Perception Enhancement System for Automotive Steering

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ABSTRACT

Laboratory-based experiments were conducted to evaluate the effect of the frequency and scale of transient vibration events on the human detection of road surface type by means of steering wheel vibration. The study used steering wheel tangential direction acceleration time histories which had been measured in a mid-sized European automobile that was driven over three different types of road surface. The steering acceleration stimuli were manipulated by means of the mildly non-stationary mission synthesis (MNMS) algorithm in order to produce test stimuli which were selectively modified in terms of the number, and size, of transient vibration events they contained. Fifteen test participants were exposed to both unmanipulated and manipulated steering wheel rotational vibration stimuli, and were asked to indicate, by either “yes or no”, whether the test stimuli was from a target road surface which was displayed on a board. The findings suggested that transient vibration events play a key role in the human detection of road surface type in driving situations. Improvements of up to 20 percentage points in the rate of correct detection were achieved by means of selective manipulation of the steering vibration stimuli. The results also suggested, however, that no single setting of the MNMS algorithm proved optimal for all three road surface types that were investigated.

Keywords

Perception, information, vibration, steering, automobile.

INTRODUCTION

Modern automobiles are safer and more comfortable than ever before. If there is one criticism that can be made, however, it is that the achievement of higher levels of comfort has sometimes come at the expense of a lack of driver involvement. The issue of driver involvement can become critical in the case of by-wire systems since these systems do not necessarily have a predetermined path, or transfer mechanism, for carrying stimuli to the driver. The question of what stimuli should reach the driver has therefore assumed great importance (Jurgen, 1999).

Research has also shown that the global performance of a coupled person-machine system can be improved when certain low level perceptual and cognitive functions are assigned to the machine (Quek and Petro, 1993). The introduction of electronic technology has placed greater requirements on human cognitive activity, thus, while there are typically reductions in physical workload, mental workload has often increased (Weiner, 1989). In addition, in many work environments, computerization has shifted the role of the operator from that of manual control of simple systems to supervisory control of highly complex, automated systems. Aircraft pilots, for example, now supervise complex automated flight systems via multi-display computerized cockpits.

Human information-processing characteristics are therefore central to the design of many modern systems. Examples of this trend include graphical displays that tailor to human perceptual characteristics (Cleveland, 1985; Sanderson et. al., 1992; Woods, 1984), systems whose design involves the use of human performance models that enable explicit consideration of human memory and attentional constraints (Card et.al., 1983; Kieras and Polson, 1985), and error tolerant systems developed to minimise human error (Brown and Newman, 1985; Norman, 1983; Woods et. al., 1994).

Among the sources of the cognitively-relevant information used by automobile drivers, vibrational stimuli help in the understanding of many things such as the type of road surface, the presence of water or snow, tyre slip, and the dynamic states of subsystems such as the engine, the steering and the brakes. The stimuli are perceived, compared to models from long term memory, and interpreted, with the consequent interpretation then influencing decision taking.

One means of improving the flow of information to the driver, and thus of making the driving task easier, is to incorporate a perception enhancement system (PES) into the design of the automobile steering as shown in Figure 1. Such an electromechanical system would have the function of identifying the significant vibrational stimuli which originate from the tyres and suspensions, and would also have the function of transforming the stimuli in order to optimise detection and awareness.

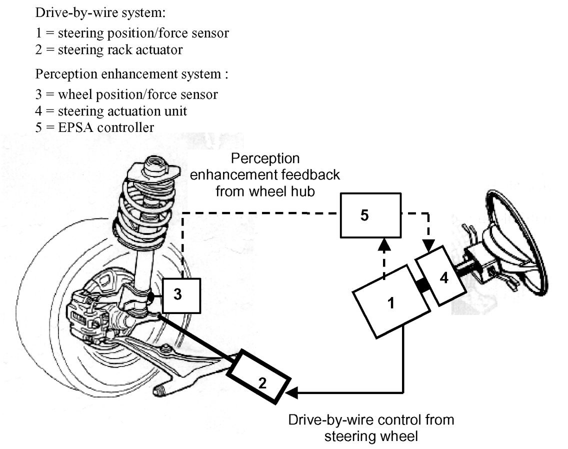


Figure 1. A perception enhancement system for use with "by-wire" automotive steering.

