DEVELOPMENT OF AN OCCUPANT POSITION SENSOR SYSTEM TO IMPROVE FRONTAL CRASH PROTECTION

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ABSTRACT

In motor vehicle crashes where an occupant has been seriously or fatally injured from a deploying air bag, a common finding has been that the occupant was in close proximity to the air bag (or out-of-position) at the time of deployment. The occupant may have been out-of-position for a variety of reasons including: driver loss of consciousness, pre-impact braking, multiple impacts, rear facing child seat installation, or late firing of the air bag after the occupant has already been forced against the air bag by the crash deceleration. Considerable research has been initiated to develop new or enhanced injury countermeasures to mitigate injuries to persons, particularly children, who are out-of-position at the time of air bag deployment. This paper reports on the development of an occupant position sensor that might be used in conjunction with dual stage or multi-stage inflation technologies for modulating air bag deployment.

The occupant position sensor system described in this paper uses ultrasonic transducers in conjunction with pattern recognition algorithms for the discrimination of out-of-position occupants and rear facing child safety seats. Four ultrasonic transducers operating at 40 kHz, located strategically within the occupant compartment, emit unfocused, wide-beam pulses toward the passenger volume. These pulses are emitted sequentially and each produce return echoes which contain information for discrimination in approximately 10 msec. Thus, the occupant position is updated every 40 msec. The decision algorithm processes the returned information to classify the occupant through the use of a uniquely trained neural network. The logic of the neural network was developed through extensive in-vehicle training with thousands of realistic occupant size and position scenarios. The ultrasonic occupant position sensor can also be used in conjunction with other technologies, (such as weight sensing, seat belt sensing, crash severity sensing, etc.) to feed information to the air bag system's central processor to govern the deployment decision of the air bag.

BACKGROUND

The ultrasonic occupant position sensor embraces the fields of sensing, detecting, monitoring and identifying various objects that are located within the passenger compartment of a motor vehicle. In particular, it is an efficient and highly reliable system for detecting the orientation of an object in the passenger compartment, such as a rear facing child seat (RFCS) situated in the passenger compartment in a location where it may interact with a deploying occupant protection apparatus, such as an airbag, and for detecting an out-of-position occupant. The system permits the control and selective suppression of deployment of the occupant protection apparatus when the deployment may result in greater injury to the occupant than the crash forces themselves. This is accomplished in part through the judicious placement of transducers in the vehicle, and the use of a pattern recognition system including a method of training a neural network to analyze signals from the transducers.

Whereas thousands of lives have been saved by airbags, a large number of people have also been injured, some seriously, by the deploying airbag, and thus significant improvements to the airbag system are necessary. For a variety of reasons, vehicle occupants may be too close to the airbag before it deploys and can be seriously injured as a result of the deployment. Also, a child in a rear facing child seat that is placed on the right front passenger seat is in danger of being seriously injured if the passenger airbag deploys. For these reasons occupant position sensing and rear facing child seat detection systems are required in order to minimize the damage caused by deploying airbags.

Initially, these systems will solve the out-of-position occupant and the rear facing child seat problems related to current airbag systems and prevent unneeded and unwanted airbag deployments when a front seat is unoccupied. However, airbags are now under development to protect rear seat occupants in vehicle crashes and all occupants in side impacts. A system will therefore be needed for these new applications to detect the presence of occupants, determine if they are out-of-position and to identify the presence of a child seat.

The automatic adjustment of the deployment rate of the airbag based on occupant identification and position and on crash severity has been termed "smart airbags". Central to the development of smart airbags is the occupant identification and position determination systems described here and in the references below.

This system is based on pattern recognition technologies as taught in numerous textbooks and technical papers (1), (2). The theory of neural networks including many examples can be found in several books on the subject including (4-8). A more detailed description of the present and some systems under development can be found in (3).

Neural networks may be used to tailor the airbag inflation to the size, position and relative velocity of the occupant. Other factors such as crash severity, seatbelt usage, seat and seat back positions, vehicle velocity, and any other relevant information can also be included in the general system described here. The combination of these systems in various forms can be used to optimize inflation and deflation of the airbag to create a "smart airbag" system.

