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Sensor performance and weather effects modeling for Intelligent Transportation Systems (ITS) applications

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ABSTRACT

Optical sensors are used for several ITS applications, including lateral control of vehicles, traffic sign recognition, car following, autonomous vehicle navigation and obstacle detection. This paper treats the performance assessment of a sensor/image processor used as part of an on-board countermeasure system to prevent single vehicle roadway departure crashes. Sufficient image contrast between objects of interest and backgrounds is an essential factor influencing overall system performance. Contrast is determined by material properties affecting reflected/radiated intensities, as well as weather and visibility conditions. This paper discusses the modeling of these parameters and characterizes the contrast performance effects due to reduced visibility. The analysis process first involves generation of inherent road/off-road contrasts, followed by weather effects as a contrast modification. The sensor is modeled as a charge coupled device (CCD), with variable parameters. The results of the sensor/weather modeling will be used to predict the performance on an in-vehicle warning system under various levels of adverse weather. Software employed in this effort was previously developed for the US Air Force Wright Laboratory to determine target/background detection and recognition ranges for different sensor systems operating under various mission scenarios.

1.0 INTRODUCTION

This paper presents a method *to* determine the performance envelope of an imaging sensor and corresponding processing algorithm to avoid single vehicle roadway departure (SVRD) crashes. These crashes are the source of considerable fatalities, injuries and property damage. For example, in 1990, there were over 1.5 million police reported (PR) single vehicle crashes with 16,438

associated fatalities. Single vehicle roadway departures represented approximately 24.2 percent of all PR crashes and 36.9 percent of all crash fatalities in 1990. These statistics were obtained from the 1990 General Estimates System (GES) and Fatal Accident Reporting System (FARS).

There are several causal factors associated with single vehicle roadway departure crashes. Some of these factors include: driver inattention (15.5%), vehicle speed (20%), evasive maneuver (13.7%), and loss of directional control on road surface (20.2%). These are weighted percentages and include both straight and curved roads.

1.1 Autonornous driving systems and crash avoidance

Addressing these causal factors builds heavily on systems that have been developed for other applications with system functional goals that require lateral and longitudinal control. For example, during the last 10 years, Carnegie Mellon University has been building increasingly competent systems for autonomous driving. The CMU approach has been to develop smart vehicles capable of driving in natural outdoor environments without intervehicle communication or infrastructure modifications.

The CMU computer-controlled vehicles now drive themselves without human intervention at speeds up to 55 mph and for distances of over 90 miles on public roads. They are capable of driving both during the day and night on a wide variety of road types and can also sense and avoid obstacles. as well as automatically parallel park. These technologies have been developed as part of ARPA's Unmanned Ground Vehicle (UGV) program. with the goal of reducing the need for human presence in hazardous situations such as battlefield surveillance missions.

These technology advances can also be employed to reduce the risk to civilian drivers as part of Advanced Vehicle Control Systems (AVCS). The techniques developed by CMU are suitable both for Automated Highway System **(AHS)** applications where the vehicle is controlled automatically, and in driver warning systems where the role of the system is to monitor the environment and suggest actions for the human driver.. These techniques include: artificial neural networks for road following, model-based image processing for convoy following, smart obstacle maps based on sonar. ladar and microwave sensor processing and integrated control systems.

1.2 Image processing for autonomous driving and crash avoidance

ALVINN (Autonomous Land Vehicle In a Neural Network) is a perception system which learns to control CMU NAVLAB vehicles by " watching" a person drive. ALVINN's architecture consists of a single hidden layer back propagation network. The input layer of the network is a 30x32 unit two dimensional "retina," which receives input from the vehicle's video camera. Each input unit is fully connected to a layer of five hidden units, which are in turn fully connected to a layer of 30 output units. The output layer is a linear representation of the direction the vehicle should travel in order to keep the vehicle on the road.

A video image from the on-board camera is injected into the input layer to drive the vehicle. Activation is passed forward through the network and a steering command is generated at the output layer. The most active output unit determines the direction in which to steer.

To teach the network to steer, ALVINN is shown video images from the on-board camera as a person drives, and noting the steering direction in which the person is current]),steering. The hack propagation algorithm alters the strengths of connections between the network nodes so that the network produces the appropriate steering response when presented with a video image of the road ahead of the vehicle. After about 3 minutes of training while watching a person drive, ALVINN is able to take over and continue driving on its own.

