# UTILIZING BIOMIMETIC IMAGE PROCESSING TO RAPIDLY DETECT ROLLOVER THREATS

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## ABSTRACT

Rollover incidents of military vehicles have resulted in soldiers incurring injuries or losing their lives. A recent report identified that one cause of vehicle rollovers is the driver's inability to assess rollover threat, such as a cliff, soft ground, water, or culvert on the passenger side of the vehicle. The vehicle's width hinders the driver's field of view. To reduce the number of military vehicles rolling over, a road edge detection and driver warning system is being developed to warn the driver of potential rollover threats and keep the driver from veering off the side of the road. This system utilizes a unique, ultra-fast, image-processing algorithm based on the neurobiology of insect vision, specifically fly vision. The system consists of a Long-Wavelength Infrared (LWIR) camera and monochrome video camera system, a long-range laser scanner, a processing module in which a biomimetic image processor detects road edges in real-time, and a Driver's Vision Enhancer (DVE) which displays the road image, detected boundaries and road-side terrain steepness in real-time for the driver.

## 1. INTRODUCTION

A crew of two soldiers is in a High-Mobility Multipurpose Wheeled Vehicle (HMMWV) driving at night without the headlights turned on, on an unpaved, unmarked road. Unexpectedly, a camel crosses the road and the driver quickly swerves to the side of the road to avoid hitting the camel. Unbeknownst to the driver and the passenger, there was a twelve foot ditch on the passenger side of the vehicle. The HWWVW rolled over and ejected the soldiers out of their seats, since neither of them were wearing seatbelts. Neither of the soldiers were seriously injured, but they did suffer a broken arm and a sprained neck This accident is only a theoretical example of what soldiers can experience while driving military vehicles in various theaters. A recent report identified that one cause of rollovers is the driver's inability to assess rollover threat, such as a cliff, soft ground, water, or culvert on the passenger side of the vehicle. The vehicle's width hinders the driver's field of view. Each year, Army personnel and soldiers are involved in military vehicle accidents, many of which could have been avoided. There are several ways to decrease military vehicle rollovers and associated accident fatalities; one way is a road edge detection and driver warning system. Engineers and research scientists are currently developing a road edge detection and driver warning system to warn the driver of potential rollover threats and to keep the driver from veering off the side of the road.

## 2. ROAD EDGE DETECTION SYSTEM

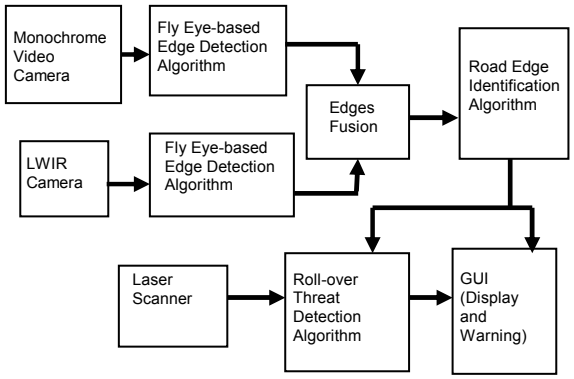


Fig. 1: General architecture of the road edge detection system

Figure 1 shows the conceptual general architecture of the system. This diagram shows the video and LWIR cameras which provide images for daytime, nighttime, smoke, fog, snow, and rain operation. The laser scanner measures the terrain steepness. The video images are read in by a processing unit. The algorithms embedded in the processing unit include fly vision-based, edge fusion, road edge identification and roll-over threat determination. The fly vision-based algorithm is applied to detect all edges present in the video and LWIR images. The edge fusion algorithm combines the detected edges into a single set of edges. It is part of a processing unit that fuses images from the cameras, extracts edges from the images, detects road edges and identifies the road boundary on the passenger side of the vehicle, and integrates the terrain steepness information with the road boundary information to assess rollover threat and warn the

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driver. The road edge identification algorithm identifies, among all the detected edges, those pertaining to the road boundary. The rollover threat detection algorithm detects the presence of negative roadside terrain on the passenger side of the road, and warns the driver acoustically and visually using alarm signals.

