Multi-Modality Fidelity in a Fixed-Base-Fully Interactive Driving Simulator

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ABSTRACT

Creating a simulated environment that accurately represents the real-world is a challenge for virtual world designers. In a fixed-based fully interactive driving simulator, the designer is often limited to representing the visual real-world through shapes and textures that when combined, form a virtual visual world. Unfortunately, the driving environment is not limited to the visual world, it is a multi-modal environment. Information is presented to drivers through different modes. One such application, rumble strips, have been used to alert the driver of impending danger, ultimately leading to a reduction in the frequency of run-off-road crashes. Although there are a number of options for evaluating a novel traffic control device, a fixed-based-f fully-interactive driving simulator was used. Achieving a desired level of fidelity required the incorporation of multi-modal devices into the simulated world. Sounds and vibrations from rumble strip incursions were field recorded, adjusted, and broadcasted through the simulator’s sound system. This paper describes the details of integrating the multi-modal audible and haptic stimuli in the University of Massachusetts’ fixed-base-f fully-interactive driving simulator, resulting in an accurate representation of the driving environment.
INTRODUCTION

Transportation professionals use a variety of traffic control devices (TCD) such as pavement markings, signs, and signals to communicate clear, unambiguous messages to drivers. Traditionally, imperative information is presented to the driver in a visual medium. One TCD that relies on other senses is rumble strips. Specifically, in addition to traditional visual cues, these TCDs rely on audio and haptic cues, thereby falling outside of the traditional traffic control devices. This reliance on sensory mediums outside of the traditional requires professionals to work collaboratively with researchers to determine the best way of presenting information to drivers.

Rumble strips have been used since the early 1950’s on roadway shoulders to alert the driver of their lane departure and the impending danger if corrective actions are not performed. Recently, states have started to use rumble strips on the centerline of two-lane, undivided roadways. Installation on the centerline was aimed at reducing the number of cross-over-centerline-crashes (COCC) and fatalities. In an effort to determine whether or not the novel application was effective, research was performed.

There were two basic methods that were considered to evaluate driver's reactions to centerline rumble strips, either in the real-world environment or in a controlled facility. In the real-world, videotaping random incursions from a static location was considered; however, the financial burden to record and transcribe the tapes, as well as the probability of a large sample size incurring on the strips may this approach impractical. Based on this, a controlled environment exercise was performed. A fixed-based-fully-interactive driving simulator was used for evaluation. Not only was the researcher able to create situations in which incursions were unavoidable, the testing medium also provided an opportunity to debrief the participants.

One of the limitations of the fixed-base system is its lack of haptic feedback. There are a number of ways in which more technologically advanced simulators provide haptic feedback to the driver; however, most are unavailable in the fixed-base environment due to hardware and possibly even financial constraints. To overcome this limitation, a number of components were considered. Based on the existing configuration of the simulator and the manner in which sound is broadcast, bass shakers were used to provide the haptic feedback to drivers.

BACKGROUND

Multiple Resource Theory

Sound and vibration provide specific sensations for the driver, allowing them to continue to concentrate on the visual task required for vehicle control, navigation, and guidance. By using different modalities, the cognitive workload is distributed among different senses, reducing the interference and the attention division required when multiple senses
are competing for the same resource. Using multiple resource theory, there is little competition for other memory information. Based on this observed difference, it was imperative to the evaluation to provide a level of haptic feedback that closely mirrored that experienced in the real world.

Studies have demonstrated that auditory signals elicit quicker response times when compared to visual signals (1). It is hypothesized that this is based on two reasons, instinct and the physical reaction to sound by humans. Instinctually, animals react quickly to sounds, and the bridge can be made to human behavior. From a physiological standpoint, processing sounds is quicker than processing images. Signals reach the brain from the ears in approximately eight to 10 milliseconds while a visual signal takes 20-40 milliseconds (2). This may be the result of the way in which information is transferred to the brain. Auditory signals captured by the ears are transferred to the brain through almost an entirely mechanical process. When compared to other senses, hearing is the most efficient sense - all other senses, including vision, require a chemical reaction to convert information received to that which can be processed by the brain. Furthermore, in a laboratory environment, researchers have found that subjects reaction time is quicker for auditory stimuli when compared to visual stimuli, roughly 30 to 50 milliseconds faster (2). This finding is critical when considering the driving environment. Providing drivers with additional reaction time is critical - the more time they have to react, the less likely they are to react in error. Considering a centerline incursion, if a driver were to have an additional 30 to 50 milliseconds to correctly respond to a stimulus, they may be able to avoid severe consequences.