SMART AIRBAGS

Smart airbags can take several forms which can be roughly categorized into four evolutionary stages, which will hereinafter be referred to as Phase 1 (2,3,4) Smart Airbags, as follows (2):

1) Occupant sensors use various technologies to turn off the airbag where there is a rear facing child seat present or if either the driver or passenger is out-of-position to where he or she is more likely to be injured by the airbag than from the accident. This is the focus of the occupant detection system described here.
2) Occupant sensors are used along with variable inflation or deflation rate airbags to adjust the inflation or deflation rate to match the occupant, first as to his or her position and then to his or her morphology. The neural network occupant sensors discussed in (3) will also handle this with the addition of an occupant weighing system. One particular weight measuring system, for example, makes use of strain gages mounted onto the seat supporting structure. At the end of this phase, little more can be done with occupant measurement or characterization systems.
3) The next improvement is to use a neural network as the basis of a crash sensor not only to determine if the airbag should be deployed, but also to predict the crash severity from the pattern of the initial portion of the crash pulse. Additionally, the crash pulse can continue to be monitored even after the decision has been made to deploy the airbag to see if the initial assumption of the crash type, based on the pattern up to the deployment decision, was correct. If the pattern changes indicating a different crash type, the flow rate to the airbag can be altered instantaneously.
4) Finally, anticipatory sensing using neural networks can be used to identify the crash before it takes place and select the deployment characteristics of the airbag to match the anticipated crash with the occupant size, position, velocity, etc.

Any of these phases can also be combined with various methods of controlling the pretensioning, retraction, or energy dissipation characteristics of the seatbelt. Although the main focus here is the control of the flow of gas into and out of the airbag, the control of the seatbelt can also be accomplished and the condition of the seatbelt can be valuable input information into the neural network system.

The smart airbag problem is complex and difficult to solve by ordinary mathematical methods. Crash sensors can predict that a crash is of a severity that requires the deployment of an airbag for the majority of real world crashes. A more difficult problem is to predict the crash velocity versus time function and then to adjust the airbag inflation or deflation over time so that just the proper amount of gas is in the airbag at all times even without considering the influence of the occupant. To also simultaneously consider the influence of occupant size, weight, position and velocity renders this problem, for all practical purposes, unsolvable by conventional methods. A pattern recognition system is therefore required.

Pattern recognition techniques, such as artificial neural networks, are finding increased application in solving a variety of problems such as optical character recognition, voice recognition, and military target identification.

In the automotive industry, neural networks have now been applied to engine control and to identify various objects within the passenger compartment of the vehicle, such as a rear facing child seat. They have also been proposed for use with anticipatory sensing systems to identify threatening objects, such as an approaching vehicle about to impact the side of the vehicle. Neural networks have also been applied to sense automobile crashes for the purpose of determining whether or not to deploy an airbag or other passive restraint, or to tighten the seatbelts, cut off the fuel system, or unlock the doors after the crash. Neural networks can be applied to forecast the severity of automobile crashes for the purpose of controlling the flow of gas into or out of an airbag in order to tailor the airbag inflation characteristics to the crash severity. Neural networks additionally can be used to tailor the airbag inflation characteristics to the size, position or relative velocity of the occupant or other factors such as seatbelt usage, seat and seat back positions, headrest position, vehicle velocity, etc.

DEFINITIONS

"Pattern recognition" generally means any system which processes a signal that is generated by an object or is modified by interacting with an object, in order to determine which set of classes that the object belongs to. Such a system might determine only that the object is or is not a member of one specified class, might attempt to assign the object to one of a larger set of specified classes, or might find that it is not a member of any of the classes in the set. The signals processed are generally a series of electrical signals coming from transducers that are sensitive to acoustic (ultrasonic) or electromagnetic radiation (radar, visible light or infrared radiation), although other sources of information are frequently included.

A "trainable or a trained pattern recognition system" generally means a pattern recognition system which is taught to recognize various patterns constituted within the signals by subjecting the system to a variety of examples. The most successful such system is the neural network. For the purposes here, the identity of an object sometimes applies to not only the object itself but also its location and orientation in the passenger compartment. For example, a rear facing child seat is a different object than a forward facing child seat and an out-of-position adult is a different object than a normally seated adult.

To "identify" generally means to determine that the object belongs to a particular set or class. The class may be one containing, for example, all rear facing child seats, all human occupants, or all human occupants not sitting in a rear facing child seat depending on the purpose of the system. In the case where a particular person is to be recognized, the set or class will contain only a single element, i.e., the person to be recognized.

An "occupying item" of a seat may be a living occupant such as a human or a dog, another living organism such as a plant, or an inanimate object such as a box or bag of groceries or an empty child seat.

"Out-of-position" generally means that the occupant, either the driver or a passenger, is sufficiently close to the occupant protection apparatus (airbag) prior to deployment that he or she is likely to be more seriously injured by the deployment event itself than by the accident. It may also mean that the occupant is not positioned appropriately in order to attain beneficial, restraining effects of the deployment of the airbag. The occupant is typically too close to the airbag, when the occupant's head or chest is closer than some distance such as about 127 mm (5 in.) from the deployment door of the airbag module. The actual distance value where airbag deployment should be suppressed depends on the design of the airbag module and is typically farther for the passenger airbag than for the driver airbag.

