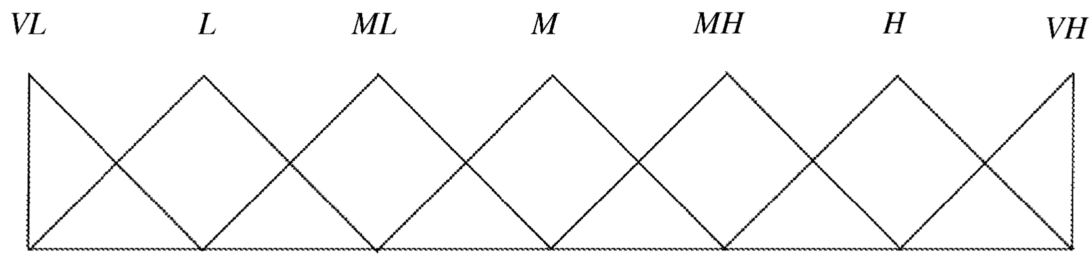
where V_∞ and V_0 are upper and lower limits of collision velocity.

In Figure 6 there is shown, by way of example only, an illustrative example of a full frontal collision case where $i = 1$ and $j = 1$. For each value of $V_c : V_0 < V_c \leq V_\infty$ in a preferred embodiment there are defined $m = 7$ arbitrary fuzzy sets for each of the host and partner vehicle. In further embodiments the number of fuzzy sets may vary.

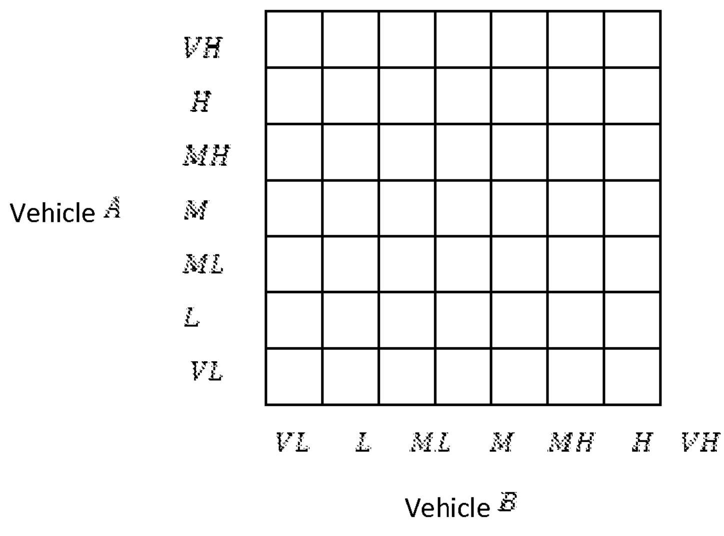
In the preferred embodiment the fuzzy sets are termed:

VL Very light
L Light
ML Medium light
M Medium
MH Medium heavy
H Heavy
VH Very Heavy

The sets are positioned on the universe of discourse as follows:

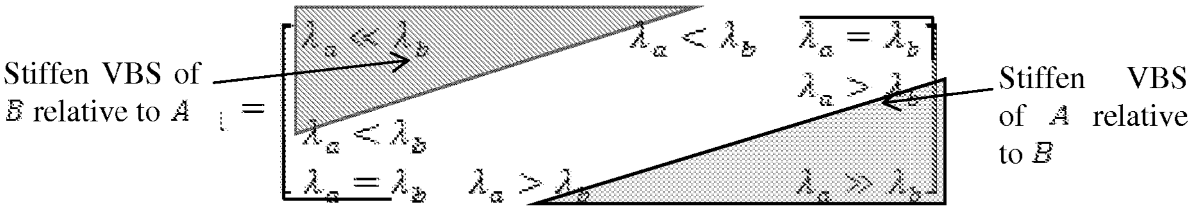


Leading to a 7 x 7 array for each V_c: $V_0 < V_c \leq V_\infty$, illustrated below.