Considering the importance of quantifying and qualifying drivers reaction to multi modal cues, researchers have attempted to provide the haptic and audible feedback in driving simulators when required. This involves using additional devices to move the vehicle with pistons and moveable bases. Unfortunately, these types of devices typically involve a significant investment in both hardware and software. Furthermore, these devices may not be a viable alternative considering the configuration of many simulators. Fixed-base simulators comprise fixed screens and hardware not designed to move with the vehicle which preclude the use of some of the more robust hardware that would "move" the vehicle.

**FEEDBACK IN A FIXED BASED SIMULATOR**

**Haptic Signature**

One of the challenges in a fixed-based simulator is providing haptic feedback to the driver. In some instances, providing haptic feedback to the driver may not be necessary and therefore the investment is not justified. In other instances, this level of detail is important. One instance where it is critical to provide haptic feedback in the simulated world is when rumble strips are considered.

In the simulator, the "real" world that is driven through is made up of polygons, each used to represent a different object in the real-world. For this particular project, a
specific attribute code was designated for polygons. These polygons were used for rumble strips. Once a coded polygon was "driven over", two events would occur - the air bag light on the dashboard was illuminated and a specific sound file would be broadcast through the simulator's sound system. Rather than rewriting code to turn on another device, further thought was given to improvise within the confines of the existing system to provide haptic feedback to the driver, similar to what one would experience if they were driving the vehicle in the field.

After a review of available technologies a decision was made to use bass shakers for providing in-vehicle haptic feedback. Two 50 watt bass shakers (Figure 1), manufactured by Aura were purchased. Bass shakers provide the vibration associated with a signal's low frequency (i.e., bass) and appeared to be the optimum solution for providing haptic feedback. Also, the physical dimensions of the bass shakers made them attractive for this installation - they are 2.2 inches high and 6.2 inches in diameter, and weigh 3.0 lbs.

There were a number of locations that were considered and tried, including some inside and outside of the vehicle. Through a series of subject beta tests, the location was narrowed down to an interior location. One prerequisite for installing the bass shakers was that regardless of their final location, they could not interfere with any pre-driving or driving tasks (e.g., seat belt adjustment, seat position). Although locations that offered installation ease and had potential to provide the degree of vibration required, these areas were avoided. The bass shakers were ultimately installed in the vehicle's cabin, on the bottom side of the driver's seat (Figure 2). After a number of trial locations, the final position appeared to provide the optimum degree of vibration while providing a relatively unobtrusive location (the driver could adjust the seat to the position of their choice and each driver would receive the same magnitude). The bass shakers, when powered, would vibrate with the sound signature.
Sound Signature

Recording rumble strip sounds was done from inside the vehicle's cabin, with the windows closed. The passenger car used for incursions was temporarily equipped with a Knowles Electronics Manikin for Acoustics Research (KEMAR (Figure 3)). The mannequin's microphones, located at an average ear elevation and location ensure that the sound level and direction is similar to that experienced by drivers in the real world.
The mannequin was placed in the passenger seat when the pattern signatures were recorded. Because the mannequin was seated in the passenger seat, the incursions were reversed – the shoulder rumble strip incursion took place on the driver’s side of the vehicle, and vice versa. This reverse approach ensured that the sounds and vibration incursions in the evaluation environment were broadcast from the proper vehicle side.