DESCRIPTION OF THE ULTRASONIC OCCUPANT SENSOR SYSTEM

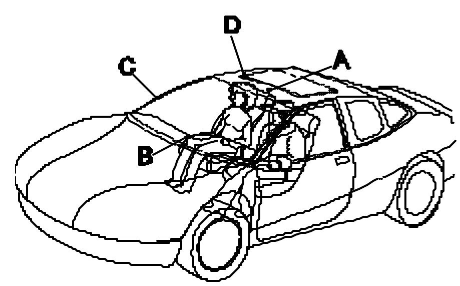

Figure 1. Occupant monitoring system.

Figure 1 illustrates an ultrasonic occupant monitoring system that is capable of identifying the occupancy of a vehicle and measuring the location and velocity of human occupants. This system has now been developed and implemented on a production vehicle. Four ultrasonic transducers are used to provide accurate identification and position monitoring of the passenger of the vehicle. Naturally, a similar system can be implemented on the driver side. The system is capable of determining the pre-crash location of the critical parts of the occupant, such as his or her head and chest, and then to track their motion toward the airbag with readings as fast as once every 40 milliseconds with the current static first generation system and 10 msec for the second generation system with dynamic out-of-position capability. This is sufficient to determine the position and velocity of the occupant during a crash event. The implementation described can therefore determine at what point the occupant will get sufficiently out-of-position so that deployment of the airbag should be suppressed.

An ultrasonic occupant position sensor is one approach for a first generation occupant sensing system and is discussed below. This system uses an Artificial Neural Network (ANN) to recognize patterns that it has been trained to identify as either airbag enable or airbag disable conditions. The pattern is obtained from four ultrasonic transducers that cover the front passenger seating area. This pattern consists of the ultrasonic echoes reflected off of the objects in the passenger seat area. The signal from each of the four transducers consists of the electrical image of the return echoes. The electronic processing comprises amplification, logarithmic compression, rectification, and demodulation (band pass filtering), followed by discretization (sampling) and digitization of the signal. Normalization, which is mapping the input to numbers between 0 and 1, is performed on the data prior to feeding the data into the neural network.

Ultrasonic spatial sensors are typically mounted on the upper portion of the A-Pillar, on or near the B-Pillar, on or adjacent to the roof or headliner and, in some cases, on the instrument panel as shown in Figure 1. The outputs of the transducers are input to a band pass filter through a multiplex circuit which is switched in synchronization with a timing signal from the ultrasonic sensor drive circuit, and then is amplified by an amplifier. The band pass filter removes a low frequency wave component from the output signal and also removes some of the noise. The envelope wave signal is input to an analog to digital converter (ADC) and digitized as measured data. The measured data is input to a processing circuit, which is controlled by the timing signal that is in turn output from the sensor drive circuit. Each of the measured data is input to a normalization circuit and normalized. The normalized measured data is input to the neural network circuit as wave data.

In addition to the ultrasonic occupant spatial sensor, a measurement of weight is frequently incorporated into the occupant sensing system as illustrated in Figure 2. Weight measuring transducers are usually associated with the seat and can be mounted into or below the seat portion or on the seat structure, for example, for measuring the weight applied onto the seat. A plurality of different sensors can be used that measure the weight applied onto the seat at different portions such as by means of an airbag or bladder, which may have one or more compartments, in the seat portion. Such sensors may also be in the form of stress, force or pressure sensors which measure the force or pressure on the seat portion or seat back, displacement measuring sensors which measure the displacement of the seat surface or the entire seat, such as through the use of

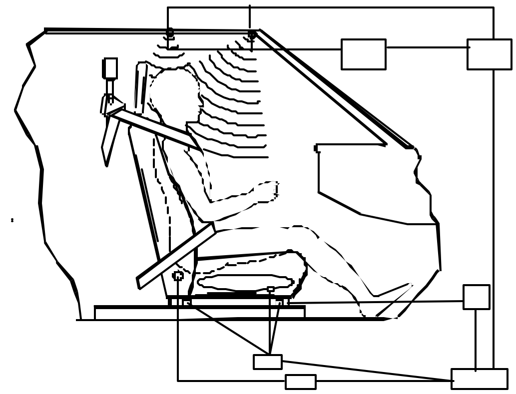

Figure 2. Occupant sensing system including weight measurement.

strain gages mounted on the seat structural members or other appropriate locations, or systems which convert displacement into a pressure wherein a pressure sensor can be used as a measure of weight.

The output of the weight sensor(s) can be treated in a variety of ways. One option is to use the weight measurement system as an independent system in series with the spatial sensor as the prime determinator of an empty seat or of the presence of a child. Alternately, it can be combined with the spatial sensor data either in the same neural network or as part of a modular neural network system.