In a modern automobile, the electrical and electro-mechanical power assistance systems used for the primary controls (steering, acceleration and braking) make these controls obvious choices for the application of low level perceptual and cognitive functions such as a steering perception enhancement system. An example of research in this direction is the study by Giacomin and Woo (2004), which investigated driver detection of road surface type. By measuring the sensitivity of the human detection task to changes in the primary characteristics (scale and bandwidth) of the vibration stimuli, the authors defined the basic dynamic specifications that an automotive steering system should have in order to be capable of applying low level perceptual assistance to the driver. The authors concluded that a single, fixed, feedback gain was not optimal. Rather, the data supported the view that optimal steering feedback gain should be determined after automated classification of the road surface type. Further, the authors defined a minimum bandwidth requirement, of approximately 0 to 80 Hz, required by drivers for the detection task.

The study presented in this paper treats instead the problem of features (Giacomin, 2005), which can be defined to be the effect that individual transient events have on human cognitive response. A natural question which arises in the case of the steering system is whether short, sharp, transients of the kind that occur when driving over cracks or stones effect the detection of surface type. The study presented here investigated the effect of the number of transient events, and the effect of the scale of the transient events, on the human detection of road surface type. The study was performed by means of laboratory-based experiments involving human participants, and involved digital manipulation of steering wheel tangential acceleration signals which were measured during road testing of a mid-sized European automobile.

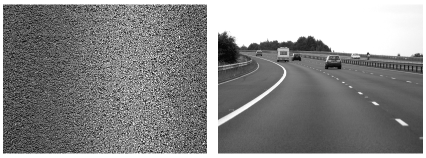
EXPERIMENTAL TESTS OF HUMAN COGNITIVE RESPONSE TO STEERING WHEEL VIBRATION

Test Stimuli

The experiments used tangential direction acceleration time histories measured in an Audi A4 when driving over three road surfaces. The automobile used to provide the acceleration stimuli for the experiments can be considered an average European saloon with average mechanical characteristics. The road surfaces that were measured were a cobblestone surface, a tarmac surface and a concrete surface. Figure 2 presents the three road surfaces, as viewed from directly above, and as seen from a distance as when driving. A 3 second segment of the acceleration time histories of the three base stimuli are presented in Figure 3, while the related global statistical properties are presented in Table 1.

Cobblestone road (vehicle speed 30 kph)

Tarmac road (vehicle speed 96 kph)



Concrete road (vehicle speed 96 kph)

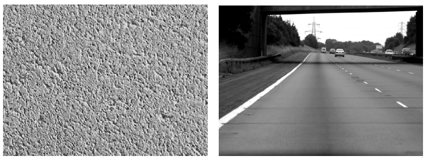


Figure 2. Road surfaces whose stimuli were chosen for use in the laboratory tests.

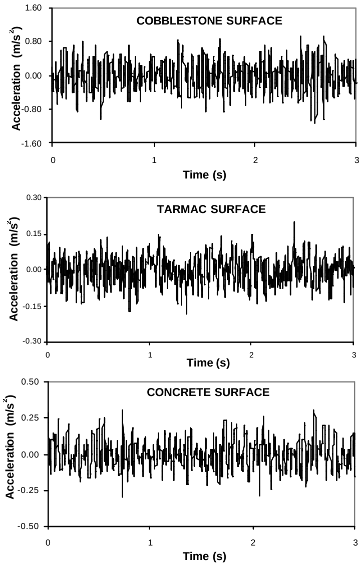


Figure 3. Steering wheel acceleration time histories that were used to create the laboratory test stimuli.

Table 1. Global statistics of the three base stimuli used for producing the laboratory test stimuli.

Global Statistics	**Cobblestone surface**	**Tarmac Surface**	**Concrete surface**
r.m.s (m/s^2)	0.27	0.05	0.09
Kurtosis (dimensionless)	3.25	3.00	3.83
Length (s)	24.2	30.0	30.0

The extraction of transient events from the base stimuli, and the reinsertion of modified (either in number or size) transient events into the test stimuli, was achieved by means of the mildly non-stationary mission synthesis (MNMS) algorithm (Giacomin et. al, 2000). MNMS acts as a compression tool to produce a shortened test sequence starting from a long non-stationary time history. MNMS uses the discrete Fourier transform (DFT), the orthogonal wavelet transform (OWT) and transient event reinsertion procedures. By means of the MNMS algorithm it was possible to selectively manipulate the transient events which were initially present in the steering vibration stimuli.