KEMAR was connected to a sound recording rig that electronically recorded the sounds. As the vehicle was driven along the roadway, a recording was made of the sounds in the vehicle's cabin. The test vehicle was driven down a roadway at 60 mph and two series of recordings were made, a baseline/background sound and an incursion sound. Once the background data were established, the vehicle was driven over the rumble strips at the pre-defined speed, with the rumble strips on the passenger side of the vehicle. Again, the acoustical signature was recorded. This reversal ensured that the acoustical sound signature realistically represented a future centerline incursion (driving the vehicle over the strips from the proper travel direction may not be realistically represented in the laboratory). This was used as the "incursion" sound that would later be used in the simulator.

**Integrating Vibration and Sound**

Sound in the simulator is provided through a Bose Acoustimass system in the laboratory. The signal from virtual world is sent to the Acoustitron system, where the particular wave (.wav) file is played. If the vehicle is properly located in the lane, then a background sound is broadcast; once the vehicle drives over the rumble strips the rumble strip sound is broadcast. The Acoustitron system is connected directly to the Acoustimass system (Figure 4).

Considering the configuration of the existing system did not allow for the bass to be sent to the directly to the bass shakers - the signal from the Acoustimass went directly to the subwoofer, after which the higher frequency sounds were transferred to the speakers. To address this design issue, a second audio receiver was added, downstream of the Acoustitron. This second receiver controlled the low frequency signal for the bass shakers. Since the second receiver had a very low output (35 watts), a 460 watt amplifier (12v DC) was used to boost the signal strength and provide a degree of haptic feedback that would provide a level of fidelity similar to that in the field.
One of the more challenging aspects of the project was determining how to get the bass shakers to switch on and off when needed. Recall that the background audio signal (i.e., road noise) is broadcast throughout the drive. If this signal were to be used for the bass shakers, then the bass shakers would provide vibration when the background audio were broadcast. To avoid having the bass shakers on throughout the drive, a PC board relay (12v DC, SPDT) was incorporated into the design (Figure 5). The relay was connected to the terminal board strip in the vehicle to the terminal that controlled the air bag light.

**Figure 4 Sound System Architecture.**
Recall that every rumble strip incursion illuminated the air bag light - this existing configuration was used to turn the bass shakers on and off as needed. The terminal screw for the air bag switch receives 12v DC power when off, and when illuminated the voltage goes to zero; therefore, the SPDT relay was used to switch between the road noise and the rumble strips. The SPDT was closed when the 12v DC source was applied, and opened when the air bag light was illuminated. The connection to the bass shakers was connected to the "open" side of the switch, receiving power as needed (Figure 6).

**Figure 5** PC Board Relay.

**Figure 6** SPDT Relay Configuration.

**HAPTIC FEEDBACK VALIDATION**

A three-axis accelerometer was used to record acceleration along three axes in the field. This information was used primarily to identify the differences in signal strength when a rumble strip incursion occurs on the left hand side of the vehicle as compared to the right hand side. The data were also envisaged to be used to ensure that the magnitude of the signal presented in the simulator was similar to that encountered in the driving environment. Since the simulator is a fixed-base system, and the acceleration along axes is non-existent, the field-recorded accelerometer data was not applicable for comparison; therefore an alternative approach was used.
Once the bass shakers were attached to the seat, a "beta" test was designed and implemented to ensure the bass shakers provided a level of fidelity that drivers could readily identify as rumble strips. This beta test ensured that the quality of the field recorded sound and vibrational signals were accurately represented and not degraded in any portion of the dynamic evaluation.

**FINDINGS**

Upon exiting the evaluation, the drivers were debriefed in an informal manner. They were told what the evaluation was focused on and they were asked a number of questions. One of the follow-up questions related to the fidelity of the haptic feedback. All of the drivers thought that the haptic feedback added to the "real world" feel of the drive and that the signal did feel like a rumble strip incursion.

Considering the magnitude of the signal, replicating real-world conditions in the simulator so they mirror field incursions would require additional financial resources - including adding haptic feedback to the steering column and other parts of the vehicle; based on this and subject feedback, it appears that the architecture described herein addressed the researcher's needs while providing opportunity for future expansion.

**REFERENCES**


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