Because it is able to learn what image features are important for particular driving situations, ALVINN has been successfully trained to drive in a wider variety of situations than other autonomous navigation systems which require fixed, predefined features (like the road's center line) for accurate driving. The situations ALVINN networks have been trained to handle include single lane dirt roads, single lane paved bike paths, two lane suburban neighborhood streets, and lined divided highways. In this last domain, ALVINN has successfully driven autonomously at speeds of up to 70 mph, and for distances of over 90 miles on a highway north of Pittsburgh.

Specialized networks are trained for each new road type. The networks are trained not only to output the correct direction to steer, but also to estimate its reliability. ALVINN uses these reliability estimates to select the most appropriate network for the current road type. and to switch networks as the road type changes.

1.3 Technical approach for mitigation of SVRD crashes

With the preceding vehicle and image processing capabilities as a basis, CMU and Battelle Memorial Institute are currently under contract to the National Highway Traffic Safety Administration (NHTSA) to develop performance specifications for countermeasure systems to prevent roadway departure crashes. Part of this effort involves modeling the combined effects of vehicle dynamics, the sensor, driver, environment and an in-vehicle countermeasure. These components will be modeled as an integrated computer program so that the user may vary the component parameters to determine the overall performance of a candidate counternieasure system.

The CMU/Battelle team is assessing four different hardware systems to address the above causal factors. These systems include: a downward looking laser scanner. a forward looking camera. sensors to monitor the pavement (e.g., temperature) and a Global Positioning Sensor (GPS) with map matching. This paper treats the forward looking camera and its image processing algorithm.

The forward looking sensor generates imagery. which can be processed to extract features such as roadway edges, center lines and curve locations. The location of these image features can be combined with a lateral displacement error metric for a vehicle's position within a lane to trigger

a Countermeasure signal once a predefined safety threshold is exceeded. The counternieasure would initiate an in-vehicle warning, for example. to avoid a potential crash due to driver inattention or excessive speed while approaching a curve. The optimum point of initiation *of* a countermeasure signal is impacted by multiple variables, including the combined sensor system and data processing algorithm capabilities to measure and distinguish variations between road and off-road pixels.

The procedure to determine sensor/image processing performance under varying conditions involves a three-step process. With the assistance of Battelle personnel, CMU has acquired several sets of roadway imagery, usually under favorable ambient conditions. Battelle then processes selected frames to transform them to specified levels of adverse weather (e.g., rain at 5 millimeters per hour.) CMU personnel utilize these converted frames to ascertain the performance of a particular image processing algorithm for a given environmental state. As the level of adverse weather becomes more intense, it is expected that a lateral position sensing algorithm, for example, will calculate lateral positions which become increasingly more unreliable. One of the objectives of our program is to provide an analytical representation of this effect.

1.4 Motivation for technical approach

Sensor models are envisioned to be of the form: under conditions X, sensor Y has an error rate of Z. For example, the precipitation rate should be related to the lateral position estimation error of a forward looking system. More concretely, such a model might indicate that in a 7mm/hr rain storm, the standard deviation of a lateral position estimation system is 10cm.

Developing such quantitative performance models for the situation assessment technologies will be a challenge. The reason is that these systems have the potential to be significantly impacted by environmental conditions. It is crucial to determine just how sensitive these systems are to such factors as weather and lighting conditions. Unfortunately, weather and lighting situations are impossible to dictate. We can't simply go out and say "today we are going to measure the performance of system *X* under conditions of 7mm/hr rain, and one mile visibility fog at dusk". Such combinations of conditions happen only rarely and for a brief period of time. When a rare combination of circumstances does occur. it is very difficult to quantify the parameters of the situation (e.g. the rain rate or visibility).

2.0 APPLICATION BACKGROUND - THE NEED FOR CONTRAST

Using a sensor system and processing algorithm to follow/track a road is similar to the military tactical problem of detecting a hard target amidst background. In both cases, a minimum threshold of intensity or thermal contrast must be measurable between the road (target) and off-road region (background) seen in the sensor system field of view. Whether using the human visual system, or a vehicle-mounted CCD camera feeding data to an automatic road-following algorithm, the integrated system comprised of the sensor and image processing must be able to discern road pixels from off-road pixels in the imaged scene. If there is not enough detectable contrast to distinguish

between the road and off-road regions, the system is effectively blind and cannot safe]),follow the road.

