A New and Novel Method for Assessing Visual Clutter in the Driving Environment

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Abstract

A paucity of research has been undertaken to develop ways in which visual clutter in the driving scene can be measured and assessed. In response to this research caveat, this manuscript outlines a framework for objectively measuring the level of visual clutter along a defined driving route. At a high-level, the steps in the framework commence by (1) collecting snapshots (i.e., pictures) of the driving environment of interest, (2) processing and measuring the visual clutter in these snapshots (inferring which areas of the driving environment are highly cluttered) using special MATLAB code, and (c) using these visual clutter measurements (or *clutter scores*) to inform recommendations for mitigating the potentially negative impact on driving behaviour this clutter can have. Based on results derived from this assessment framework, practitioners can make informed recommendations for reducing relatively high visual clutter while maintaining an appropriate level of road user information and navigation guidance.

Introduction

Driving is a complex and dynamic task, and errors in performing the driving task can result in crashes. It is crucial for the road and driving environment to support drivers in safe performance of the driving task. At present, increasing amounts of visual information from sources such as advertising billboards, road signs and markings can create a highly-cluttered environment which, in turn, can degrade driving performance and safety (Edquist, 2009). Therefore, it is imperative researchers have an objective framework to help identify road environments with high levels of visual clutter which, in turn, could aid in our assessment of how we can mitigate its potential impact on driving behaviour.

Definition of visual clutter

Visual clutter is defined as the ”...non-target information in a scene” (Ho, Scialfa, Caird, & Graw, 2001, p. 194). In the realm of driving, and for road signage in particular, the level of visual clutter in a given scene is determined by the interactions between the amount and complexity of signage and, specifically, how difficult it is to detect important objects from the background (Edquist, 2009).

Edquist and Johnston (2008) have proposed a taxonomy of visual clutter in the driving environment, based on both qualitative and quantitative research, that specifies three types of visual clutter:

1. ‘Situational clutter’ or traffic: ‘…includes all moving objects on and next to the road that must be attended for safe driving (including pedestrians as well as other vehicles).’ (p. 733)

2. ‘Designed clutter’ or signage: ‘…includes all those objects that road authorities use to communicate with the driver, such as road markings, traffic signs and signals; these items must also be attended for safe driving.’ (p. 733)

3. ‘Built clutter’ or other potential sources of visual clutter: ‘…buildings and other infrastructure, shop signage, and advertising billboards. These objects may distract attention from the driving task and/or make the background visually complex.’ (p. 733)

Mechanisms of how visual clutter may degrade driving performance

Visual clutter can affect driver performance and safety in three ways (Edquist, Horberry, Regan, & Johnston, 2007):

Distraction

Firstly, visual clutter can distract the driver. Conspicuous cluttering objects (e.g., bright/flashing signs) can divert attention away from the primary driving task (Edquist et al., 2007). This diversion of attention may reduce situational awareness and cause the driver to miss important road-related information as eyes are taken off the forward roadway (Edquist & Johnston, 2008). Edquist et al. (2007) contend that objects defined as visual clutter could potentially distract a driver via any of the following three mechanisms: involuntary (i.e., bottom-up) capture of visual attention (e.g., by brightly coloured or flashing signs) and/or cognitive resources (e.g., thinking about an interesting advertisement billboard a driver has just passed); or voluntary (i.e., top-down) direction) of visual and cognitive attention away from the primary driving task (e.g., a driver choosing to look at their favourite billboard).

Impaired visual search

Secondly, visual clutter can impair a driver's ability to visually search the road environment being navigated. Visual search is crucial for many driving subtasks such as responding to traffic signs and signals, navigating to the driver's destination, and crash avoidance (e.g., spotting potential and actual hazards on the roadway) (Brown, 1986). In the driving domain, visually cluttered environments may reduce the conspicuity of road signs, which will make the visual search for traffic signs and detection of other important road stimuli more difficult (i.e., the driver has more irrelevant visual stimuli to sift through in order to detect a relevant target or sign) (Ho et al., 2001).

Increased driver workload

Thirdly, visual clutter may increase driver cognitive workload. Searching for relevant signs in a visually cluttered environment requires a higher level of information processing (e.g., to distinguish target road signs from irrelevant signs), which can lead to increased driver cognitive workload (see Edquist, 2009 for review). High cognitive workload can undermine a drivers ability to respond to critical cues and traffic signals in the roadway environment (e.g., via inattention blindness: e.g. the 'looked at but did not see' phenomenon; Strayer, Drews & Johnston, 2003).

