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Utilizing Biomimetic Image Processing to Detect the Road Edge of Off-road Terrain

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Abstract. *Soldiers incurred injuries or even lost their lives due to rollovers while driving military vehicles. A recent report identified that the one cause of rollovers is the driver's inability to assess rollover threats, such as a cliff, soft ground, water, or a culvert on the passenger side of the vehicle, due to the vehicle's width. To reduce the number of rollover accidents, a road-edge detection and driver warning system is being developed to detect the rollover threats on the passenger side of the vehicle and warn the driver. This system utilizes a unique, ultra-fast image processing algorithm based on the neurobiology of insect vision and the study of fly vision. The system consists of a camera system, a long-range, planar laser scanner, a processing module in which a biomimetic image processor detects edges present in the images in real-time, and a Driver Vision Enhancer (DVE) which displays the current road image, detected boundaries, and road side terrain steepness.*

Keywords. rollover, road edge detection, biomimetic, image-processing algorithm, long-wavelength infrared (LWIR), Army, insect vision applications

.

1 Introduction

U.S. Army personnel and Soldiers operate their military vehicles on rugged off-road terrain and in bad weather conditions while driving their vehicles. The Soldiers often navigate and traverse over rough terrain that could inadvertently damage the vehicle and cause injury to the crew and driver. One of the situations that the driver needs to be concerned about is rollover, since Soldiers drive large military vehicles such as the High-Mobility Multipurpose Wheeled Vehicle (HMMWV), Stryker, Abrams, Bradley, or the Family of Medium Tactical Vehicles (FMTV). These vehicles are wide and have hidden blind spots that hinder the driver's field of view. Due to the vehicle's width, the driver is unable to assess rollover threats, such as driving close to the edge of the road that has a drop-off into a ditch or water, or a large obstacle that could unbalance the vehicle on the passenger side of the vehicle. The driver can not see these hazards, thus he or she might go over the edge, therefore causing the vehicle to rollover. Such rollover incident could be avoided if the Soldiers were equipped with technology to warn the driver of potential

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14. ABSTRACT

Soldiers incurred injuries or even lost their lives due to rollovers while driving military vehicles. A recent report identified that the one cause of rollovers is the driver's inability to assess rollover threats, such as a cliff, soft ground, water, or a culvert on the passenger side of the vehicle, due to the vehicle's width. To reduce the number of rollover accidents, a road-edge detection and driver warning system is being developed to detect the rollover threats on the passenger side of the vehicle and warn the driver. This system utilizes a unique, ultra-fast image processing algorithm based on the neurobiology of insect vision and the study of fly vision. The system consists of a camera system, a long-range, planar laser scanner, a processing module in which a biomimetic image processor detects edges present in the images in real-time, and a Driver Vision Enhancer (DVE) which displays the current road image detected boundaries, and road side terrain steepness.

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rollover threats. The Army is researching and developing methods to decrease military accident fatalities. One technique that engineers and scientists are currently developing is a road-edge detection and driving warning system to notify the driver of potential rollover threats and provide the driver enough time to steer the vehicle away from the threat , thus preventing a rollover.

2   Main components of the system

The Army is developing techniques to mitigate rollover incidents. One technology that is being considered, shown in Figure 1, is a system that is being developed to decrease rollover incidents. The system consists of a monochromatic video camera, a long-wavelength infrared (LWIR) camera, and a laser scanner. This system can be mounted on a HMMWV or any military vehicle that is bulky and has a limited field-of-view out of the passenger side of the vehicle.
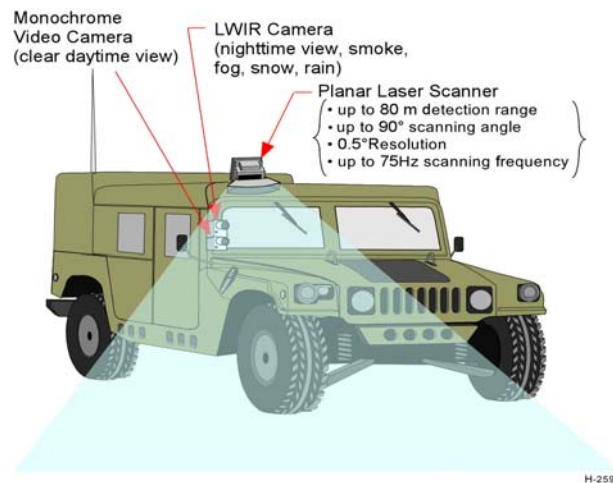
Figure 1. Video and LWIR cameras potential mounting positions.