The mildly non-stationary mission synthesis algorithm splits an original signal into wavelet levels (Chui, 1991; Daubechies, 1992). Wavelet levels consist of time histories which are obtained from the wavelet decomposition, and contain the signal energy which is specific to a specific frequency band. MNMS uses the orthogonal wavelet transform to divide the overall energy into individual signals, in a manner analogous to a parallel bank of band-pass filters. A feature which is specific to MNMS is a wavelet grouping stage which permits the user to group individual wavelet levels into larger regions of significant energy, as illustrated in the PSD plots of Figure 4, where each wavelet group (WG1, WG2, etc.) is formed of two or more automatically generated wavelet levels. For all three acceleration stimuli used in the current study, the signal was automatically divided into 12 wavelet levels, which were then grouped based on user inputs into 4 or 5 wavelet groups. As shown in Figure 4, the wavelet groups were ordered from the lowest frequency to the highest frequency for simplicity.

In MNMS, transient events are defined as oscillations which have monotonic decay properties on either side of a central maximum. Two inversion points, one on either side of the peak value, define the temporal extent of the transient event, as shown in Fig. 5. Transient event identification is achieved in each wavelet group time history by means of a user selected trigger level that is specific to the wavelet group (Giacomin, et. al, 2000). In the current study the wavelet group trigger levels were chosen to be in the range from 2.6 to 3.6 standard deviations Table 2 presents the trigger level values chosen for each individual wavelet group, as well as the number of transient events that were extracted from the original stimuli (NBE) and the number of transient events that were reinserted into the test stimuli (NBR).

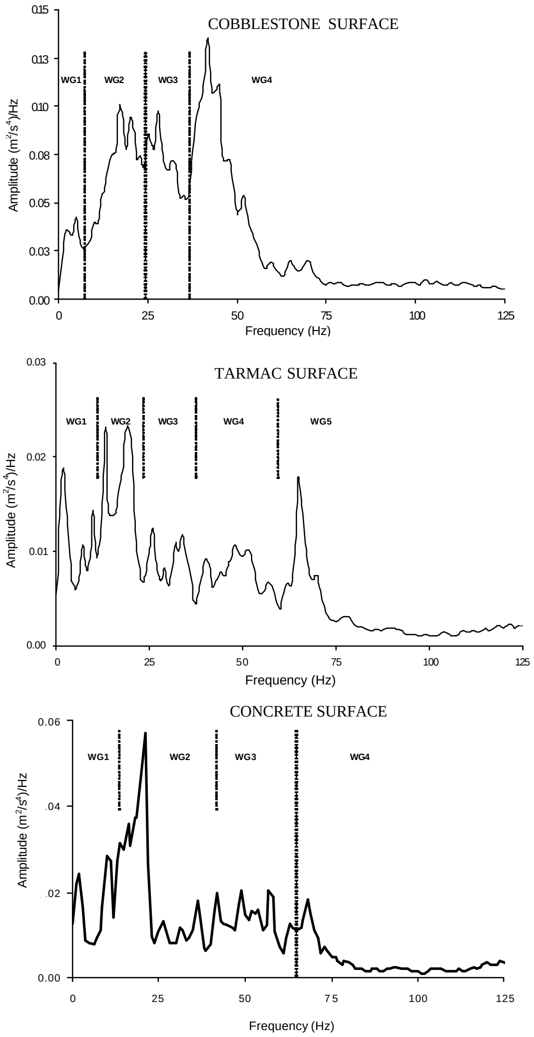


Figure 4. Power spectral densities of the experimentally acquired steering wheel acceleration signals, showing the wavelet groups chosen for use in the current study.

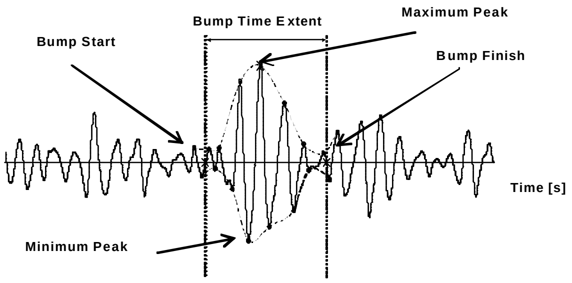


Figure 5. Example of a typical transient event identified by the MNMS algorithm.