In the case of a forward facing child seat containing a child, at times it may be desired that the airbag not be disabled in the event of an accident. However, in the event that the same child seat is placed in the rearward facing position, then the airbag is usually required to be disabled since deployment of the airbag in a crash can seriously injure the child. Furthermore if an infant in an infant carrier is positioned in the rear facing position of the passenger seat, the airbag may be disabled for the reasons discussed above. Instead of disabling deployment of the airbag, the deployment could be controlled to provide protection for the child. It should be noted that the disabling or enabling of the passenger airbag relative to the item on the passenger seat may be tailored to the specific application. For example, in some embodiments, with certain forward facing child seats, it may in fact be desirable to disable the airbag and in other cases to deploy a depowered airbag.

THEORY OF THE ULTRASONIC SENSING SYSTEM

When looking at a single ultrasonic transducer, it is not possible to determine the direction to the object that is reflecting or modifying the signal, but it is possible to know only how far that object is from the transducer. A single transducer enables a distance measurement but not a directional measurement. The object may be at a point on the surface of a three-dimensional spherical segment having its origin at the transducer and a radius equal to the distance.

Consider now two transducers where both transducers receive a reflection from the same object, the timing of the reflections depends on the distance from the object to each respective transducer. If the two transducers act independently, that is, they only listen to the reflections of waves that they themselves transmitted, then each transducer knows the distance to the reflecting object but not its direction. If we assume that the transducer radiates ultrasound in all directions within the field cone angle, each transducer knows that the object is located on a spherical surface a respective known distance from the transducer, that is, each transducer knows that the object is a specific distance from that transducer which may or may not be the same distance between the other transducer and the same object. Since now there are two transducers, and the distance of the reflecting object is known relative to each of the transducers, the actual location of the object resides on a circle that is the intersection of the two spherical surfaces. At each point along the circle, the distance to the transducer is the same. This, of course, is strictly true only for ideal one-dimensional objects.

For many cases, the mere knowledge that the object lies on a particular circle is sufficient since it is possible to locate the circle. That is, the circle that passes through the area of interest otherwise passes through a volume where no objects can occur. Thus, the mere calculation of the circle in this specific location, which indicates the presence of the object along that circle, provides valuable information concerning the object in the passenger compartment which may be used to control or affect another system in the vehicle such as the airbag system. This of course is based on the assumption that the reflections to the two transducers are in fact from the same object. Care must be taken in locating the transducers such that other objects do not cause reflections that could confuse the system.

Figure 3 for example illustrates two circles D and E, which represent the volume which is usually occupied when the seat is occupied by a person not in a child seat, or by a forward facing child seat and the volume normally occupied by a rear facing child seat, respectively. Thus, if the circle generated by the system is at a location which is only occupied by an adult passenger, the airbag would not be disabled since its deployment in a crash is desired. On the other hand, if a circle is at a location occupied only by a rear facing child seat, the airbag would be disabled.

The above discussion of course is simplistic in that it does not take into account the volume occupied by the object or the fact the reflections from more

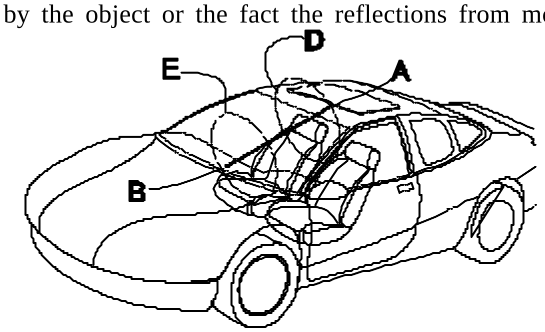

Figure 3. Spatial volumes for occupant detection.

than one object surface will be involved. In reality, one transducer is likely to pick up the rear of the occupant's head and the other transducer, the front. This makes the situation more difficult for an engineer looking at the data to analyze. It has been found that pattern recognition technologies, such as neural networks, are able to extract the information from these situations. Furthermore through a proper application of these technologies, an algorithm can be developed, which when installed as part of the system for a particular vehicle, the system accurately and reliably differentiates between a forward facing and rear facing child seat, for example, or an in-position or out-of-position forward facing human.

