IDEA

Innovations Deserving
Exploratory Analysis Programs

High-Speed Rail Program

Demonstration of IHS Wide Field Surveillance System for Rail-Road Crossings

Final Report for HSR-IDEA Project 06

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TRANSPORTATION RESEARCH BOARD • NATIONAL RESEARCH COUNCIL

INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS MANAGED BY THE TRANSPORTATION RESEARCH BOARD

This investigation by Intelligent Highway Systems, Inc. was performed as part of the High-Speed Rail IDEA program, which fosters innovative methods and technology in support of the Federal Railroad Administration's (FRA) next-generation high-speed rail technology development program.

The High-Speed Rail IDEA program is one of four IDEA programs managed by TRB. The other IDEA programs are listed below.

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IDEA Programs
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Executive Summary

This project has demonstrated an effective solution for improved safety at intermodal crossings of railway and cars. For each of the past six (6) years, prior to 1997, there has been more than one (1) accident between a railway locomotive and a vehicle for every 30 public grade level railway crossings within the continental USA. Of these 4000+ accidents per year, more than 1000 per year were with non-moving vehicles. The IHS surveillance system can monitor these crossings to provide the automated corrective action that will minimize the probability of having a stopped vehicle on the railway tracks and will preclude an accident if a vehicle does stall or stop.

The concept of the IHS single video camera machine vision system was successfully demonstrated at the Main Street crossing of the Long Island Railroad in Mineola, New York on 8 April 1997. This system surveillance camera shown in Figure 1 monitored the crossing and adjacent roadways and issued predefined alert signals based on the detected events within that area. Predefined automated electronic circuits and operators at a control center could have issued corrective actions based on these alert signals if the system were fully integrated. The 8 April demonstration results were presented to the 1997 International Highway-Rail Grade Crossing Safety Conference in Seattle, Washington on 23 July 1997.

IHS also provided cameras for all weather performance assessment and software development. These installations included; the Main Street LIRR crossing in Mineola, NY, the Blue Line Quad Gate railway crossing in Los Angeles, the staggered intersection of Main Street, Mamaroneck Avenue and Church Street in White Plains, NY, the traffic circle in Latham, NY, a maintenance area for the Tri-bourough Bridge and Tunnel Authority of New York City, NY, Renseallear Polytechnic Institute of Troy, NY, and locations with a security company with offices in Poughkeepsie and in Kingstown, NY.

IHS has also been notified that all patent claims (for several versions of the optical systems and the automated “learn mode process”) have been granted. When the formal patent and it’s contingent funding is received, IHS may resume software development.

IHS SURVEILLANCE CAMERA
FIGURE 1 Distortion free, 160^0, all weather, camera.

CONCLUSIONS

The IHS study of requirements, railway infrastructures, and demonstration results conclude a proper response to only four machine vision signals will minimize grade level railway crossing risks. This will virtually eliminate 25% of all accidents (1 out of 4 accidents are with stationary vehicles). The system will also provide statistics and evidence for the near miss and actual accidents that do occur. These four signals are:

1. **Stop Vehicle Alert**: issued when an object is in a critical zone (on tracks) for an extended time (e.g., greater than ten seconds) implying the presence of a stalled or disabled vehicle;
2. **Green Light Alert**: issued when the last of several vehicles in traffic light controlled queue implies signalization should be preempted to prevent backup of the queue onto or across the railway tracks;
3. **Signal Malfunction Alert:** issued when a train is passing through a crossing with inactive signalization. A separate lower level alert may be initiated if preset time limits are exceeded for the conditions of "start of crossing signalization to train arrival" or "train departure from the crossing until crossing signalization stops"; and
4. **Violation Alert:** issued when a vehicle (or other

object) is trespassing the railway tracks during active "stop" signalization.