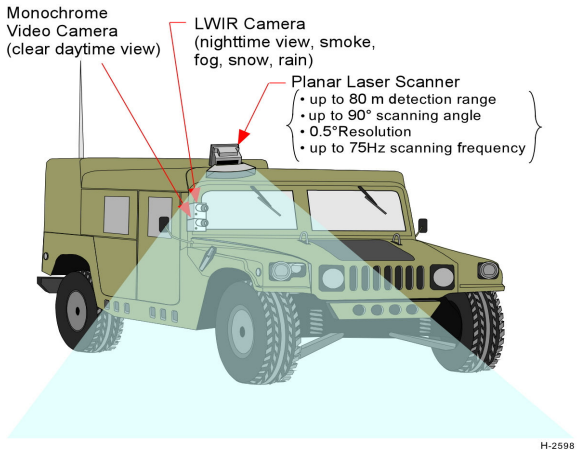



Fig. 2: Video and LWIR Cameras potential Mounting Positions.

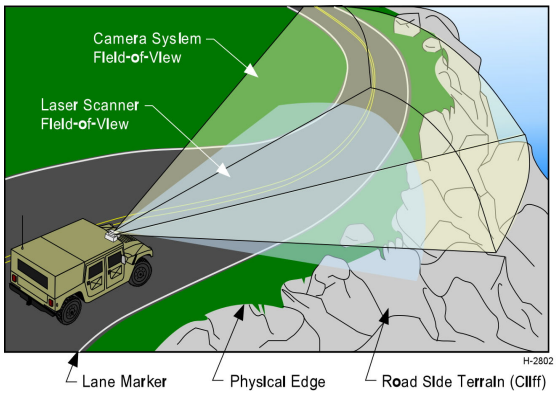



Fig. 3: Potential Scanning Range of the Camera System.

Figure 2 shows an example of how the monochrome video and LWIR cameras and laser scanner will be mounted. The different shading in Figure 3 indicates the wider field-of-view that the camera system has versus the laser scanner. The camera system provides road boundary detection and laser scanner provides range and roadside terrain steepness information.

### 2.1 Video Camera

In the past, video images have been used to detect and track road boundaries and lane markers (Wang et al., 2002; Want et al., 2004). The images obtained from the video provide the best results on roads with land markers when there is daylight and good weather conditions. 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 are not affected by bright sunlight or headlights, but are sensitive to temperature. There are two types of infrared imagery technologies, cooled and uncooled infrared detectors. The cooled infrared also has an integrated thermo-electric cooler (TEC), which makes the unit heavy and oversized. Furthermore, it also consumes more power. In addition, the cooled infrared cameras deliver higher resolution images, since the cameras often use Barium Strontium Titanate ferroelectric, but they are bulky and expensive, each unit costs more than $25,000, which is a hefty price tag in today's budget-minded Army. The uncooled infrared camera, on the other hand, is more compact since each unit uses a micro-bolometer that is sensitive to radiation in the 7-14 micron band for night time use. The uncooled infrared camera is more affordable, each unit costs less than $10,000.

The image display from a LWIR camera enables 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, utilizing both the monochrome and LWIR cameras does not supply sufficient images for detecting terrain depression as accurately, since the cameras do not provide depth perception. To overcome this hurdle, a laser scanner is also needed.

### 2.2 Laser Scanner

The laser scanner provides depth, or steepness, perception since the laser scanner can scan any point in space to indicate the present 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.

The laser scanner that the researchers and engineers are considering has a light beam that is invisible to the naked eye and should not interfere with the LWIR imaging. The laser light beam should

operate in near infrared, or less than 1μm wavelength, while the LWIR is sensitive only to long wavelengths greater than 7.0μm. The laser light needs to be inconspicuous and should not signal the vehicle's presence to an enemy. The laser scanner needs to have at least a resolution of 10mm, a 90 degree angle between the incident beam and the reflecting material for proper measurement, and at least a 75m detection range. A 75m range is needed because a short distance detection range is not beneficial to the driver. With longer distance range, the system can detect steepness of the terrain far enough ahead of the vehicle to warn the driver and allow the driver enough time to react to avoid the obstacle or the rollover threat.

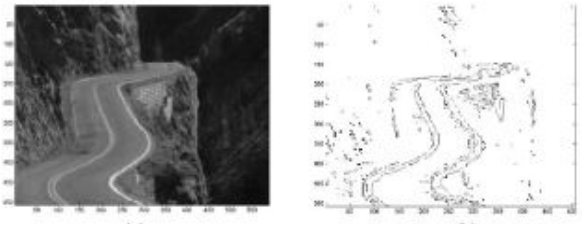
## 3. PROCESSING SYSTEM

After the monochrome and LWIR cameras capture the images, algorithms are needed to process the images. These algorithms are the fly eye-based algorithm to detect road edges, an algorithm to fuse monochrome video and LWIR images, a road boundary identification algorithm, and a roll-over threat detection algorithm.