From the above discussion, a method of transducer location is presented which provides unique information to differentiate between (i) a forward facing child seat or a forward properly positioned occupant and (ii) a rearward facing child seat and an out-of-position occupant. In actuality, the algorithm used to implement this theory does not directly calculate the surface of spheres or the circles of interaction of spheres. Instead, a pattern recognition system is used to differentiate airbag-deployment desired cases from those where the airbag should not be deployed. For the pattern recognition system to accurately perform its function, however, the patterns presented to the system must have the requisite information. That is, a pattern of reflected waves from an occupying item in a passenger compartment to various transducers must be uniquely different for cases where airbag deployment is desired from cases where deployment is not desired. The theory described above and in more detail in the references, explains how to locate transducers within the vehicle passenger compartment so that the patterns of reflected waves will be easily distinguishable in cases where airbag deployment is desired from those where deployment is not desired. In the case presented thus far, it has been shown that in some implementations the use of only two transducers can result in the desired pattern differentiation when the vehicle geometry is such that two transducers can be placed such that the circles for airbag enabled and for airbag disabled fall outside of the transducer field cones except where they are in the critical regions where positive identification of the condition occurs. Thus, the aim and field angle of the transducers are important factors to determine in adapting a system to a particular vehicle.

The use of only two transducers in a system is typically not acceptable since one or both of the transducers can be rendered inoperable by being blocked, for example, by a newspaper. Thus, it is desirable to add a third transducer which now provides a third set of spherical surfaces relative to the third transducer. The three spherical surfaces now intersect in only two points and in fact, usually at one point if the aiming angles and field angles are properly chosen. Thus, the addition of a third transducer substantially improves system reliability. Finally, with the addition of a fourth transducer even greater accuracy and reliability is attained.

Three general classes of child seats exist as well as several models that are unique. First, there is the infant only seat that is for occupants weighing up to about 9 kg (20 lbs.). This is designed to be placed only in the rear facing position. The second is for children from about 9-18 kg (20-40 lbs.) and can be used in both the forward and rear facing position and the third is for use only in the forward facing position and is for children weighing over about 18 kg (40 lbs.). All of these seats as well as the unique models are used in test setups for adapting an occupant detection system to a vehicle. For each child seat, there are several hundred unique orientations representing virtually every possible position of that seat within the vehicle. Tests are run, for example, with the seat tilted 22 degrees, rotated 17 degrees, placed on the front of the seat with the seat back fully up, with the seat fully back, and with the window open, as well as all variations of these parameters. A large number of cases are also run, when practicing the teachings of this system, with various accessories, such as clothing, toys, bottles, blankets etc., added to the child seat.

Similarly, wide variations are used for older passenger seat occupants including size, clothing and activities such as reading maps or newspapers, or leaning forward to adjust the radio, for example. Also included are cases where the occupant puts his or her feet on the dashboard or otherwise assumes a wide variety of unusual positions. When all of the above configurations are considered along with many others not mentioned, the total number of configurations that are used to train the pattern recognition system can exceed 500,000. The goal is to include in the configuration training set representations of all occupancy states that occur in actual use. Since the system is highly accurate in making the correct decision for cases that are similar to those in the training set, the total system accuracy increases as the size of the training set increases, providing the cases are all distinct and not copies of other cases.

In addition to all of the variations in occupancy states, it is important to consider environmental effects during the data collection. Thermal gradients or thermal instabilities are particularly important since sound waves can be significantly diffracted by density changes in air. There are two aspects of the use of thermal gradients or instability in training. First, the fact that thermal instabilities exist and therefore data with thermal instabilities present should be part of the database. For this case, a rather small amount of data collected with thermal instabilities would be used. A much more important use of thermal instability comes from the fact that they add variability to data. Thus, considerably more data is taken with thermal instability in order to provide variability to the data so that the neural network does not memorize but instead generalizes from the data. This is accomplished by taking the data with a cold vehicle with the heater operating and with a hot vehicle with the air conditioner operating. Additional data is also taken with a heat lamp in a closed vehicle to simulate a stable thermal gradient caused by sun loading.

To collect data for 500,000 vehicle configurations is not a formidable task. A trained technician crew can typically collect data in excess of 2000 configurations or vectors per hour. The data is collected typically every 50 to 100 milliseconds. During this time, the occupant is continuously moving, assuming a continuously varying position and posture in the vehicle including moving from side to side, forward and back, twisting his or her head, reading newspapers and books, moving hands, arms, feet and legs, until the desired number of different seated state examples are obtained. In some cases, this process is practiced by confining the motion of an occupant into a particular zone. In some cases, for example, the occupant is trained to exercise these different motions while remaining in a particular zone that may be the safe zone, the keep out zone, or an intermediate gray zone. In this manner, data is collected representing the airbag disable, depowered airbag enabled or full power airbag enabled states. In other cases, the actual position of the back of the head or the shoulders of the occupant are tracked using string pots, high frequency ultrasonic transducers, or optically. In this manner, the position of the occupant can be measured and the decision as to whether this should be a disable or enable airbag case can be decided later. By continuously monitoring the occupant, an added advantage results in that the data can be collected to permit a comparison of the occupant from one seated state to another. This is particularly valuable in attempting to project the future location of an occupant based on a series of past locations as would be desirable, for example, to predict when an occupant would cross into the keep out zone during a panic braking situation.