Given the potentially negative impacts that visual clutter in the driving scene may have on driving performance, it is appropriate that a methodology be developed to allow practitioners to identify segments of the road environment that are highly cluttered. This, in turn, can inform the development of strategies to prevent and mitigate any degradation in driving performance and safety that may derive from clutter.

Methods for objectively measuring visual/sign clutter

The objective measure of visual clutter has received relatively little empirical attention. To the best of our knowledge, Rosenholtz, Li, and Nakano (2007) were the first to develop computational software to objectively measure and quantify the level of clutter in a visual scene. Here, the authors developed special code using MATLAB, a high-performance mathematical and computation software program, which can produce a numerical and visual indication of visual clutter for a given snapshot (e.g., a picture file) of a visual scene. That is, for a given snapshot, this code outputs a clutter scalar (i.e., a numerical visual clutter 'score'), where a higher score indicates a higher level of visual clutter within that visual scene. Using the input snapshot, the code can also produce a clutter map, which highlights the areas of the scene in which clutter is particularly high (indicated by relatively bright-lit regions or 'hotspots'). Thus, not only does this code allow the level of visual clutter in multiple snapshots to be compared based on their clutter scalar, but also allows us to pinpoint regions in these snapshots contributing to this score (i.e., which regions are most cluttered) based on their clutter maps. The code measures clutter based on the variance of features (e.g. colour, contrast) in a visual scene, where a higher variance of features is associated with higher clutter (known as 'feature congestion'; Rosenholtz et al., 2007). The authors have also validated this computational measure of visual clutter, showing that snapshots or pictures of higher clutter scalars are inversely related to visual search performance (Rosenholtz et al., 2007).

Empirical attention directed towards objective measures of visual clutter in the realm of driving are severely lacking. Although road authorities have attempted to regulate the levels of visual clutter in the road environment, these are primarily based on engineering judgement, conventions and international standards (Edquist, 2009). Given the often-subjective element in defining and identifying clutter (van den Berg, Cornelissen, & Roerdink, 2009), an objective and computational measure of clutter could not only help in identifying driving environments of high clutter, but also help, and increase the consistency across, regulatory efforts by road authorities to mitigate its potential negative impact on driving performance and safety.

Therefore, the aim of this paper is to propose a framework, which lends itself from the seminal work of Rosenholtz et al. (2007), for objectively measuring visual clutter in the driving scene. To the best of our knowledge, this is the first paper to apply this methodology to the realm of driving.

Method

Informed by the expert opinion of human factors researchers and engineering practitioners, as well as the empirical research of Rosenholtz et al. (2007), this section outlines a proposed framework for measuring visual clutter in the driving environment. The steps of this framework, along with a more detailed description of the associated activities, are noted in Table 1. At a high-level, the steps in the framework commence by collecting snapshots of the driving environment of interest (Steps 1 and 2), to processing and measuring the visual clutter in these snapshots (inferring which areas of the driving environment are highly cluttered) (Steps 3 and 4), which lastly inform recommendations for mitigating the clutters potential negative impact on driving behaviour (Steps 5 and 6).

Table 1. Proposed framework to objectively measure visual clutter

Step no.	Description	Tasks
1	Survey route being audited for visual clutter	Position a GPS-enabled video camera securely just below driver eye height on the front windscreen of the vehicle (just left of centre) and use to record video footage during the route survey of the driving environment.
2	Identify road segments	Upon completion of the route survey, snapshots (from the video footage recorded) of the driver's view should be taken at equal increments (e.g., taken every 100m). Save snapshots as a picture file (e.g. 'jpeg'), which can be input into the special MATLAB code
3	Input into MATLAB	Input snapshot into MATLAB, which will output: • a *clutter scalar* (i.e., a numerical clutter 'score'); and • a *clutter map* (i.e., a visual map indicating, with bright light, regions in the snapshot where clutter is highest).
4	Relative results of clutter measure	Compare and rank snapshots based on clutter scalars – this will provide areas along the driving route which are particularly cluttered (a snapshot with a higher clutter scalar = higher visual clutter in that snapshot).

