

Enhanced Camera/Video Imaging Systems (E-C/VISs) on Heavy Vehicles

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ABSTRACT

Large trucks were involved in more than 26,000 crashes between April 2001 and December 2003 as a result of making lane changes, merges, and turns [1]. As an alternative to mirrors (surrogate system), or to be used in combination with mirrors (enhancement system), the industry has been developing Camera/Video Imaging Systems (C/VISs) directed toward improving visibility to the sides and rear of heavy vehicles. The current study describes development of an Enhanced C/VIS (E-C/VIS) directed at improving visibility in less favorable environmental conditions, such as nighttime and inclement weather.

INTRODUCTION

The implementation of C/VISs is becoming more common on heavy vehicles. As a result, the National Highway Traffic Safety Administration (NHTSA) contracted with Virginia Tech Transportation Institute (VTTI) to develop concepts and specifications for these systems and also to test them in realistic environments (Contract DTNH22-00-C-07007, Task Order 18, Track 2) [2]. These types of systems were demonstrated useful in improving commercial vehicle safety by VTTI. These systems were tested, however, in daytime conditions with good visibility. As the original contract continued, NHTSA awarded another contract to VTTI (Contract DTNH22-05-D-01019, Task Order 6, Track 4). This project extended the work of the original contract into less favorable environmental conditions, namely nighttime and inclement weather. A three-camera/video imaging system was to be developed and tested: one system on each side of the heavy vehicle and one at the rear (Figure 1). The purpose of this design was that the driver of the heavy vehicle would be better informed regarding the environment around the sides and rear of the heavy vehicle, that is, he or she would have better situation awareness. VTTI was tasked to develop a system using "best available technologies": with consideration given to total cost of implementation of a final system for use in a heavy vehicle. The system was envisioned as an enhancement, that is, the side mirrors would remain on the vehicle even though the video systems would be added. Under such circumstances,

malfunction of any of the three video chains would still allow the heavy vehicle to be driven in a conventional manner. There were two phases to this project. Phase 1 consisted of initial laboratory testing of the "best available technologies", development of the passenger side C/VIS, and finally formal human factors stationary testing in multiple conditions, e.g. nighttime, daytime, rain, and wind. Phase 2 consisted of developing the final system and performing a formal human factors dynamic test on the Virginia Smart Road. The purpose of this paper is to discuss the methodology used in Phase 1, some results obtained, and to describe the final system design to be tested in Phase 2.

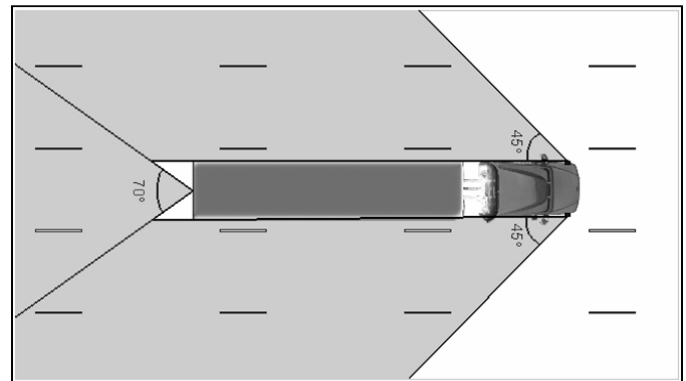


Figure 1. Proposed initial concept of an enhanced camera/video imaging system.

INITIAL LABORATORY TESTING

Prior to any formalized human factors testing, it was deemed necessary to reduce the number of alternatives of "best available technologies" to a manageable level. This testing involved evaluation of combinations of cameras (3 CCD color cameras and 1 CMOS black & white camera), filters, and illumination sources (visible and infrared) in hopes of finding combinations that worked well in darkness. Tests on candidate components were performed in a storage building in which lights were extinguished. This testing saved resources because a wide variety of combinations could be tested using one-of-a-kind items. This testing was performed by VTTI researchers directly involved in the project. The testing was set up to be similar to a nighttime situation in which a car was alongside the

heavy vehicle, as shown in Figure 2. The cameras had lenses set for approximately 45 degree horizontal fields of view, as would be the case for the side cameras on the tractor. A single illuminator was used for each test. It was located closer to the parked vehicle, similar to an arrangement in which the illuminator would be along the side of the tractor-trailer combination. A dark blue, mid-size sedan (2001 Saab 9-5) was used as the object. This color had low reflectivity and was therefore deemed appropriate for the tests because the results for lighter vehicles would probably be better. The image of the sedan could be tested both with its lights on and with lights off. Both conditions were considered important. The lights-off condition would correspond to a dark object alongside, such as a vehicle or trailer without exterior lighting, whereas the lights-on condition would correspond to the usual situation in which a vehicle is alongside and illuminated in the usual manner for nighttime driving.