THE PROCESS FOR TRAINING A VEHICLE

Adapting an ultrasonic occupant sensing system to a particular vehicle platform involves the determination of the hardware configuration and the software algorithms. Each vehicle model or platform will generally have a different hardware configuration and different algorithms.

The steps for adapting an ultrasonic system to a vehicle will now be described.

1. Select transducer and horn designs to fit the vehicle. At this stage, usually full horns are used which are mounted so that they project into the passenger compartment. No attempt is made at this time to achieve an esthetic matching of the transducers to the vehicle surfaces. An estimate of the desired transducer fields is made at this time either from measurements in the vehicle directly or from CAD drawings.
2. Make polar plots of the transducer sonic fields. Transducers and candidate horns are assembled and tested to confirm that the desired field angles have been achieved. This frequently requires some adjustment of the transducers in the horn.
3. Check to see that the fields cover the required volumes of the vehicle passenger compartment and do not impinge on adjacent flat surfaces that may cause multipath effects. Redesign horns if necessary.
4. Install transducers into vehicle.
5. Map transducer fields in the vehicle and check for multipath effects and proper coverage.
6. Adjust transducer aim and re-map fields if necessary.
7. Install daily calibration fixture and take standard setup data.
8. Acquire 50,000 to 100,000 vectors.
9. Adjust vectors for volume considerations by removing some initial data points if cross talk is present and some final points to keep data in the desired passenger compartment volume.
10. Normalize vectors.
11. Run neural network algorithm generating software to create algorithm for vehicle installation.
12. Check the accuracy of the algorithm. If not sufficiently accurate collect more data where necessary and retrain. If still not sufficiently accurate, add additional transducers to cover holes.
13. When sufficient accuracy is attained, proceed to collect ~500,000 training vectors as described above.
14. Collect ~100,000 vectors of independent data using other combinations of the above.
15. Collect ~ 50,000 vectors of "real world data" to represent the acceptance criteria and more closely represent the actual seated state probabilities in the real world.
16. Train network and create algorithm using the training vectors and the independent data vectors.
17. Validate the algorithm using the real world vectors.
18. Install algorithm into the vehicle and test.
19. Decide on post-processing methodology to remove final holes in system.
20. Implement post-processing methods into the algorithm.
21. Final test. The process up until step 13 involves the use of transducers with full horns mounted on the surfaces of the interior passenger compartment. At some point, the actual transducers, which are to be used in the final vehicle, must be substituted for the trial transducers. This is either done prior to step 13 or at this step. This process involves designing transducer holders that blend with the visual surfaces of the passenger compartment so that they can be covered with a screen or mesh to retain the esthetic quality of the interior. This is usually a lengthy process and involves several consultations with the customer. Usually, therefore, the steps from 13 through 20 are repeated at this point after the final transducer and holder design has been selected. The initial data taken with full horns gives a measure of the best system that can be made to operate in the vehicle. Some degradation in performance is expected when the esthetic horns are substituted for the full horns. By conducting two complete data collection cycles an accurate measure of this accuracy reduction can be obtained.
22. Ship occupant detection system to customers to be used in production vehicles.
23. Collect additional real world validation data for continuous improvement.

Three databases are generally used to develop the neural network, the training database, the independent database and the validation or real world database. The training database generally contains several hundred thousand vectors where each vector is made up of the signals from the four ultrasonic transducers at each time step or about 40 msec.

The independent database is used as an accuracy check on the training process and helps to prevent the neural network from memorizing the particular data in the training database. Although the independent database is not actually used in the training of the neural network, it has been found that it significantly influences the network structure. Therefore, a third database, the validation or real world database, is used as a final accuracy check of the chosen system. It is the accuracy against this validation database that is considered to be the "system accuracy".

The validation database is composed of vectors taken from setups that closely correlate with vehicle occupancy in real cars on the roadway. Initially the training database is the largest of the three databases. As time and resources permit the independent database, which perhaps starts out with 100,000 vectors, will continue to grow until it becomes approximately the same size as the training database. The validation database, on the other hand, will typically start out with as few as 50,000 vectors. However, as the hardware configuration is frozen, the validation database will continuously grow until, in some cases, it becomes larger than the training database. This is because near the end of the program, vehicles will be operating on highways and data will be collected in real world situations.