For a given value of V_c each element in the array corresponds to a given value of collision energy, denoted ΔE, obtained from the laws of conservation of energy and momentum as per equations 1 to 4.

As can be derived from these basic principles when $m_a = m_b$ the desired buckling eigenvalues λ_a and λ_b are also equal. Accordingly it may be deduced that the desired active control or fuzzy rule base matrix, denoted R_λ, corresponding to the desired of active control to achieve a reversal of the energy distribution will take the form



By defining the degree of membership to a general fuzzy set F of a variable x as $\mu F(x)$, so that the vectors of degrees of membership for the variables m_a and m_b to the 7 arbitrary fuzzy sets are as follows:

$$P_{m_a} = \begin{bmatrix} \mu VH(m_a) \\ \mu H(m_a) \\ \mu MH(m_a) \\ \mu M(m_a) \\ \mu ML(m_a) \\ \mu L(m_a) \\ \mu VL(m_a) \end{bmatrix} \triangleq \begin{bmatrix} P_{m_{a_1}} \\ P_{m_{a_2}} \\ P_{m_{a_3}} \\ P_{m_{a_4}} \\ P_{m_{a_5}} \\ P_{m_{a_6}} \\ P_{m_{a_7}} \end{bmatrix} \text{ and } P_{m_b} = \begin{bmatrix} \mu VH(m_b) \\ \mu H(m_b) \\ \mu MH(m_b) \\ \mu M(m_b) \\ \mu ML(m_b) \\ \mu L(m_b) \\ \mu VL(m_b) \end{bmatrix} \triangleq \begin{bmatrix} P_{m_{b_1}} \\ P_{m_{b_2}} \\ P_{m_{b_3}} \\ P_{m_{b_4}} \\ P_{m_{b_5}} \\ P_{m_{b_6}} \\ P_{m_{b_7}} \end{bmatrix}$$

From the vectors P_{m_a} and P_{m_b} a matrix of firing strengths (a measure to which the sets match the inputs) is obtained via a fuzzy minimisation (fuzzy Min) operation

$$P_{m_a} \cap P_{m_b} = Min\{P_{m_a} P_{m_b}\}$$

$$P_{m_a} \cap P_{m_b} = \begin{bmatrix} Min\{P_{m_{a_1}}, P_{m_{b_7}}\} & Min\{P_{m_{a_1}}, P_{m_6}\} & Min\{P_{m_{a_1}}, P_{m_{b_5}}\} & \cdots & Min\{P_{m_{a_1}}, P_{m_{b_1}}\} \\ Min\{P_{m_{a_2}}, P_{m_{b_7}}\} & Min\{P_{m_{a_2}}, P_{m_6}\} & Min\{P_{m_{a_2}}, P_{m_5}\} & \cdots & Min\{P_{m_{a_2}}, P_{m_{b_1}}\} \\ Min\{P_{m_{a_3}}, P_{m_{b_7}}\} & Min\{P_{m_{a_3}}, P_{m_6}\} & Min\{P_{m_{a_3}}, P_{m_5}\} & \cdots & Min\{P_{m_{a_3}}, P_{m_{b_1}}\} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ Min\{P_{m_{a_7}}, P_{m_{b_7}}\} & Min\{P_{m_{a_7}}, P_{m_{b_6}}\} & Min\{P_{m_{a_7}}, P_{m_5}\} & \cdots & Min\{P_{m_{a_7}}, P_{m_{b_1}}\} \end{bmatrix}$$

Effectively the matrix $P_{m_a} \cap P_{m_b}$ will produce a 4 x 4 area of influence (which determines the firing strengths)

$$P_{m_a} \cap P_{m_b} = \begin{bmatrix} & & [+] & [+] \\ & & [+] & [+] \\ & & & \end{bmatrix}$$

where the 4 x 4 area of influence overlays the control action rule base matrix to determine the ratio of $\lambda_a : \lambda_b$ which will reverse the energy absorption distribution.