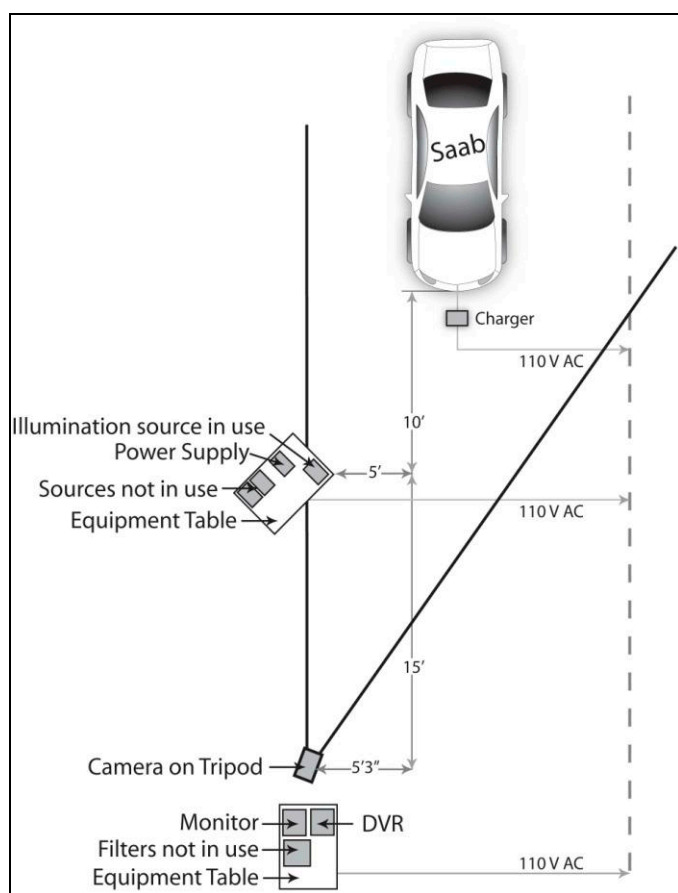


Figure 2. Equipment layout for the initial laboratory testing.

A single viable system (with two possible sources of illumination) was derived from these tests. A Toshiba IK-64DNA camera was recommended as the camera having the best overall performance. It was sensitive at very low levels of illumination, and responded to both visible and near infrared (IR) illumination. It had both nighttime black and white (B/W) capability and daytime color capability. Consequently, for the intended application, only three of these cameras would be required: one on each side of the tractor and one at the

back of the trailer or cargo box. The recommended visible illuminators for the rear of the heavy vehicle produced red illumination that had an appropriate horizontal spread. Each illuminator was a composite device made up of a base containing LEDs and a dispersive lens epoxied to the base. The recommended visible illuminators for the sides of the heavy vehicle produced amber (yellow) illumination that had an appropriate horizontal spread. The illuminator was a composite device made up of a base containing the LEDs and a dispersive lens epoxied to the base. The recommended near IR illuminators were rectangular arrays that produced no visible light and were composed of arrays of 140 LEDs which produced narrowband illumination at 940nm. There was no additional filter that provided an improvement in video image. Therefore, no additional filters were recommended for further testing. Post processing was recommended to proceed with the idea of improving the images obtained with the IK-64DNA. It should be mentioned that digital video recordings were made of the candidate final arrangements, so that post-processing of the images could be examined for potential benefits.

HUMAN FACTORS STATIONARY OUTDOOR TESTING

A major research facility was developed specifically to allow stationary human factors testing of the system derived on the basis of the initial laboratory testing. This facility was basically an outdoor stationary simulator of highway conditions. This facility was developed to test the better configurations in both clear and rainy conditions. The experimental tests were intended to determine image quality of an E-C/VIS as judged by naïve VTTI personnel in a controlled experiment. An additional goal was to determine the degree to which visible illumination would affect "other" drivers as they approached the side and rear of the equipped heavy vehicle. Tests were run both during daytime and nighttime; however, the nighttime tests required a larger number of conditions. In particular, the effects of illumination sources had to be studied, and glare tests associated with the visible illumination sources had to be performed for the nighttime runs.