The degree of road/off-road contrast measured by a sensor is scenario-dependent. impacted by the road and background materials, lighting and atmospheric conditions, range, and sensor performance characteristics. Poor weather and visibility conditions degrade the apparent contrast seen by the sensor and reduce the available information subsequently processed by a road-detection algorithm. A robust algorithm should be able to "see" the road/off-road intensity contrast amidst noisy data. When excessive noise is introduced into the measured imagery, the road edge gradient may "bleed" into a smooth. barely discernable transition, making it more difficult for an algorithm to process the information and follow the road. Battelle's Tactical Decision Aid (TDA) and Electro-Optical Visualization Tool (EOVAST) are software products that are being used to support the analysis of these effects.

2.1 TDA and EOVAST analytical tools

Since 1980, Battelle has been the primary development contractor for the Air Force Research Grade (RG) Tactical Decision Aids (TDAs). The RG TDAs are automated analysis tools designed and validated to predict the performance of electro-optical, precision guided munitions and target acquisition systems as a function of target engagement geometry and environmental conditions. TDAs have been developed for long-wave and middle-wave infrared sensors. passive daylight and low-light-level television cameras, active (laser-illuminated) television systems, 1.06 μm nonimaging laser receivers/designators, direct view devices (telescopes, binoculars. etc.) and night vision goggles.

Battelle's Electro-Optical Visualization and Simulation Tool (EOVAST): originally developed for military targeting applications, generates and displays images as they would appear to a combat crew during an actual mission, considering the sensor system and environmental conditions. EOVAST's predicted images incorporate faceted representations of targets, predicted radiometric target and background signatures generated by a thermal signature model, the degradation in contrast due to atmospheric attenuation for the modeled environment, and blurring effects for the implemented sensor system. .

2.2 Running the TDA/EOVAST Software to Deerade the Imagery

The TDNEOVAST analysis process being employed by the CMU-Battelle team uses a series of frames of actual road scene imagery collected by CMU under relatively clear. normal conditions. The effects of adverse weather and poor visibility conditions are then introduced with the TDA/EOVAST software to generate simulated apparent images under weather-degraded conditions. Weather and illumination variables affecting sensor performance include visibility. degree of overcast. time of day, rain rate, and signal-to-noise ratio (S/N). Illumination is a derived parameter comprised of the overcast condition and time of day factors. To support the effort, a sensor

mathematical model was developed consisting of mathematical representations of the signal transfer and noise characteristics of CMU's CCD camera.

3.0 EXPERIMENTAL CALIBRATION

Several steps were required before the roadway imagery could be electronically processed to various levels of simulated adverse weather. These steps, which are summarized below, entail camera calibration and collection of radiometric ground truth.

Camera characterization tests were conducted on CMU's Sony XC-711 CCD color camera with the Computar M10Z-1118AMS zoom lens and included signal transfer tests and noise measurements. The camera system was set with the gamma correction and electronic shutter off. The gain control setting was tested with the AGC on and off (0dB gain.) The signal transfer characteristics were tested using a grayscale chart, a light box, a monitor and an oscilloscope. The noise levels of the four channels were also measured on the oscilloscope

The output waveforms of the video, red, green and blue channels were recorded to obtain the signal transfer curves at various scene luminance levels and to characterize the AGC of the camera system. With AGC on at high scene luminance levels, the camera reduces the signal transfer curve to prevent signal saturation. However, when the brightest scene luminance levels are reduced, the camera attempts to increase the signal transfer curve to fully utilize its dynamic range.

Battelle engineers transported radiometric measurement equipment to CMU to collect ground truth data in conjunction with the highway imagery collection. During the collection period, specific ground truth data elements included:

- terrain spectral radiance (for concrete, grass, asphalt, line markings)
- solar spectral radiance
- spot meter readings of road and grass
- camera geometry and FOV
- frame grabber dark level and saturation level

From these ground truth measurements, Battelle derived the following parameters:

- terrain spectral reflectivities
- digitization correction factors
- scene-viewing geometry effects
- a conversion factor for terrain radiance to digital values

The weather during the data collection was very clear and occasionally partly cloudy. Most of the highway scenes were imaged in bright sunlight, although some of the frames were taken with the sun behind the clouds. This highway imagery contained some shadows from bridges and other vehicles. The country road images contained segments with and without shadows from trees.