Test signals were produced from each of the three experimentally acquired base signals using four time compression ratios of 1.0, 2.0, 3.0 and 4.0 and five transient event scale factors of 0.8, 1.0, 2.0, 3.0 and 4.0. Figure 6 presents the test stimuli time histories obtained by means of MNMS from the concrete base stimuli. Figure 7 presents instead the power spectral densities obtained for the original concrete road stimuli and for the test stimuli. The close correspondence of the curves of Figure 7 suggests that the energy distribution was accurately retained after manipulation by MNMS.

Table 2. Wavelet group transient event trigger levels used in the current study.

SIGNALS	CR	WG 1	WG 2	WG 3	WG 4	WG 5	NBE	NBR
COBBLE-STONE	**1.0**	**2.80**	**3.30**	**3.10**	**3.00**	**-**	**56**	**56**
	2.0							**56**
	3.0							**54**
	4.0							**52**
TARMAC	**1.0**	**2.60**	**3.10**	**3.30**	**3.40**	**3.50**	**53**	**53**
	2.0							**51**
	3.0							**49**
	4.0							**44**
CONCRETE	**1.0**	**3.00**	**3.10**	**3.10**	**3.60**	**-**	**21**	**20**
	2.0							**19**
	3.0							**18**
	4.0							**17**

WG= Wavelet Group
NBE= number of transient events extracted.
NBR= number of transient events reinserted.

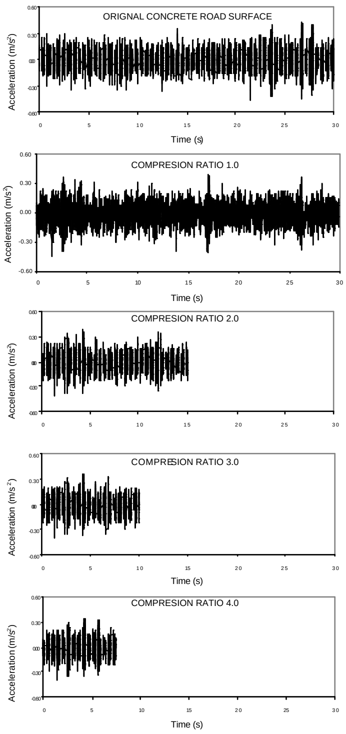


Figure 6. Laboratory test stimuli that were produced using the steering wheel acceleration time history obtained while driving over the concrete road surface.

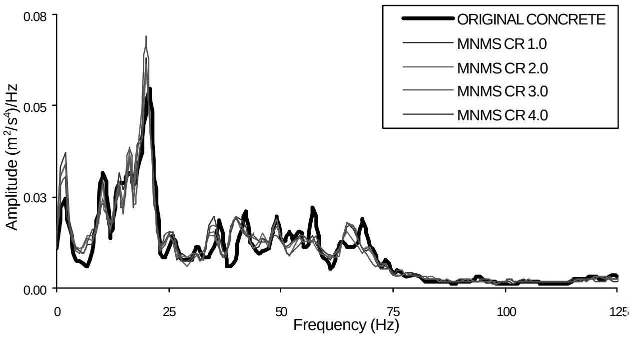


Figure 7. Power spectral density of the original concrete road base stimuli and of the test stimuli obtained using compression ratios of 1.0, 2.0, 3.0 and 4.0.

Test Facility

The experiments were performed in the Sheffield University Perception Enhancement Systems laboratory. The steering wheel rotational test rig that was used is presented in Figure 8. The rotational system consisted of a 325mm diameter aluminium wheel attached to a steel shaft which was in turn mounted to two bearings. The shaft was connected to the electrodynamic shaker head by means of a copper stinger-rod. Table 3 presents the main geometric dimensions of the test rig, which were chosen based on data from a small European automobile. The seat was fully adjustable in terms of horizontal position and back-rest inclination as in the original vehicle. Rotational vibration was applied by means of a G&W V20 electrodynamic shaker driven by PA100 amplifier (Gearing & Watson Electronics Ltd, 1995). The steering wheel tangential acceleration was measured by means of an Entran EGAS-FS-25 accelerometer attached to the top left side of the wheel. The accelerometer signal was amplified by means of an Entran MSC6 signal conditioning unit (Entran Devices Inc., 1991). Control and data acquisition are performed by means of the LMS TMON software system coupled to a DIFA SCADASIII unit (LMS International, 1996).