The general flow-chart of the architecture, which includes the hardware and software for the rollover detection system, is shown in Figure 2. The hardware includes the video and LWIR cameras, the laser scanner, and the Driver's Vision Enhancer (DVE). The video and LWIR cameras enable the driver to see images during daytime and nighttime driving, and also in poor weather conditions such as fog, snow, and rain. The software reads in the video images from the video or LWIR camera and processes the images. The processing unit includes the fly eye-based edge detection, the edges fusion, the road-edge identification, and the roll-over threat detection algorithms. The fly vision-based algorithm integrates all the relevant edges that are present in the video or LWIR camera and decomposes them into a single set of edges or contours. The road edge identification algorithm then defines the edges that are relevant to the road boundary. The rollover threat detection algorithm determines whether the terrain steepness, which is measured by the laser scanner, is negative or positive on the passenger side of the road. The rollover threat detection algorithm integrates the terrain steepness with the road boundary information to assess rollover threat. This assessment will notify the driver visually and acoustically when the system determines that the driver is driving close to the edge of the road and risks rolling the vehicle.
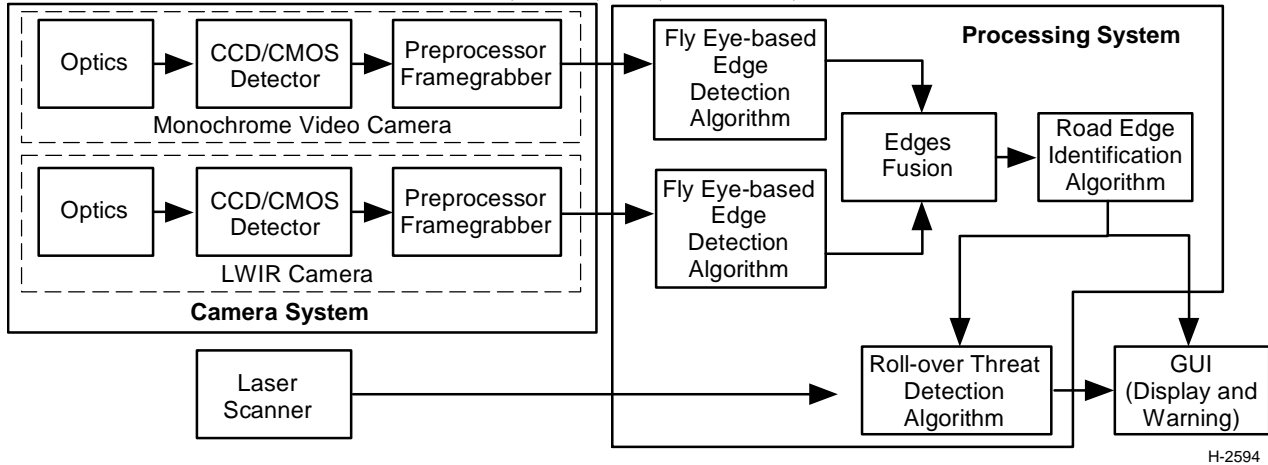
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Figure 2. Flow-chart of the road edge detection system

2. 1   *Hardware: Cameras and Laser Scanner*

Video images have been used to detect and track road boundaries and lane markers. The images obtained from the video provide the best results on roads with lane markers, during daylight, and in good weather conditions (Wang et al., 2004). However, video images are difficult to use during nighttime, rain, snow, fog, smoke, and on unmarked terrain. To improve viewing, the scenery during nighttime, or in the presence of smoke, fog, snow, and rain, and on all terrain conditions, both video and LWIR cameras are needed.

LWIR cameras allow the users to capture images through smoke, fog, snow and rain. There are two types of infrared imagery technologies: cooled and uncooled infrared detectors. The Army is interested in the uncooled infrared detector, since it is compact and affordable. The uncooled infrared detector uses a micro-bolometer which is insensitive to light, since it can operate in long-wavelength infrared region, 7-14 μm, thus making it beneficial for nighttime usage.

The images displayed from a LWIR camera allow the driver to distinguish the different types of materials used on the roads, such as asphalt, dirt, or gravel, and from the embankment, such as grass, rock, or a cliff. This distinction provides better contrast, thus making detection of the road boundary and embankment easier during nighttime driving and under different weather conditions. However, a video camera and LWIR camera can not provide sufficient depth perception, since the users can not extract depth from the video or LWIR camera. It is possible to determine depth perception when multiple cameras are mounted at different angels, but having multiple cameras on a vehicle takes up space, which is limited on military vehicles, increases the overall cost of the system, and increases the computational power requirements such as processing and memory. A laser scanner is needed to overcome this hurdle.