The system described so far has been based on the use of a single neural network. It is frequently necessary to use multiple neural networks or other pattern recognition systems. For example, for determining the occupancy state of a vehicle seat there are really two requirements. The first is to establish what is occupying the seat and the second is to establish where that object is located. Generally, a great deal of time, typically many seconds, is available for determining whether a forward facing human or an occupied or unoccupied rear facing child seat, for example, occupies the vehicle seat. On the other hand, if the driver of the car is trying to avoid an accident and is engaged in panic braking, the position of an unbelted occupant can be changing rapidly as he or she is moving toward the airbag. Thus, the problem of determining the location of an occupant is time critical.

Typically, the position of the occupant in such situations should be determined in less than 50 milliseconds. There is no reason for the system to have to determine that a forward facing human is in the seat while simultaneously determining where that forward facing human is positioned. The system already knows that the forward facing human is present and therefore all of the resources can be used to determine the occupant's position. Thus, in this situation a dual level neural network can be advantageously used. The first level determines the occupancy of the vehicle seat and the second level determines the position of that occupant. This is an example of a simple modular neural network.

The data that is fed to the pattern recognition system typically will be preprocessed to extract the important information from the data that is fed to the neural network. The techniques of preprocessing data will not be described in detail here. However, the preprocessing techniques influence the neural network structure in many ways. For example, the preprocessing used to determine what is occupying a vehicle seat is typically different from the preprocessing used to determine the location of that occupant.

Although implicit in the above discussion, an important feature of this system that should be emphasized is the method of developing a system having distributed transducer mountings. Other systems which have attempted to solve the rear facing child seat (RFCS) and out-of-position problems have relied on a single transducer mounting location or at most, two transducer mounting locations. Such systems can be easily blinded by a newspaper or by the hand of an occupant, for example, which is imposed between the occupant and the transducers. This problem is almost completely eliminated through the use of three or more transducers that are mounted so that they have distinctly different views of the passenger compartment volume of interest. If the system is adapted using four transducers as illustrated in the distributed system of Figure 1, for example, the system suffers only a slight reduction in accuracy even if two of the transducers are covered so as to make them inoperable.

ENHANCEMENTS

Other techniques that may or may not be part of the process of designing a system for a particular application include the following:

1. Fuzzy logic. Neural networks frequently exhibit the property that when presented with a situation that is totally different from any previously encounter, an irrational decision can result. Frequently when the trained observer looks at input data, certain boundaries to the data become evident and cases that fall outside of those boundaries are indicative of either corrupted data or data from a totally unexpected situation. It is sometimes desirable for the system designer to add rules to handle these cases. These can be fuzzy logic based rules or rules based on human intelligence. One example would be that when certain parts of the data vector fall outside of expected bounds that the system defaults to an airbag enable state.

2. Genetic algorithms. When developing a neural network algorithm for a particular vehicle, there is no guarantee that the best of all possible algorithms has been selected. One method of improving the probability that the best algorithm has been selected is to incorporate some of the principles of genetic algorithms. In one application of this theory, the network architecture and the node weights are varied pseudo-randomly to attempt to find other combinations that have higher success rates. The discussion of such genetic algorithms systems appears in the book Computational Intelligence referenced above.

3. Pre-processing. For military target recognition it is common to use the Fourier transform of the data rather than the data itself. This can be especially valuable for categorization as opposed to location of the occupant and the vehicle. When used with a modular network, for example, the Fourier transform of the data may be used for the categorization neural network and the non-transformed data used for the position determination neural network. Recently wavelet transforms have also been considered as a preprocessor.

4. Occupant position comparison. The position of the occupant can be used as a filter to determine the quality of the data in a particular vector. This technique can also be used in general as a method to improve the quality of a vector of data based on the previous positions of the occupant. This technique can also be expanded to help differentiate live objects in the vehicle from inanimate objects. For example, a forward facing human will change his position frequently during the travel of the vehicle whereas a box will tend to show considerably less motion. This is also useful, for example, in differentiating a small human from an empty seat. The motion of a seat containing a small human will be significantly different from that of an empty seat even though the particular vector may not show significant differences. That is, a vector formed from the differences from two successive vectors is indicative of motion and thus of an occupant.

5. Blocked transducers. It is sometimes desirable to positively identify a blocked transducer and when such a situation is found to use a different neural network which has only been trained on the subset of unblocked transducers. Such a network, since it has been trained specifically on three transducers, for example, will generally perform more accurately than a network that has been trained on four transducers with one of the transducers blocked some of the time. Once a blocked transducer has been identified, the occupant can be notified if the condition persists for more than a reasonable time.