By way of example only, the following is an illustrative collision in which complete energy absorption reversal

Consider, a collision event between two vehicles having masses m_b =500kg and m_a =2000kg respectively, with the 7 membership functions as before. The corresponding 7x7 array of ratios $\lambda_a : \lambda_b$ is deduced as follows. Define R_λ: to be the rule base matrix containing the ratios $\lambda_a : \lambda_b$

$$R_\lambda = \begin{bmatrix} 1:4 & 7.5:20 & 1:2 & 12.5:20 & 3:4 & 17.5:20 & 1:1 \\ 5:17.5 & 7.5:17.5 & 10:17.5 & 12.5:17.5 & 15:17.5 & 1:1 & 20:17.5 \\ 1:3 & 1:2 & 2:3 & 12.5:15 & 1:1 & 17.5:15 & 4:3 \\ 5:12.5 & 7.5:12.5 & 10:12.5 & 1:1 & 15:12.5 & 17.5:12.5 & 20:12.5 \\ 1:2 & 7.5:10 & 1:1 & 15:10 & 3:2 & 17.5:10 & 2:1 \\ 5:7.5 & 1:1 & 10:7.5 & 12.5:7.5 & 2:1 & 17.5:7.5 & 20:7.5 \\ 1:1 & 7.5:5 & 2:1 & 12.5:5 & 3:1 & 17.5:5 & 4:1 \end{bmatrix}$$

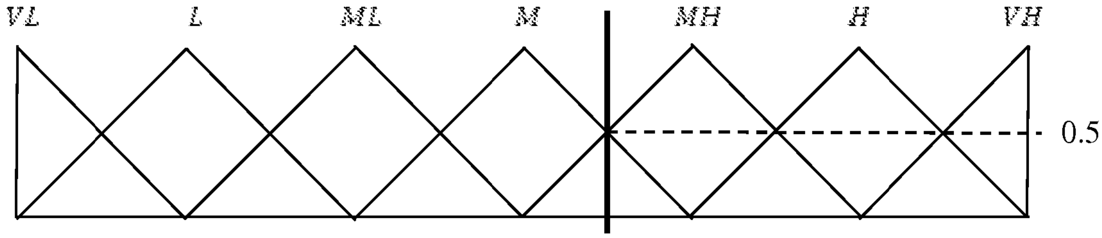
Now define the matrix R_{λ_a/λ_b} to be

$$R_{\lambda_a/\lambda_b} = \begin{bmatrix} 0.25 & 0.375 & 0.50 & 0.625 & 0.75 & 0.875 & 1.0 \\ 0.286 & 0.429 & 0.571 & 0.714 & 0.857 & 1.0 & 1.429 \\ 0.333 & 0.50 & 0.667 & 0.833 & 1.0 & 1.167 & 1.333 \\ 0.40 & 0.60 & 0.80 & 1.0 & 1.2 & 1.4 & 1.6 \\ 0.50 & 0.75 & 1.0 & 1.25 & 1.50 & 1.75 & 2.0 \\ 0.667 & 1.0 & 1.333 & 1.667 & 2.0 & 2.333 & 2.667 \\ 1.0 & 1.50 & 2.0 & 2.5 & 3.0 & 3.5 & 4.0 \end{bmatrix}$$

Now suppose P_{m_a} and P_{m_b} are found to be:

$$P_{m_a} = \begin{bmatrix} 0 \\ 0 \\ 0.5 \\ 0.5 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

implying that Vehicle A is half way between Medium Heavy and Medium i.e.

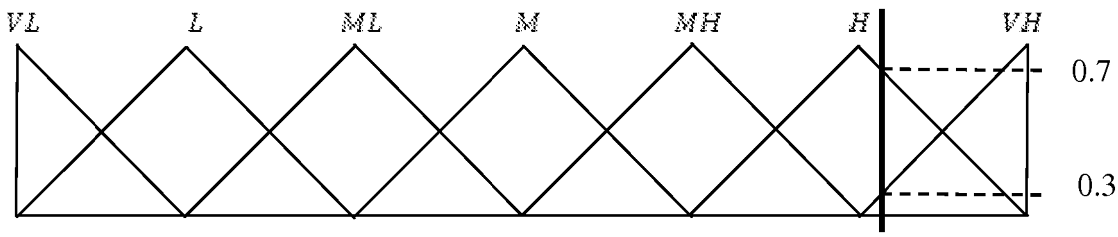


$\mu M(ma) = 0.5$
$\mu MH(ma) = 0.5$

and

$$P_{m_b} = \begin{bmatrix} 0.3 \\ 0.7 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

i.e.