The laser scanner provides depth or steepness perception since the laser scanner can scan any point in space to indicate the presence of a cliff or an obstacle. An *increase* in the slope of the scanning denotes a terrain depression such as a cliff that is on the passenger side, while a *decrease* in the slope will denote positive terrain such as a big rock or an obstacle that is on the passenger side of the vehicle. Figure 3a shows a parking lot, from left to right, the flat surface (the parking lot), a positive terrain (grass), and a negative terrain (a drop-off onto the adjacent

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road). Figure 3b shows the results from the laser scanner algorithm. The dark line on the left represents the flat surface, the middle curve (the light color) represents the positive terrain, and the slight curve on the right represents the negative terrain. The threshold for positive and negative terrain was set arbitrarily to one foot, relative to the flat surface. If the algorithm for the scanner detects a negative or positive slope that is greater than one foot, then the slope appears on the graph as a positive or negative terrain.
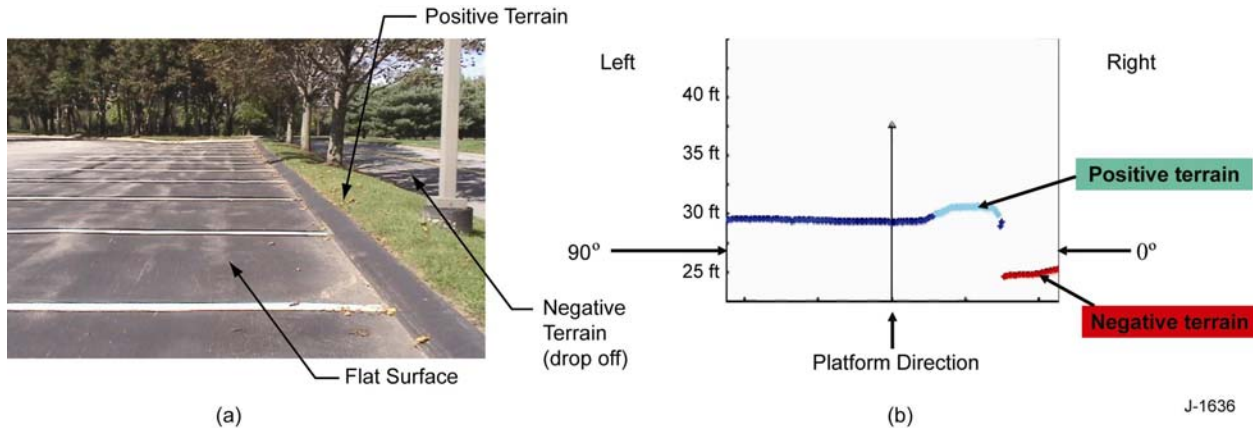

Figure 3. (a) Parking lot used to test laser scanner (b) Results from the laser scanner

The laser scanner that the researchers and engineers are considering has a light beam that is invisible to the naked eye and will not interfere with the LWIR imaging. The laser scanner needs to have at least a 75 meter range since the scanner needs to measure the steepness in front of the vehicle and provide enough time to warn the driver of potential barriers or drop-offs and enable the driver enough time, about 2 seconds, to react and veer the vehicle away from the potential rollover hazard.

However, the monochromatic video and LWIR cameras and laser scanner by themselves are not advantageous to the driver, since the cameras and scanner cannot warn the driver of potential rollover threats. Algorithms are needed to extract the images and terrain steepness, and that information is used to warn the driver visually and acoustically using alarm signals.

3 Processing Unit

After the monochromatic and LWIR cameras capture the images and the laser scanner returns the measured distance, algorithms are needed to process the images and analyze the distance. There are four algorithms used 1) a fly eye-based algorithm to detect road edges, 2) an algorithm to fuse monochromatic video and LWIR images, 3) a road boundary identification algorithm, and 4) a roll-over threat detection algorithm.