6. Other Basic Architectures. The back propagation neural network is a very successful general-purpose network. However, for some applications, there are other neural network architectures that can perform better. If it has been found, for example, that a parallel network as described above results in a significant improvement in the system, then, it is likely that the particular neural network architecture chosen has not been successful in retrieving all of the information that is present in the data. In such a case an RCE, Stochastic, Logicon Projection, or one of the other approximately 30 types of neural network architectures can be tried to see if the results improve. This parallel network test, therefore, is a valuable tool for determining the degree to which the current neural network is capable of using efficiently the available data.

7. Transducer Geometry. Another technique, which is frequently used in designing a system for a particular vehicle, is to use a neural network to determine the optimum mounting locations, aiming directions and field angles of transducers. For particularly difficult vehicles it is sometimes desirable to mount a large number of ultrasonic transducers, for example, and then use the neural network to eliminate those transducers which are least significant. This is similar to the technique described above where all kinds of transducers are combined initially and later pruned.

8. Data quantity. Since it is very easy to take large amounts data and yet large databases require considerably longer training time for a neural network, a test of the variability of the database can be made using a neural network. If for example after removing half of the data in the database, the performance of a trained neural network against the validation database does not decrease, then the system designer suspects that the training database contains a large amount of redundant data. Techniques such as similarity analysis can then be used to remove data that is virtually indistinguishable from other data. Since it is important to have a varied database, it is undesirable generally to have duplicate or essentially duplicate vectors in the database since the presence of such vectors can bias the system and drive the system more toward memorization and away from generalization.

9. Environmental factors. An evaluation can be made of the beneficial effects of using varying environmental influences during data collection on the accuracy of the system using neural networks along with a technique such as design of experiments.

10. Database makeup. It is generally believed that the training database must be flat meaning that

all of the occupancy states that the neural network must recognize must be approximately equally represented in the training database. Typically, the independent database has approximately the same makeup as the training database. The validation database, on the other hand, typically is represented in a non-flat basis with representative cases from real world experience. Since there is no need for the validation database to be flat, it can include many of the extreme cases as well as being highly biased towards the most common cases. This is the theory that is currently being used to determine the makeup of the various databases. The success of this theory continues to be challenged by the addition of new cases to the validation database. When significant failures are discovered in the validation database, the training and independent databases are modified in an attempt to remove the failure.

11. Biasing. All occupancy states are not equally important. The final system must be nearly 100% accurate for forward facing in-position humans. Since that will comprise the majority of the real world situations, even a small loss in accuracy here will cause the airbag to be disabled in a situation where it otherwise would be available to protect an occupant. A small decrease in accuracy will thus result in a large increase in deaths and injuries. On the other hand, there are no serious consequences if the airbag is deployed occasionally when the seat is empty. Various techniques are used to bias the data in the database to take this into account. One technique is to give a much higher value to the presence of a forward facing human during the supervised learning process than to an empty seat. Another technique is to include more data for forward facing humans than for empty seats. This, however, can be dangerous as an unbalanced network leads to a loss of generality.

FUTURE DEVELOPMENTS

The system described above has been termed a static or first generation system. Work is progressing on the next generation ultrasonic system that will generate a vector every 10 msec rather than 40 msec for the initial system. This is being accomplished through the use of transducers tuned to different frequencies so that they can all be fired together rather than sequentially.

CONCLUSION

The ultrasonic occupant sensing system described here has now been released on a production vehicle as the first spatial occupant sensing system. It is the first deployment of a safety system based on neural networks and thus its performance will be closely observed. The widespread use of pattern recognition technologies such as neural networks will depend on the performance of the systems observed in the field. Finally, this paper has been only to briefly touch on this fascinating field and the reader is thus referred to the references for additional information.

REFERENCES

1. Breed, D.S. Breed, D. S. "How Airbags Work" presented at the International Conference on Seatbelts and Airbags in 1993, in Canada
2. Breed, D.S., "A Smart Airbag System", 16th International Technical Conference on the Enhanced Safety of Vehicles, 1998.
3. U.S. Patents 5,563,462, 5,748,473, 5,822,707 5,829,782, 5,835,613, 5,845,000, and 5,943,295.
4. Techniques And Application Of Neural Networks, edited by Taylor, M. and Lisboa, P., Ellis Horwood, West Sussex, England, 1993.
5. Eberhart, R., Simpson, P. and Dobbins, R., Introduction to Artificial Neural Systems, West publishing Co., N.Y., 1992 and, Digital Neural Networks, by Kung, S. Y., PTR Prentice Hall, Englewood Cliffs, New Jersey, 1993,
6. Computational Intelligence PC Tools, Academic Press, Inc., 1996, Orlando, Florida
7. Naturally Intelligent Systems, by Caudill, M. and Butler, C., MIT Press, Cambridge Massachusetts, 1990.
8. Digital Neural Networks, by Kung, S. Y., PTR Prentice Hall, Englewood Cliffs, New Jersey, 1993.