HARDWARE CONFIGURATIONS - The facility included a high-power wind/rain generation system, rain towers, wheel mist generation systems, a rain production system, a target vehicle, a lead vehicle, a passenger side video chain, visible and near IR illuminators, digital processing and, of course, a tractor and trailer. Tests were run using VTTI's 1994 Peterbilt tractor with a new Utility 4000 D-X 53 ft (16.2 m) trailer. Initially, the target automobile was a 2001 Saab 9-5 sedan, dark blue in color. Later, this vehicle was changed for reasons that will be explained. An additional vehicle, an older Volvo sedan, was used to provide a readable lead-vehicle target for the glare/discriminability tests. The Volvo sedan's rear lighting was energized for the test. Further

detailed descriptions of major components of the facility are described in the sections to follow.

Camera – The initial laboratory tests demonstrated that the Toshiba IK-64 DNA camera had the capability of operating effectively both in daylight and at night. It was also sensitive to both visible and near IR illumination. This camera provided color capability for daytime use and B/W capability for nighttime use. A filter inside the camera for use at night was removed using an internal electromechanical device. This filter could be removed automatically, or it could be controlled externally. In the tests, the filter was controlled externally by using a switch connected to the control contacts of the camera. This camera was mounted at the passenger-side front fender of the Peterbilt. The camera lens was mounted in a special enclosure designed specifically to protect the camera from rainwater. The camera enclosure was filled with nitrogen gas to limit moisture condensation inside the enclosure (Figure 3).



Figure 3. Camera and Illuminators mounted at the tractor passenger-side front fender.

Monitor - The monitor to be viewed by the participant was placed at the passenger side A-pillar. It was intended that the monitor should be Size 2 as defined in the previous research [2]. Tests demonstrated that the computer-processed image used in this research produced unacceptable delays if the processed computer image was re-converted to analog format. Consequently, it became necessary to use a different monitor which would accept a signal in Video Graphics Array (VGA) format, making re-conversion unnecessary. This monitor had an image surface that was 10.2 cm (4.02 in) high by 13.4 cm (5.28 in) wide, with a corresponding diagonal dimension of 16.6 cm (6.54 in). The image produced was therefore very nearly the same size as the Size 2 monitor image. The monitor was mounted near the lower end of the A-pillar. The image

on the monitor was a mirror image; that is, it was reversed left to right (horizontally).

Illumination Sources – Two sources of illumination were added to the heavy vehicle: visible and narrowband near IR. These sources could be used at night either singly or together, allowing the testing of four nighttime conditions; that is: no added illumination, narrowband near IR illumination, visible illumination, or both forms of added illumination combined.

Near IR Illumination Sources - In regard to the near IR illumination sources, four units were installed on the tractor-trailer combination, all of which were 140 LED units. One unit was installed at the lower rear portion of the tractor front fender (Figure 3), two units were installed along the passenger side of the trailer, and one unit was installed on the right rear corner of the trailer. The units mounted on the side of the tractor-trailer were aimed rearward with a centerline of 22.5 degrees (45 degree horizontal spread). The units mounted on the rear of the trailer were aimed straight back with the same horizontal spread.

Visible Illumination Sources - In regard to the visible illumination sources, four units were installed on the tractor-trailer combination at the same locations as the IR units. A fifth unit was installed on the driver-side rear of the trailer for use in the glare tests. The three units on the side were amber. A typical side unit is shown in Figure 3. The two units installed at the rear were red. The visible illuminator colors were selected to match current standards requiring amber lights on the sides and red (steady) lights at the rear. The units mounted on the side of the tractor-trailer were aimed rearward with a centerline of 20 degrees (40 degrees horizontal spread). The units mounted on the rear of the trailer were aimed straight back with the same horizontal spread.

Wind/Rain Generation System - Several steps were involved in obtaining a good simulation of rain at highway speed. Earlier, in preparation for the outdoor stationary tests, a typical sedan was equipped with a regular color camera mounted at the center of the windshield and aimed forward. The vehicle was then driven by one of the experimenters on a local multilane highway during rain. This driver approached several tractor-trailers for the purpose of obtaining recorded video of the spray pattern. Video was recorded as the experimenter closed in the adjacent right lane. The video continued as the experimenter's car approached and came alongside the heavy vehicle. The purpose of the video was to determine the specific elements of the spray pattern and then use them for simulating the artificial rain in the static experiments. The recorded video was analyzed and showed that there were several main sources of spray associated with typical tractor-trailers. Principal among these was the mist pattern that emanates from between the two sets of tires at the rear of the trailer near the top of the tires. This mist pattern results from the fronts of the tires on the rear axle moving downward while the backs of the tires on the second-from-rear axle move

upward. The effect is to produce a mist that exits to the side of the trailer. A similar pattern emerges from the two sets of tires at the rear of the *tractor*; these tires are actually under the trailer. The mist pattern for these rear tractor tires is almost identical to the pattern for the trailer tires, in that the mist moves outward from the top between the two sets of tires. The second aspect of the pattern is the general spray that comes from the tires as they sling water after it is forced out from under the tires or is picked up by the tires. This pattern produces a spray that is outward and rearward. Finally, there is the pattern of rain hitting the windshield of the car directly. This pattern is largely the result of the rain itself falling from the sky. The rain collides with the windshield at approximate highway speed horizontally and rain-falling speed vertically, because the car would also be moving at highway speed. Figure 4 shows the layout of the rain and wind-producing equipment.