4.0 PRELIMINARY RESULTS

This section presents some digitally degraded imagery and spectral contrast plots for various roadway and shoulder materials. This imagery is preliminary, since a complete set of roadway imagery is being processed at the present time. They are included to visually illustrate the effect that adverse weather is expected to have on an imaging sensors for lateral/longitudinal control applications. Imagery currently being processed are subjected to more severe levels of degradation than shown here.

Figure 1 (frame 40) depicts an original image (a divided four lane highway) and three sets of corresponding images related to fog, medium rain and fog plus light rain. Each image set (e.g., fog) is spectrally filtered in the blue, green and red band. The applied level of degradation is characterized by a visibility range in kilometers and rain rate in mm per hour. In Fig. 1, some slight differences in contrast can be discerned between each spectral band ,with the blue region providing the best contrast. A similar set of images is shown in Fig 2 (frame 1) for the case of a rural road. Once again, the blue spectral band appears to provide slightly better contrast than the other wave bands.

The degraded images shown in Figs. 1 and 2 include atmospheric effects due to transmission loss and the addition of path radiance. These modeled effects are range dependent and are correctly simulated across the total scene field of view. Not included in these sample frames were the effects of noise and camera AGC settings, since the specific ambient light levels were not defined and are required for accurate simulation. However, these effects are being incorporated into the images currently being processed.

Battelle generated several plots (Figs. 3 and 4) of spectral contrast for different combinations of road and shoulder materials. Examples of combinations are (1) asphalt against live grass, dead grass. dry clay and (2) smooth concrete against gravel, dry clay, etc. The contrast is represented by a number from zero to one and is plotted against wavelength (0.4 to 1.0 microns.)

These contrast plots were created to underscore the need for an optimum sensor waveband for run-off-road collision avoidance. For example, we anticipate using a forward-looking sensor to measure real-time lateral displacement as the subject vehicle travels along a roadway. Lateral displacement will be determined from lane markings and road edges, which will be located by an image processing algorithm. The performance of the latter is critically dependent on the level of contrast between, say, lane markings and the pavement.

The contrast plots that were generated show a roadway/shoulder materials dependence and contrast peak at different wavelengths. It would be desirable to operate on a contrast peak at all times, but this will not be possible, since run-off-road crashes occur at various roadway/shoulder settings (i.e., different combinations of roadway/shoulder materials.)

5.0 CONCLUSION

Although these results are still preliminary, they indicate that testing on degraded imagery can be a powerful technique for quantitative performance assessment of ITS technology.