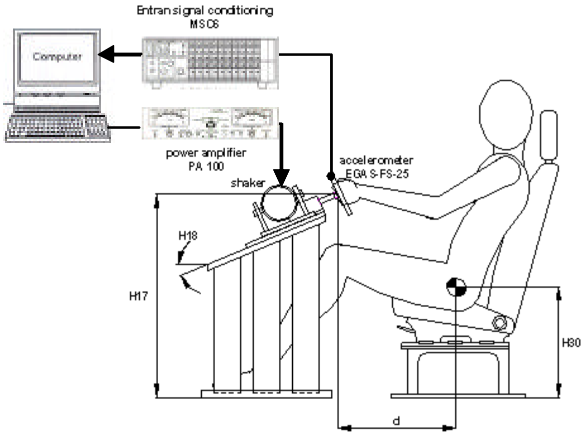


Figure 8. Steering wheel rotational vibration test facility.

Table 3. Geometric dimensions of the steering wheel rotational vibration test rig.

Geometric Parameter	Value
Steering column angle (H18)	23°
Steering wheel hub centre height above floor (H17)	710 mm
Steering wheel diameter (W9)	325 mm
Steering wheel tube diameter	12.5 mm
Horizontal distance from H point to steering wheel hub centre (d= L11-L51)	390–550 mm
Seat H point height from floor (H30)	275 mm

Test Subjects

15 Sheffield University staff and students participated in the laboratory experiments (9 males and 6 females). The mean age for the group was 28.2 years, while the mean height was 1.72 m and the mean mass was 72.6 kg. No participant declared any condition which might effect the perception of hand-arm vibration, and none declared having ingested coffee prior to testing.

Test Protocol

Upon arriving in the laboratory, each subject was asked to sit in the test bench and to adjust the seat so as to achieve a realistic driving posture. He or she was then asked to fix his or her eyes on a board directly in front of the bench, which displayed a picture of a road surface. Prior to commencing formal testing, the subject was provided an example of each of the three stimuli types which would be used later, in order to become acquainted with the detection task.

The detection task was to state, by means of “yes” or “no”, whether each vibration stimuli that was actuated during the course of the experiment was from the road surface that was illustrated by the picture on the board directly in front of the test bench. When the actuated vibration stimuli had been produced using the base stimuli from the displayed road surface, the response was taken to be a correct detection. False alarms, on the other hand, were taken to be those situations when the participant responded “yes” to a stimulus which was not derived from the displayed road surface. No feedback was provided by the experimenter to the test participant regarding whether the identifications were correct or incorrect.

Three laboratory experiments were performed. A single road surface was displayed in front of the participant for each experiment. The stimuli actuated at the wheel during each experiment consisted of examples taken from all three road surface types. The time duration of the individual test stimuli was either 7.5, 10, 15 and 30 seconds depending on the compression ratio adopted. Three different series of 15 tangential acceleration stimuli were applied to evaluate each road surface type. In each series, each stimulus was separated from each other stimulus by a 5 second gap in which the participant was asked to state his or her judgment of road surface type. The order of stimuli presentation was fully randomised for each participant in each experiment.

RESULTS

Figure 9 presents the results obtained from the experiment to determine the effect of the number of transient events on the human ability to detect road surface type. The results are presented in terms of percent correct detection, from 0 to 100 percent. Percent correct detection is presented along the ordinate, while the ratio of signal compression (the increases in the number of transient events) is presented along the abscissa. The original base stimuli are labelled as O, and the four compressed test stimuli are labelled as +1, +2, +3 and +4 to indicate compression ratios from 1 to 4.

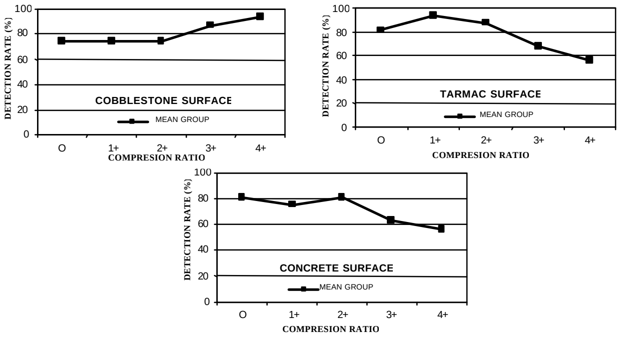


Figure 9. Results of the laboratory experiment to measure the effect of the number of transient events on the human detection of road surface type.