### 3.1 Road Edge Detection Algorithm

The road edge detection algorithm extracts the edges in the images. Typically, images from the video require intensive computational power and time. This lag causes a delay of the information displayed to the user so it is not in real-time. To address this, an innovative method to process the video images has been developed, which requires less computational power and provides real-time information to the user. This technique applies the fly eye-based vision. This concept of the fly eye-based vision, or biomimetric edge vision, is based on the neurobiology of insect vision, since insects rely on edge detection to avoid obstacles (Agassounon et al., 2004; Douglass and Strausfseld, 2003; Sinakevitch and Strausfeld, 2004). The way an insect uses its vision significantly reduces the intensity of visual signal processing in the insect's brain.

An example of using the fly eye-based edge detection algorithm is shown in Figure 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. The double edge lines on the passenger side correspond to the lane marker and the actual road edge where the cliff begins.



(a) (b)

Fig. 4: (a) Image of the Road and (b) Image Using Fly-eye Based Detection Algorithm

Since an insect only sees the edges, software leveraging this type of cognitive vision response system increases 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 relevant edge data is utilized. This process also requires less storage space because only the relevant edge information is captured. The other information is not necessary.

The monochrome video and LWIR images obtained from the ultra-fast, fly-eye-based edge-detection algorithm need to be fused to form a single, robust estimate of the detected edges. This process is used to increase the probability of detection of the road edge and to decrease the probability of a false alarm.

### 3.2 Fusion Algorithm

Using only the video camera or the LWIR camera does not optimize the detection of the road edge. Thus, both the video and the LWIR cameras need to be used especially for driving at night or under different weather conditions. The video camera and the LWIR camera will be placed and oriented such that both the images share roughly the same field-of-view, so that the images captured by both cameras can be superimposed. Therefore, the image from each camera, once processed through the edge detector, will provide a set of detected edges representing the edge information.

The fusion process merges the edges detected in each of the individual images captured by the video and LWIR, into a single, enhanced set of edges that can be displayed to the driver on a monitor. This method is modular in the sense that one detector, either the video or LWIR cameras, can be removed for a given platform or application

without changing the fundamental algorithm operation. This allows the framework to be applied to a wide range of systems of various practicality and payload.

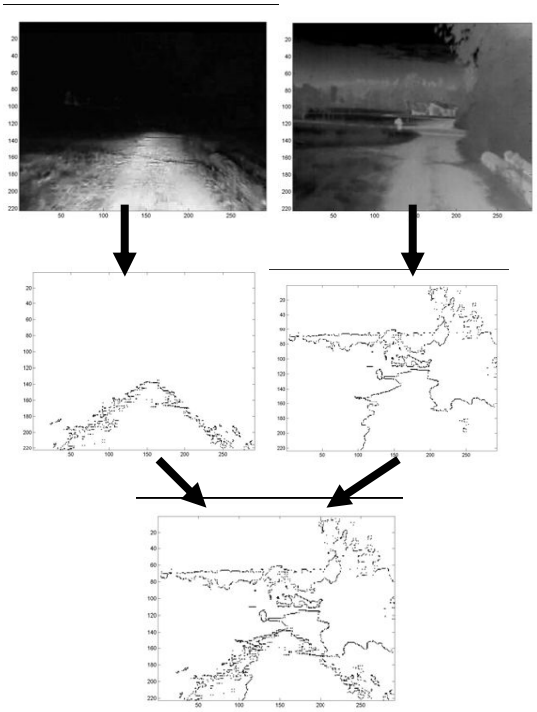


Fig. 5: Edges fusion example. (Images are courtesy of Zeiss Optronics.)

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. Equation 1 shows how the weighted sum is calculated:

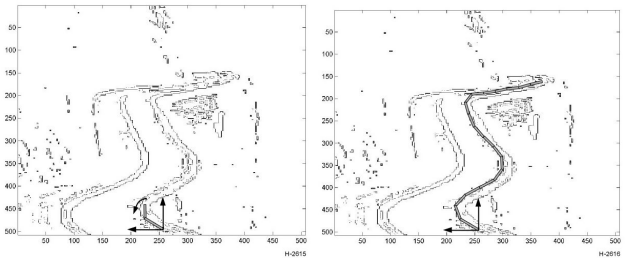
$$I_{fused}(x,y) = \alpha\, I_{visible}(x,y) + (1-\alpha)\, I_{LWIR}(x,y) \qquad (1)$$

In Equation 1, $I_{visible}(x,y)$ and $I_{LWIR}(x,y)$ are the intensities of the edge pixels in the visible and the LWIR images at position (x,y), and $\alpha$ is the weight of the fusion ($0 \le \alpha \le 1$). The contribution from either the LWIR camera or the video camera can be increased or decreased by varying $\alpha$. Figure 5 shows and example of the edge fusion, where $\alpha$=0.5. In Figure 5, the picture on the left is of the road taken at night using a monochrome video camera, while the picture on the right is 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

The road boundary identification algorithm identifies edges that are part of the road boundary and reconstructs the road boundary with the selected edges since not all the edges are associated with the road boundary. The algorithm applies 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. This algorithm is similar to the one proposed by Wilson (Wilson and Dickson, 1999).