$\mu VM(m_b) = 0.3$

$\mu MH(m_b) = 0.7$

It follows from $P_{m_a} \cap P_{m_b}$

Area of influence

$$P_{m_a} \cap P_{m_b} = \begin{bmatrix} 0 \\ 0 \\ 0.5 \\ 0.5 \\ 0 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.5 & 0.3 \\ 0 & 0 & 0 & 0 & 0 & 0.5 & 0.3 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0.7 & 0.3 \end{bmatrix}$$

Hence the rule base matrix R_{λ_a/λ_b} is activated with the firing strengths indicated in $P_{m_a} \cap P_{m_b}$ with the rules

$$R_{\lambda_a/\lambda_b} = \begin{bmatrix} & & & & & & \\ & & & & & 1.167 & 1.333 \\ & & & & & 1.4 & 1.6 \\ & & & & & & \\ & & & & & & \end{bmatrix}$$

being activated by the Centre of Gravity method

$$\frac{\lambda_a}{\lambda_b} = \frac{0.5 * 1.167 + 0.3 * 1.333 + 0.5 * 1.4 + 0.3 * 1.6}{0.5 + 0.3 + 0.5 + 0.3}$$

$$= 1.352$$

- λ_a:λ_b= 1.35:1.0 which implies that Vehicle A should be stiffened 1.35 times higher than Vehicle B.
- The magnitude of the eigenvalues will be dependent on the collision velocity, denoted V_c.

Note that the first guess would use the fuzzy Max operation obtained from

$$P_{m_a} \cup P_{m_b} = \begin{bmatrix} Max\{P_{m_{a_1}} P_{m_{b_7}}\} & Max\{P_{m_{a_1}} P_{m_6}\} & Max\{P_{m_{a_1}} P_{m_{b_5}}\} & \cdots & Max\{P_{m_{a_1}} P_{m_{b_1}}\} \\ Max\{P_{m_{a_2}} P_{m_{b_7}}\} & Max\{P_{m_{a_2}} P_{m_6}\} & Max\{P_{m_{a_2}} P_{m_5}\} & \cdots & Max\{P_{m_{a_2}} P_{m_{b_1}}\} \\ Max\{P_{m_{a_3}} P_{m_{b_7}}\} & Max\{P_{m_{a_3}} P_{m_6}\} & Max\{P_{m_{a_3}} P_{m_5}\} & \cdots & Max\{P_{m_{a_3}} P_{m_{b_1}}\} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ Max\{P_{m_{a_7}} P_{m_{b_7}}\} & Max\{P_{m_{a_7}} P_{m_{b_6}}\} & Max\{P_{m_{a_7}} P_{m_5}\} & \cdots & Max\{P_{m_{a_7}} P_{m_{b_1}}\} \end{bmatrix}$$

which would select the fuzzy rule with the highest firing strength (here 0.7 is the highest) and the higher of the two rules selected

$$P_{m_a} \cap P_{m_b} = \begin{bmatrix} 0 \\ 0 \\ 0.5 \\ 0.5 \\ 0 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.7 & 0.5 \\ 0 & 0 & 0 & 0 & 0 & 0.7 & 0.5 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0.7 & 0.3 \end{bmatrix}$$

When this is superimposed on the rule base R_{λ_a/λ_b} the highest value is selected corresponding to the highest firing strength

$$R_{\lambda_a/\lambda_b} = \begin{bmatrix} & & & \\ & & 1.167 & 1.333 \\ & & 1.4 & 1.6 \\ & & & \end{bmatrix}$$

Hence a value of 1.4 would have been chosen as the initial first guess (pre-calculated) ratio of $\lambda_a : \lambda_b$. Use of fuzzy MIN operation and Cenre of Gravity then provides the first refinment to the ratio.