3.1 Fly Eye-based Road Edge Detection Algorithm

Viewing images from a monochromatic camera on a computer system demands intensive computational power and time, which is not very ideal, since excessive computational time means that there will be a lag in the images being displayed to the driver on the monitor. This lag in the images can be dangerous to the driver since the images are not processed in real-time, and the driver is unable to determine whether the vehicle is close to the edge of the road or not. To resolve the issue of delayed images being displayed on the monitor, an innovative

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technique to quickly process the video images is being implemented for the road-edge detection and warning system. The technique that is being utilized is based on the cognitive neurobiology of a fly. Since the brain of a fly is small and a fly needs to maneuver quickly to avoid obstacles, the fly flies by detecting the edges of objects to avoid slamming into them (Agassounon et. al, 2004). Since the fly has limited brain space, it needs to quickly see the images and efficiently process the images. This neurological process of the fly has been modeled and simulated for use in detecting the boundaries of objects or roads .
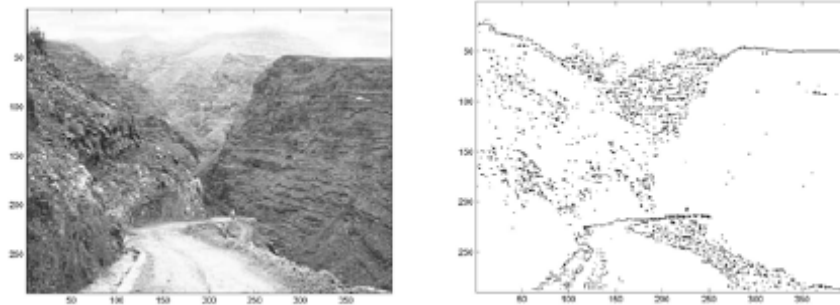
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Figure 4. (a) Image of the road   (b) Image using fly-eye based detection
algorithm

An example of using the fly-eye-based edge detection algorithm is shown in Figures 4a and 4b. Figure 4a shows an image of the road and Figure 4b shows the same images using the fly-eye-based detection algorithm. From looking at Figure 4b, one notices that the algorithm captures the relevant contour pixels of the image, which are the lane maker, cliff edge and road boundary.

Since the fly registers the edges of objects, software leveraging this type of cognitive vision responses augments the robustness and computational speed of the system. The fly-eye-based, edge-detection algorithm is thousands of times faster than the traditional, gradient-based algorithm because only the relevant pixels, such as the boundaries of the objects in the video, are stored, thus increasing the processing speed and consuming less memory (Sinakevitch and Strausfeld, 2004).

However, using the ultra-fast, fly-eye-based, edge-detection algorithm by itself is not advantageous since images are being captured by both the LWIR and monochromatic video cameras. The road-edge detection system does not know which images to use, thus to improve the probability of detection, the two images need to be combined into a single robust image that the system can utilize for road-edge detection.

3.2   Fusion Algorithm

When using images from both the video and LWIR cameras, the images do not lay on top of one another. To overcome this minor stumbling block, the video and LWIR cameras need to be mounted and oriented so that the fields-of-view for both cameras line up, thus enabling images taken from both cameras to superimpose on top of each other. The fusion algorithm combines the edges detected from each of the cameras into a single set of edges that can be displayed to the driver, otherwise the driver might get dizzy looking at two different images.

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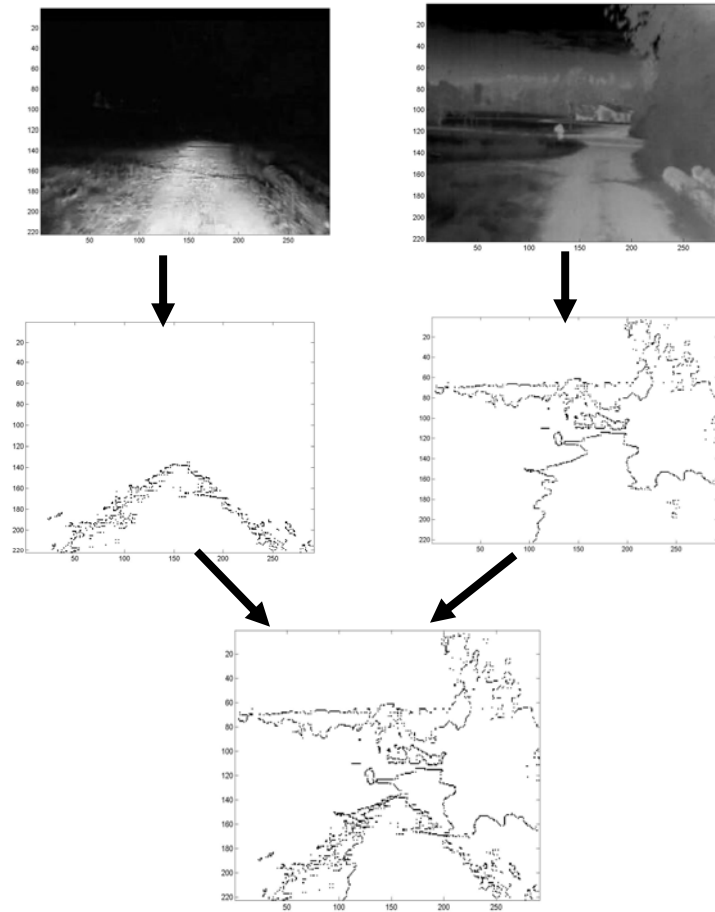Fairbanks, Alaska, USA, June 23-26, 2007