Simulated Weather Effects for IVHS Road Imagery (Frame 40) FIGURE 1

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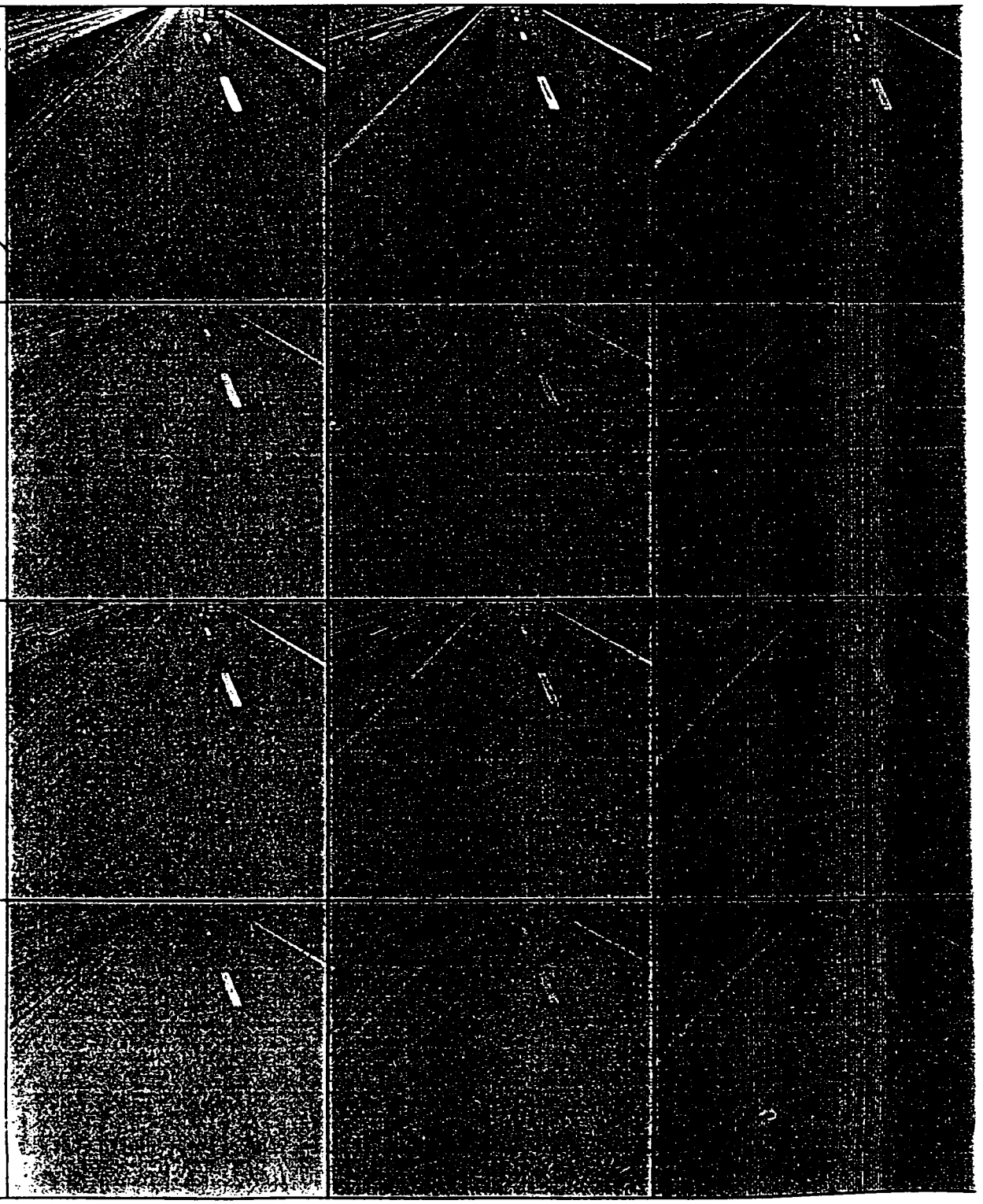
WEATHER	VIS	RR
ORIGINAL IMAGE		
FOG	0.5	0
MEDIUM RAIN	5	25
FOG + LIGHT RAIN	0.2	5

BLUE GREEN RED



VIS ~ VISIBILITY IN KM

Simulated Weather Effects for IVHS Road Imagery (Frame 1)