Step no.	Description	Tasks
5	Identify elements contributing to clutter	Particularly important for high clutter snapshots/areas, visually inspect clutter maps to identify the physical elements (e.g., signs, buildings) contributing to the clutter at these locations. The elements contributing to the clutter were those associated with the most brightly lit areas (i.e., the clutter 'hot spots') in the snapshot. Elements judged to be commonly contributing to visual clutter include the presence of other vehicles on the road, buildings and overhangs, signs and road line markings. In lieu of objective thresholds for level of clutter should be considered 'high', it is logical to categorise those snapshots/areas in the top ranked quartile as 'high'. It is recommended that at least two researchers/practitioners inspect these clutter maps to ensure a level of inter-rater reliability.
6	Recommended areas for improvement	Based on the sources of clutter in the 'high' clutter snapshots/environments, recommend/propose changes to mitigate clutter and its potential effects on driver performance. For example, in areas of high clutter, it may be recommended that future additional signs not be erected in these locations as they may increase driver workload and be less conspicuous due to the surrounding clutter. Alternatively, these areas may be reviewed with the aim of removing unnecessary signs to reduce clutter and make the more relevant signs more conspicuous.

Example of MATLAB output

An example of the clutter map that the MATLAB code provides is depicted in Figure 2 (with the input snapshot of the driving scene depicted in Figure 1). The clutter score, also provided by MATLAB, for this visual scene was considered relatively high. Upon inspection of Figure 2 by the researchers, it was judged that signs, line marking and buildings are all contributing to the relatively high clutter in this visual scene. In particular, the features just left of the centre of the picture seem to be the most brightly and densely lit, inferring that the features in this area are significantly contributing to the clutter. Features in this area of the visual scene include a mixture of buildings, trees, road furniture and directional signs.

Figure 3 depicts a snapshot and feature congestion map of another area on the same approach as that depicted in Figure 1 and 2 for comparison. As noted before, the snapshot/area depicted by Figures 1 and 2 was one of relatively high clutter (clutter score = 4.34), while that depicted in Figure 3 was one of relatively low visual clutter (clutter score = 2.93).

Figure 1. Snapshot of southbound travel approaching Sydney Harbour Bridge

Figure 2. Example of feature congestion clutter map using Figure 1 ('hotspots' indicate areas of relatively high clutter)

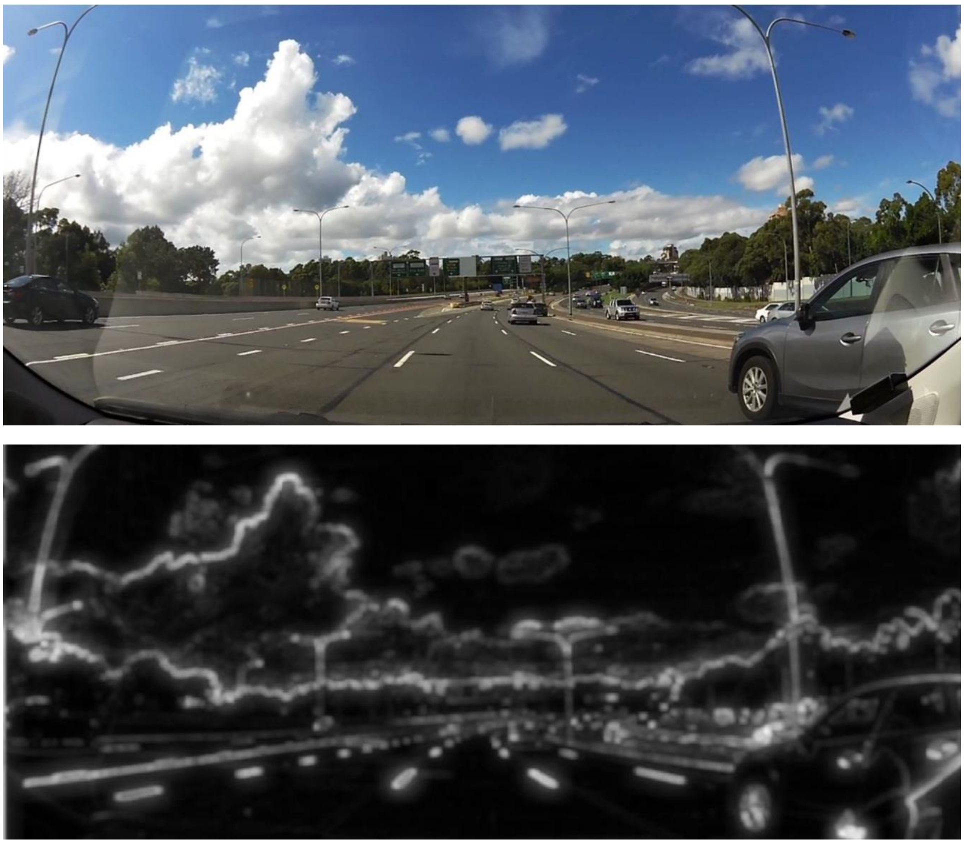

Figure 3. Snapshot (top) and feature congestion map (bottom) of southbound travel approaching Sydney Harbour Bridge. This an example of a snapshot/area of relatively low visual clutter.