Figure 5. Edges fusion example. (Images are courtesy of Zeiss Optronics.)

The fusion algorithm uses a weighted sum of the pixel intensities of detected edges in the visible and LWIR images. Thus, this method integrates the edge information into a single-edge image. The contribution from either the LWIR camera or the video camera can be increased or decreased by varying pixel intensities. Figure 5 shows an example of the edge fusion. The picture on the left is of the road taken at night using a monochromatic video camera, while the picture on the right is taken with a LWIR camera. The bottom picture is a superimposed image of the two pictures using the fusion algorithm.

3.3 Road Boundary Identification Algorithm

In addition to the fusion algorithm, a road boundary identification algorithm is required since all the edges in the image such as trees, big boulders, or buildings are displayed. To minimize confusion to the driver, the road edges need to be well defined and outlined. The road boundary algorithm utilizes a technique that Wilson discovered called position of pivot point estimating trajectory (POPPET) (Wilson and Dickson, 1999). This algorithm capitalizes on a model-based technique to fit consecutive segments of the road boundary with a curve fragment by fitting the road edge segment with a short 2D vector using pivot points. This algorithm automatically searches for the origin of the road boundary in the lower right quadrant of the edge image by looking for the origin of the bottommost, rightmost straight line. Then a short vector of a selected

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length or fitting window is drawn from the origin. The algorithm then counts the number of detected edges belonging to the vector by rotating the vector about the origin point within a region defined by the original reference to find the best fit. The best fit corresponds to the position for which the fitting vector has the most edge points and represents the detected fragment for the road boundary. The tip of the vector becomes the new origin. The procedure is repeated to detect the full road boundary fragment by fragment. Figure 6 shows an example of the road boundary algorithm being implemented, where the dark line in Figure 6a and white line in Figure 6b highlight the edge of the road.
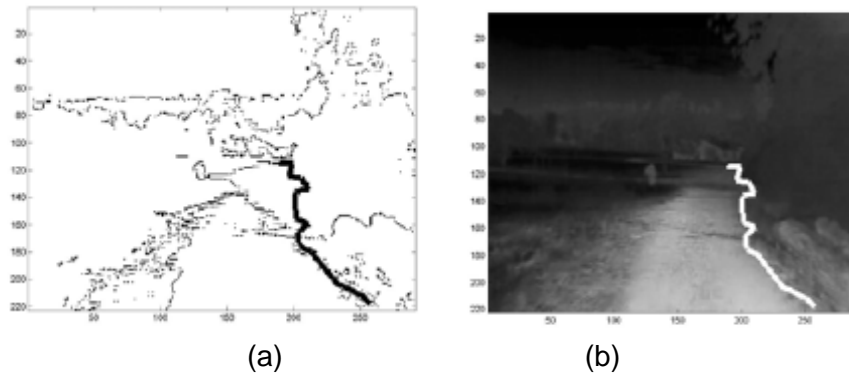

(a)   (b)

Figure 6. (a) Black line represents the road boundary (b) White line represents the road boundary.

3.4   Rollover Threat Detection Algorithm

After the edges of the road boundary have been identified, the laser or radar scanner measures and detects the presence of a drop-off or an obstacle on the roadside, and whether the vehicle is about to cross a certain threshold that would cause the vehicle to rollover if the driver does not steer back onto the road. To calculate the road edge crossing, the rollover threat detection algorithm uses the vehicle's heading, current speed of the vehicle, and the distance to the point of rollover. The distance to the edge crossing point is computed based on the average speed of the vehicle and the position of the road boundary detected in the image. When the road edge crossing is below a certain threshold, which is related to the driver's reaction time, an acoustic signal and a visual signal will simultaneously warn the driver of the danger. The visual warning and real-time video images will be displayed on the DVE.