This algorithm works by automatically searching for the origin of the road boundary in the lower right quadrant of the edges image by looking for the origin of the bottommost, rightmost straight line. Then a short vector of selected 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 illustrates the road boundary identification procedure.



(a) (b)

Fig.6: Illustration of road boundary identification procedure; (a) a fitting vector is drawn from a selected origin, rotated about the origin to find the best fit; (b) tip of vector becomes the new origin and the procedure is repeated to detect the full road boundary fragment by fragment.

### 3.4 Rollover Threat Detection Algorithm

Once the road boundary is detected, the presence of a negative terrain on the roadside, and whether the vehicle is on course to cross the boundary on the passenger side and rollover are also considered. In addition, the time to road edge crossing is computed. To estimate the road edge crossing, the threat detection algorithm uses the

vehicle's heading, current speed of the vehicle, and the distance to the point of rollover. When a terrain depression is detected on the passenger side or when the road edge crossing is below a certain threshold, which is related to the driver reaction time, an acoustic signal and a visual signal will simultaneously warn the driver of the danger. The acoustic signal could be something similar to the stall-horn on small airplanes or a beeping sound, and the visual signal could be a red flashing light-emitting diode (LED) on the Graphical User Interface (GUI) screen to indicate rollover point. The threshold will be set according to the driver's reaction time, which will allow the driver to steer the vehicle back on track. The output of the processing system will be displayed on a screen inside the vehicle using a GUI.

### 3.5 Driver's Vision Enhancer (DVE)

The information obtained from the LWIR and monochrome video camera system is combined with the digital signal processing unit to be displayed on the Driver-Vehicle Interface (DVI). The Driver-Vehicle Interface is similar to a GUI. The DVI allows the driver to interact with and control the road edge detection system. The DVI will be used to display the current image of the terrain, such as the road ahead as seen from the monochrome and LWIR cameras, the detected road edges, and the roadside terrain steepness information. The displayed image will be a composite image made of the images captured by the video and LWIR cameras. The driver will be able to initialize the edge detection and identification procedure by selecting a point on the screen. This point will be used as the starting point for the algorithm. Other features that will be considered for the display are GPS, compass, and dead reckoning. Figure 7 shows an example of a potential DVI display for the driver.

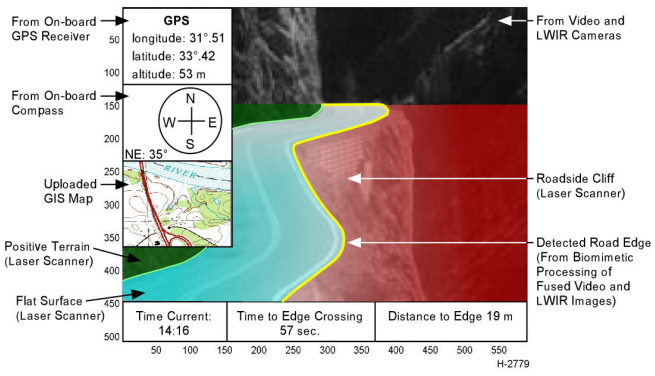



Fig.7: Conceptual design for the DVI Display

## 4. CONCLUSION

The development of the road edge detection and driver warning system will decrease the number of rollover incidents since the system will notify the driver of potential rollover threats. 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 monochrome video camera system, a long-range laser scanner, a processing module in which a biomimetic image processor detects edges in real-time, and a Driver-Vehicle Interface (DVI) which displays the road image, detected boundaries and road-side terrain steepness in real-time for the driver.

The rapid, road-edge detection based on biomimetic image processing has the potential to be implemented in the Future Combat Systems' (FCS) Automated Navigation System (ANS). The road edge detection system can enhance the capability of the FCS by aiding mobile, autonomous ground robots, detecting potential rollover threats, and preventing the autonomous vehicle from rolling over. Furthermore, this system can be embedded in FCS Manned Ground Vehicle (MGV) to reduce rollover accidents, thus minimizing the number of injuries and ultimately saving soldiers' lives.

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