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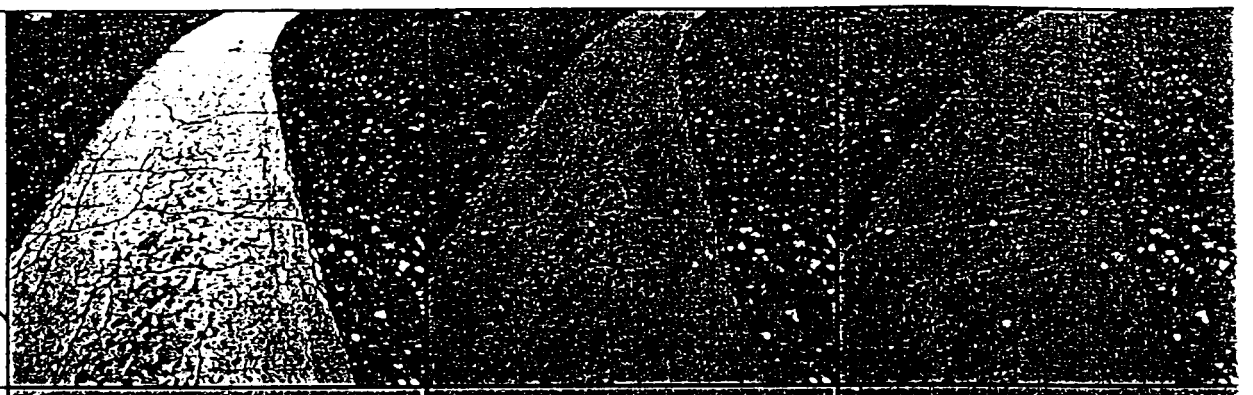
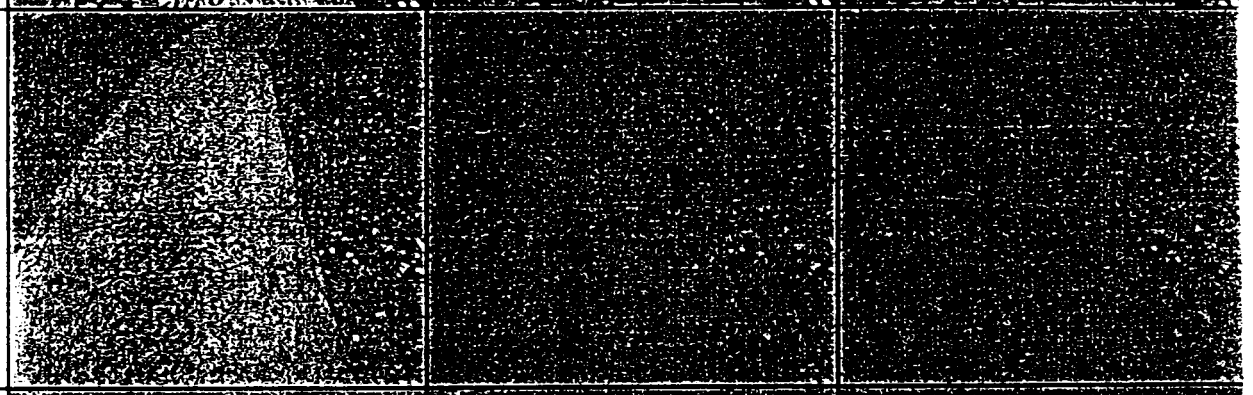
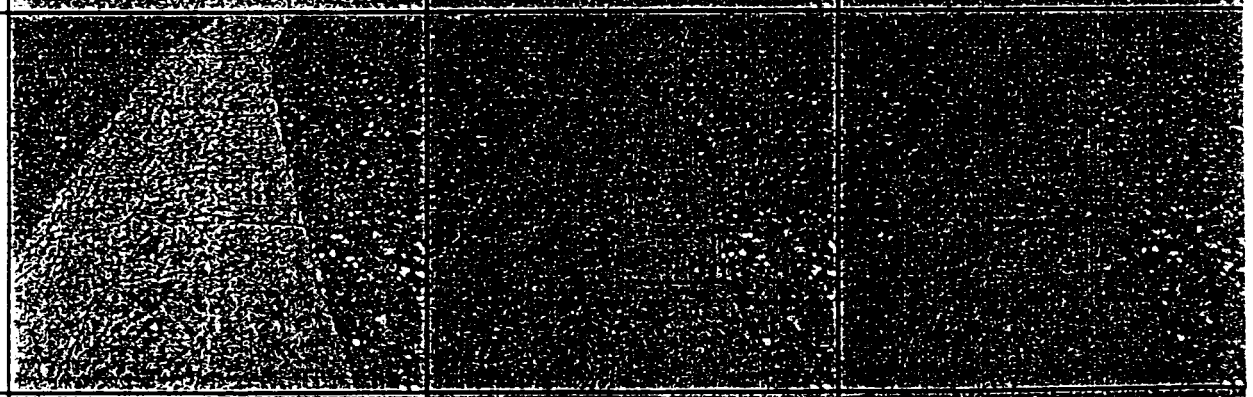
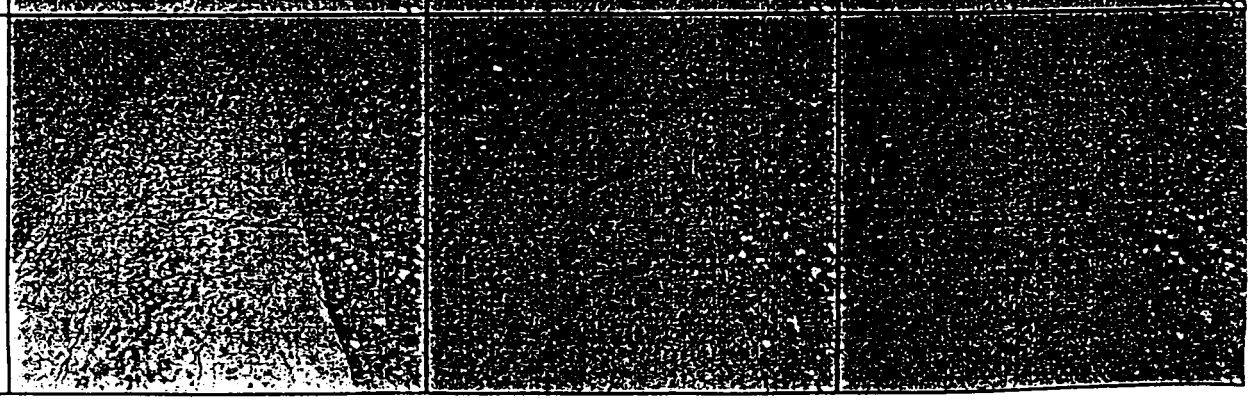
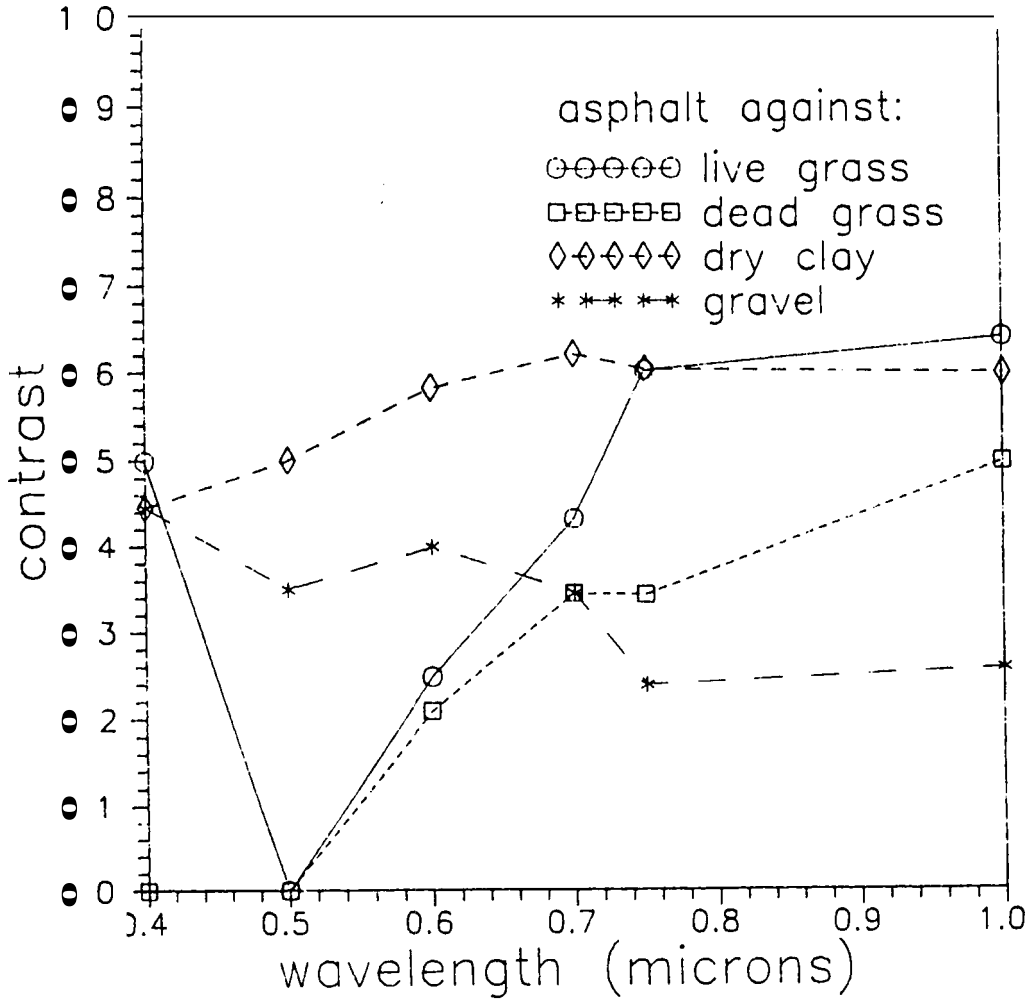
W	VIS	RR	BLUE	GREEN	RED
ORIGINAL IMAGE					
	0.5	0			
MEDIUM RAIN	5	25			
FOG + LIGHT RAIN	0.2	5			

VIS ~ VISIBILIN IN KM

Spectral Inherent Contrast
Asphalt FIGURE 3



Spectral Inherent Contrast
Smooth Concrete FIGURE 4