3.5 Driver's Vision Enhancer (DVE)

The images from the LWIR and monochromatic video cameras are processed by the algorithms and displayed on the Driver Vision Enhancer (DVE) as shown in Figure 7. The DVE is currently installed in most military vehicles. The DVE will be used to display the real-time images. The real-time images are fused images from the LWIR and monochromatic cameras of the terrain such as the road boundaries, and the terrain steepness information on the passenger side. Other features that will be considered are GPS, compass, distance to the edge, and red-flashing button to notify the driver of potential threats. Figure 8 shows an example of a potential display for the driver that will be integrated on the DVE.   The three-light threat status will be used to alert the driver of potential rollover threats. .

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Table 1 shows the different warning stages of the road edge detection system. When the road edge crossing point is detected at a distance greater than 75 meters, no audio alarm is sounded and all three status lights remain green. When the crossing point is between 60m and 75m, there are two green lights and one red light, and there is a single beep sound. When the threat is between 45m and 60m, there are two red lights and one green light, and there is a double beep sound. When the threat is between 25m and 45m there are three red lights and a triple beep sound. Finally, when the threat is within 25m of the vehicle, there are three red lights and a repeating triple beep sound that lasts as long as the threat remains within the 25m range. The choice of 75 m is arbitrary, but allows at least two seconds of reaction time to the driver before the vehicle can reach the threat. Two seconds represents a normal reaction time for an average, healthy, sober driver. A vehicle moving at a speed of 50 MPH travels 75 meters in about 3.4 seconds. Therefore, this range appears as a safe distance that leaves enough time for the driver to react and maneuver the vehicle appropriately. The DVE and audio system will be further investigated when the developed system is tested on a vehicle.
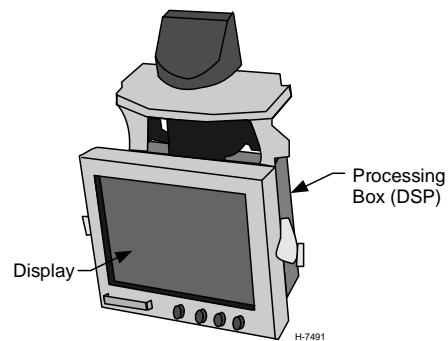

Figure 7. Driver's Vision Enhancer (DVE) uses to display the images in the vehicle

Figure 8. Conceptual design of the information shown to the driver

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Table 1. Warning Stages

Warning	Distance/Range	Light	Sound
No Detection	75m < d	G-G-G	--
1st stage	60m < d < 75m	G-G-R	Single
2nd stage	40m < d < 60m	G-R-R	Double
3rd stage	25m< d < 45m	R-R-R	Triple
4th stage	d < 25m	R-R-R	Triple Repeating

4   CONCLUSION

Further work is still being done on this system. The researchers and engineers are planning to use a radar scanner instead of a laser to measure the terrain steepness, since the radar sensors are more cost efficient for the Army. The Army is also planning to implement and field test the system on a HMMWV and have Soldiers drive the vehicle over an off-road terrain to assess the system performance and determine which components of the road edge detection system need to be optimized to maximize the system. Furthermore, the Army is planning to do an evaluation of how the soldiers will react to the road edge detection systems while driving under different scenarios.

The road edge detection and driver warning system has the potential to minimize the number of rollover incidents since the system will notify the driver of potential rollover threats and enable the driver to react in a timely manner to the threats. This system is helpful to Soldiers who are traversing on unknown, off-road or rugged terrain. In addition, the system will enable the driver to avoid going into a river or rolling over a cliff when driving along the side of riverbank, canal, or cliff, especially when the driver is driving at night, or navigating in poor weather conditions such as in fog, snow or a rain storm. This detection system utilizes a unique, ultra-fast, image-processing algorithm based on the neurobiology of insect vision, specifically the vision of a fly. The system consists of a Long-Wavelength Infrared (LWIR) camera and a visible spectrum monochromatic video camera system, a long-range laser scanner, and a processing module in which a biomimetic image processor detects edges in real-time. In addition, a Driver's Vision Enhancer (DVE) displays the video road image, detected boundaries and road-side terrain steepness, in real-time, for the driver. This system has the potential to be implemented on most military vehicles that are operating on off-road terrain to aid the driver and reduce preventable rollover incidents.

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