Discussion and Conclusion

The aim of this paper was to propose a framework, which lends itself from the seminal work of Rosenholtz et al. (2007), for objectively measuring visual clutter in the driving scene.

To the best of our knowledge, this is the first paper to apply this methodology to the realm of driving. Although there has not yet been research undertaken to link clutter scores and driving behaviour in difference driving environments, we are able to make some inferences based on visual clutter research more generally. The framework described in this paper allows researchers and practitioners to identify areas along a driving route which are particularly cluttered. In reference to previous research (e.g., Rosenholtz et al. 2007), the areas which are objectively ranked as being relatively cluttered are likely to be areas in which the visual search performance of the driver may be impaired. This means that, in such areas, important road signs and other visual information (e.g., pedestrians) may have difficulty in capturing driver attention in the surrounding of other irrelevant visual information (Edquist, 2009). In addition, it is reasonable to contend that clutter, due to signage for example, may be particularly distracting and impairing if the driver is unfamiliar with the road in question and is hence reliant on signage for direction. A driver who has been repeatedly exposed to the particular section of road, and the existing signage, may be not be distracted or impaired to the same extent because the stimuli is no longer 'novel'. However, independent of driver familiarity with the road and existing signage, visual clutter may still impact driving behaviour through other mechanisms (e.g. impair search times for other important information). Moreover, while the use of in-vehicle navigation systems may reduce driver reliance on road signage (e.g., for directions) it may be the case that drivers search for signs to confirm the output of such systems (e.g. ensure the directions are correct), for which clutter may hinder. Nonetheless, assuming that a road environment will always be unfamiliar to some drivers, and that many drivers will not always have the opportunity to use navigation systems for directions and other information, this framework can help illuminate areas in which mitigation strategies may need to be employed to reduce clutter and its impact on driving safety. This notion forms the basis for the frameworks practical significance – it helps us identify road environments with high levels of clutter and, in turn, helps us assess how we can mitigate potential degradation in driving performance and safety deriving from clutter.

A number of limitation of the proposed framework should also be noted. Given that this framework has only been very recently developed, and has not yet been evaluated in the realm of driving, we have no concrete evidence that areas with high clutter scores are associated with poorer driving performance. However, given the relatively high and consistent correlations between clutter scores of visual scenes (generated by the same software) and visual search performance in these scenes more generally (Rosenholtz et al., 2007), this forms a strong theoretically-driven hypothesis that the visual search performance) of drivers (e.g., detection of signs and other important information on the roads will, too, be impaired in driving scenes with high clutter scores (as informed by our framework). Prospective studies should aim to test this hypothesis in both simulated driving and real-world studies. In addition, to establishing the link between clutter scores produced through the present framework and real-world driving consequences, it would be informative to link scores in a certain area with the prevalence of crashes in the same area (if this data were available). Lastly, vehicle technologies which can automatically ‘read’ signs (e.g., through forward facing cameras and advanced vision algorithms) and alert the driver of the information they contain (e.g., the speed limit in a certain area) are become increasingly commonplace on our roads. Therefore, a fruitful avenue for future research should investigate how clutter may impact the abilities of such advanced technologies. If we find that clutter does, indeed, negatively impact the efficacy of these technologies, this would provide further justification for the present framework for assessing visual clutter along different roadways and identifying problematic areas.

In sum, the framework described in this paper for objectively measuring the level of visual clutter along a driving route is a new and novel contribution to road safety research. This simple method can be applied to any defined driving route and, based on the results of the assessment, can be used to make informed recommendations to address the level of visual clutter, while maintaining an appropriate level of road user information and navigation guidance. While this framework is a promising first step to the objective assessment of visual clutter in the driving scene, further work is required to link clutter scores with driving performance and safety outcomes.

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