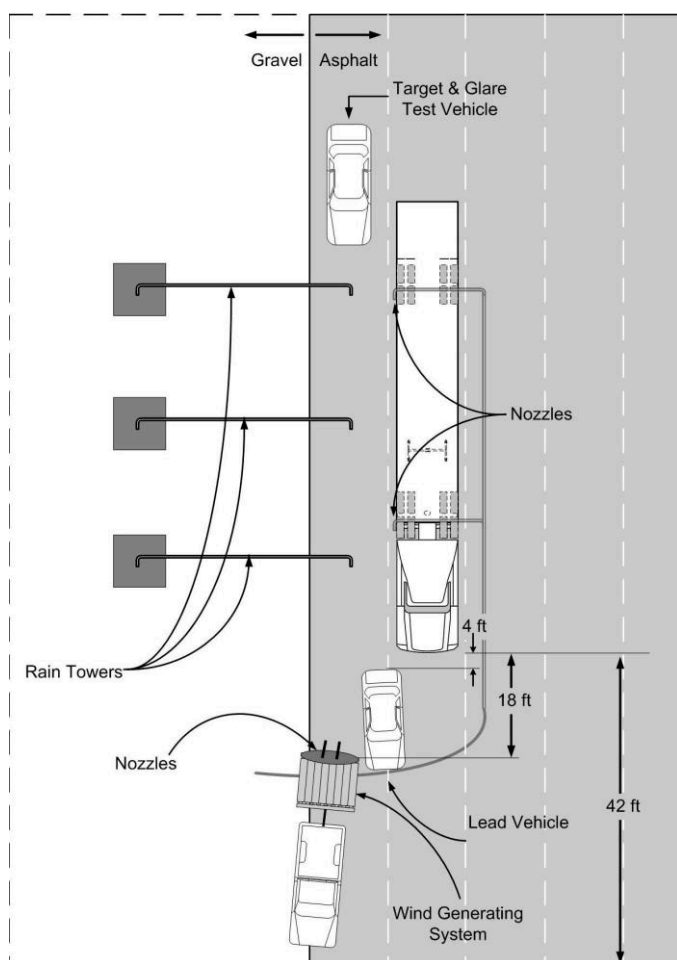


Figure 4. Layout of the rain and wind-producing equipment.

The mist between tires was simulated using two mist nozzles: one between the axles of the trailer and one between the rear axles of the tractor. The spray was simulated by using a coarser set of ten nozzles in a circular pattern in front of the wind generation system, and the falling rain was simulated using overhead towers and spray nozzles. It should be noted that the wind generation system was composed of a converted airboat

power-plant and propeller in a safety cage. The system used the same type of vertical vanes that are used on an airboat (Figure 5.)



Figure 5. Wind/spray generation system.

This system was capable of producing sustained wind speeds of 73 mph (117.5 km/h) as measured with an anemometer. For the tests, the speed used was approximately 60 mph (96.6 km/h). It should be mentioned that special precautions were taken when the rain test runs preceded the clear runs. When this occurred, the target vehicle was wiped with large towels after the group of rain runs was completed, to eliminate water beading that might affect the results of the following clear runs.

METHOD

PARTICIPANTS – Eight naïve VTTI employees were used as participants. They were excused from work for participation during normal working hours. For the nighttime tests they received compensatory time off work. They read and signed an informed consent form that detailed all of the important aspects of their participation. They were given visual acuity tests to ensure that their vision was adequate (20/25 or better, corrected if necessary). Participants were assigned randomly to conditions. However, some care was taken to ensure that the number of males and females was approximately equal. As it turned out, five males and three females volunteered.

EXPERIMENTAL DESIGN – The human factors stationary outdoor testing was conducted in both a nighttime setting and daytime setting.

Nighttime Testing – The nighttime tests were the most comprehensive. They included factorial combinations of clear and rainy weather, four illumination conditions, and three target vehicle (automobile) locations (Figure 6). In addition, as mentioned earlier, tests were carried out to determine the effects of glare on the "other driver"; that is, the automobile (target vehicle) driver for the visible illumination condition. In this case four positions were