As shown in Figure 9, the percentage of correct detection for the original base stimuli was approximately 75% for the cobblestone stimuli, 83% for the tarmac stimuli and 82% for the concrete stimuli. These values can be compared to the values of approximately 48%, 80% and 46% respectively obtained by Giacomin and Woo (2004) for the same three surfaces. The higher percentages of correct detection found in the current study can be partially attributed to the fact that only three road surface types were used in the current study, as opposed to the four types used in the previous research by Giacomin and Woo. The detection task was therefore performed against a less complicated noise background.

As shown in Figure 9 by the results obtained for compression ratio 1, the use of the MNMS algorithm to manipulate the signals without increasing the number of transient events, or their size, produced only mixed results. The percentage of correct detection remained constant for the cobblestone stimuli, improved for the tarmac stimuli and decreased for the concrete stimuli. Figure 9 does suggest, however, the potential usefulness of controlling transient events in steering vibration stimuli. Important increases in correct detection occurred for all compression ratios greater than 2 for the cobblestone stimuli, for compression ratio of 1 and 2 for the tarmac stimuli, and for compression ratio 2 for the concrete stimuli

Figure 10 presents the results obtained from the experiment to determine the effect of transient event scaling on the human ability to detect road surface type. The stimuli used in this experiment had a compression ratio of 2.0, which was chosen because it was the mean compression ratio considered in the current study. The results are again presented in terms of percent correct detection, from 0 to 100 percent. The scale factors applied to the individual transient events (0.8, 1.0, 2.0, 3.0 and 4.0) by means of the MNMS algorithm are presented along the abscissa.

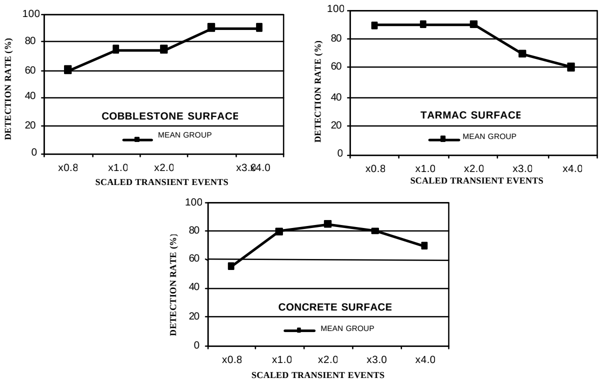


Figure 10. Results of the laboratory experiment to measure the effect of transient event scaling on the human detection of road surface type.

For the stimuli involving transient events which were maintained at their natural scale (x1.0), the percentages of correct detection were 75% for the cobblestone stimuli, 92% for the tarmac stimuli and 80% for the concrete stimuli. In the case of the cobblestone stimuli the optimum detection was achieved at the largest scale that was tested (x4.0), while for the tarmac stimuli optimal detection occurred for the smallest scale value tested (x0.8), and detection for the concrete stimuli was optimum at the mean value (x2.0). For all three road surface types, optimal detection occurred for stimuli having transient events which were different in size from those occurring naturally in the original stimuli.

DISCUSSION

Comparison of the current results to those previously obtained by Giacomin and Woo (2004) suggests similarities. The curves of percent correct detection which are presented here, both those as a function of transient event frequency and those as a function of transient event scale, show similar qualitative behaviour to the curves obtained by Giacomin and Woo as a function of overall signal scale. For example, the monotonic improvement in detection rate as a function of increasing compression ratio found for the cobblestone surface in this study mirrors the monotonic increase obtained by Giacomin and Woo as a function of overall signal scale, but with smaller changes in detection across the various test conditions.

The results of both the previous study reported by Giacomin and Woo (2004) and the current study suggest that the manipulation of steering wheel vibrational feedback can improve driver detection of the road surface. In the current study, the rate of correct detection was improved by as much as 20 percentage points by the adoption of stimuli manipulation. The results seem to suggest the case for adopting perception enhancement systems for automobile steering systems.

The results of both the previous study reported by Giacomin and Woo (2004) and the current study also suggest, however, that a fixed increase in the frequency of transients events, or a fixed increase in transient event scale, or a fixed change of overall signal scale, will not work in the case of all road surface types. Individual road surface types appear to require individual signal manipulation settings. The conclusion suggests that an important function of an automobile perception enhancement system would be that of pattern recognition. Automated real-time classification of stimuli type would permit a perception enhancement system controller to determine the needed optimal feedback gains.

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