A similar fuzzy Max operation applies to selecting the value of ΔE from the nearest (i.e. highest degree of membership) from the fuzzy sets on the universe the discourse corresponding to the collision velocity. The prediced value of V_c will be closest to one of the pre-calculated matrix layers and this value is taken initially, with refinement using the on-board state and parameter estimation scheme and fine tuned using interpolation between the matrix layers of the MDLT. From ΔE Buckling load is proportional to the total energy to be dissipated, and the ratio of dissipated energy is inversely proportional to the stiffnesses.

Therefore the calculation of the collision energy distribution (and the stiffness of the crash structure) may be further refined in an optimal manner using the above techniques to best determine parameters which at the point of collision will mostly be unknown.

The process can be summarised as thus:

i) Collision avoidance strategies deployed, e.g. collision avoidance, emergency braking
ii) Collision declared imminent via V2V and on-board mass/velocity information exchange/commuted

iii) Activate fuzzy MAX operator on one or both host and partner vehicles to determine the ratio of $\lambda_a : \lambda_b$ and pre-stiffen VBS accordingly

iv) Activate fuzzy MIN operator and Centre of Gravity to fine tune ratio of $\lambda_a : \lambda_b$

v) Via on-board Kaman filter or other state/parameter estimation algorithm fine tune V_r, keeping ratio $\lambda_a : \lambda_b$ as in iv) fine tune the relative magnitudes

vi) Repeat v) as appropriate up to a finite time Δt before collision

vii) Freeze λ_a and λ_b at time Δt before actual collision

Therefore, the present invention allows for a collision to be managed in such a manner that the energy distribution between two or more vehicles is controlled to reduce, or manage, any potential imbalance in the energy distribution. Thus the invention reduces the effect of the aggressivity of a crash where a heavier vehicle (which would typically be configured to absorb more energy without permanent damage) would normally absorb less energy than a lighter vehicle (which is typically able to absorb less energy). Thus the imbalance between the energy absorbed by the vehicles is reduced. Further as the stiffness of the crash structures is variable the weight of the crash structure is reduced as less material is required. This has advantages in fuel saving (as the vehicles weigh less) whilst being able to provide a safe structure (as the crash structure is able to stiffen at the time of impact).

Claims

1. A method of managing collisions between a plurality of vehicles in a active collision management system, wherein one or more the of the vehicles has a crash structure whose stiffness can be adjusted and one or more object detection sensors, the method comprising the steps of:

determining whether a collision event between the plurality of vehicles is to occur based on data measured by one or more object detection sensors; and in the event that a collision event is to occur,

for a first vehicle involved in the collision event:

identifying a first crash structure and

determining an initial stiffness of the crash structure; and subsequently

determining a level of aggressivity of the collision based on a predicted energy absorption as result of the collision for each of the plurality of vehicles;

determining a subsequent stiffness value for the first crash structure based on the predicted energy absorption and level of aggressivity of the collision such that the energy absorbed by the crash structure is changed and the level of aggressivity of the collision is reduced; and

stiffening the first crash structure to the subsequently determined stiffness value.

2. The method of claim 1 wherein the step of determining the aggressivity comprises the steps of:

predicting an initial mass and/or velocity of a plurality of the vehicles involved in the collision based on information received from one or more object detection sensors; and

calculating the energy absorption for each vehicle based on the predicted mass and/or velocity.

3. The method of any preceding claim wherein the prediction of the mass of vehicle is based on information received from an object recognition camera and the method further comprises the step of determining a likely make and model, and mass, of the vehicle from the information received by the object recognition camera.

4. The method of any preceding claim further comprising the step of the first vehicle initiating communication with a second vehicle via a vehicle to vehicle communicator; and

the second vehicle communicating to the first vehicle the mass and/or velocity of the second vehicle.

5. The method of any preceding claim wherein the initial stiffness of the first crash structure is based on modal structural modelling of the crash structure and vehicle and the minimisation of the eigenvalue of the crash structure.

6. The method of claim 5 wherein the determination of the subsequent stiffness of the crash structure comprises the steps of:

optimising the ratios of the eigenvalue of the crash structure

optimising the magnitude of the optimised eigenvalue

7. The method of claim 6 where the optimisation of the ratio of the eigenvalue and magnitude of the optimised occurs using multi-dimensional look up tables

8. The method of any preceding wherein the subsequent stiffness is determined based on in part on using subsequently determined vehicle masses and/or velocities.

9. The method of claim 8 when dependent on any of 5 to 7 wherein the subsequently determined masses and/or velocities are predicted using prediction correction algorithm.

10. The method of claim 10 wherein the prediction correction algorithm is a Kalman filter.

11. The method of any preceding wherein the steps of identifying a crash structure and the subsequent variation of the stiffness of the crash structure is repeated for one or more further vehicles.

12. The method of any preceding claim wherein one or more further crash structures are identified and their stiffness varied so as to reduce the agressivity of the collision.

13. The method of claim 11 or 12 wherein the ratio of the eigenvalues between two crash structures is varied to reduce the aggressivity of the collision.

14. The method of claim 13 wherein the ratio of eignevalues is varied using fuzzy logic to determine a desired ratio in order to reduce aggressivity.

15. The method of any preceding wherein the crash structure comprises a portion made of one or more of a: piezoelectric polymer, shape memory alloy, magnetorheological material.

16. A vehicle having an active buckling system stored thereon, the vehicle comprising:

a first crash structure having a portion of an actively controlled material configured to vary in stiffness;

a first object detection sensor;

an on board processor, the on-board processor configured to:

determine whether a collision event between the vehicle and a second vehicle is to occur based on data measured by the first object detection sensor; and in the event that a collision event is to occur,

determine an initial stiffness of the first crash structure;

determine a level of aggressivity of the collision based on a predicted energy absorption as result of the collision for the first and second vehicles;

determine a subsequent stiffness value for the first crash structure based on the predicted energy absorption and level of aggressivity of the collision such that the energy absorbed by the crash structure is changed and the level of aggressivity of the collision is reduced; and

send a control signal to stiffen the first crash structure to the subsequently determined stiffness value.

17. The vehicle of claim 16 wherein the processor is configured to perform the steps of any of the method claims 1 to 15.

17. A computer readable medium having instructed stored thereon which when executed on a processor cause the processor to execute the steps of any of method claims 1 to 15.

Application No:	GB1320489.6	**Examiner:**	Peter Gardiner
Claims searched:	1 to 18	**Date of search:**	18 June 2014

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
Y	1-4,8,11,12,15-17	US 7046167 B2 (RAO) See the whole document, in particular the active stiffening system activated in the event of an imminent collision.
Y	1-3,8,11,12,15-17	US 2004/0061598 A1 (KING) See the whole document, in particular the calculation of the kinetic energies of both vehicles and the determination of a collision severity which is used to trigger countermeasures.
Y	1,2,4,8,11,12,15-17	US 2004/0254729 A1 (BROWNE) See the whole document, in particular the communication between the two vehicles so that energy levels of both vehicles can be calculated and occupant protection devices can subsequently be triggered.
Y	1,2,4,8,11,12,15-17	US 2002/0169533 A1 (BROWNE) See the whole document, in particular the embodiment of figures 10 to 12 where communications are established between two vehicles so that kinetic energy levels and crash severity levels can be calculated.
Y	1,2,4,8,11,12,15-17	US 2002/0099485 A1 (BROWNE) See the whole document, in particular how communications are established between two vehicles so that kinetic energy levels and crash severity levels can be calculated.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

B60R; B62D; G01S

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC

International Classification:

Subclass	Subgroup	Valid From
B60R	0021/0134	01/01/2006
B62D	0021/15	01/01/2006