Along with the computer generated alerts, the system will provide real time video and historical data to support forensic and statistical evaluations. Three data packages for this effort include:

1. **Digitized Image Files** of the railway tracks and adjacent roadways acquired (at 1 or 2 frames per second) and stored to reconstruct the events before, during and after one or more of the above alerts. The obsolete files, when no alerts were present, can be erased as required to maintain storage space on the local computer. Transmittal of these files to the control center and retention facilities are automated whenever an alert is present during "Active Stop Signalization or Lowered Barrier Gates" signals;
2. **Full Video Data** retained (VCR) whenever a "Stop Vehicle" or "Green Light" alert plus an "Active Stop Signalization or Lowered Barrier Gates" signal are simultaneously present. The VCRs are also controllable from the control room and possibly from the locomotive cabin (a locomotive engineer may see something which should be recorded).
3. **Time tagged Crossing's Statistics** are computer stored and selectively transmitted for each alert type. As a minimum, the statistics include elapse time from the start of the crossing's stop signals to the train's arrival, elapse time of train in crossing, and the elapse time from the train's crossing departure to the end of the crossing's stop signal. Statistics for per lane vehicular classification along with the average delay, speed, volume, stops and queue lengths are also provided.

The demonstration success was primarily based on the use of IHS's 160^0 degree, distortionless, panoramic surveillance system that acquires more than 100 feet of roadway and the crossing gate arms on each side of the railway's tracks, even when the train is in the intersection, from an elevation of only 27 feet. By this novel optical approach, a single video system replaces the multiple sensors that are presently required to monitor, evaluate, or control the traffic flow within an entire area. Such areas may also include each inbound and exiting lane on both sides of an entire toll plaza, complex intersection, rotary circle, divided freeway, parking lot, or storage area.

Distortionless viewing also provides fixed scaling across the entire field of view (FOV). Hence, constant speed objects, at a given elevation, have a fixed size and rate on the monitor and in the digitized data arrays for data processing.

The project's software also demonstrated the potential for real-time tracking and statistically reporting the omni-directional movements from all vehicles within complex intersections and rotaries.

In addition to the above performance and data parameters, the system is environmentally compatible with virtually no maintenance. Elements of both the IHS surveillance and the traffic vision systems have been in operation for more than 1-1/2 years and there has been no evidence of discernible degradation or required maintenance. The installation's cost effectiveness is extended to reduced requirements for infrastructure, control room displays, and for data processing, transmission and storage since only one camera is required to monitor the entire crossing.

Viewing an entire intersection with one distortionless system eliminates the requirement to synchronize, multiplex and process multiple signals normally required to monitor all inbound and exiting lanes of an intersection. Therefore, this single sensor reduces the system data processing required to automate the placement of detection zones relative to the observed traffic patterns (patent claims were just granted). With automated detection zone placement on all inbound and exiting lanes, traffic surveys and advanced traffic management reports can be implemented with no (minimal) system alignment or software intervention during or after the installation. Such automated reports would provide time phased traffic statistics of the traffic flow between all detection zones (inbound lane to outbound lane) including U-turns.

INTELLIGENT HIGHWAY SYSTEMS, INC. (IHS)
FINAL REPORT

IVHS-IDEAS PROJECT ITS-06

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IDEA PRODUCT

This project has focused on an effective solution for improved safety at intermodal grade level crossings of railway and cars. For each of the past six (6), years prior to 1997, there has been more than one (1) accident between a railway locomotive and a vehicle for every 30 public grade level railway crossings within the continental USA. Of these 4000+ accidents per year, more than 1000 were with non-moving vehicles. The IHS surveillance system can monitor these crossings to provide the automated corrective action that will minimize the probability of having a stopped vehicle on the railway tracks and will preclude an accident if a vehicle does stall or stop.

CONCEPT OF INNOVATION

The concept of using the IHS wide field of view video camera to monitor an entire grade level rail-road crossing intersection was originally conceived by the Federal Railway Administration and the IDEA's program office.

IHS then self funded a study to determine the requirements for an ideal system to mitigate the risks and optimize statistical information for such crossings. Based on this study, IHS concluded that the proper response to only four machine vision signals will minimize grade level railway crossing risks and accidents. These four signals are:

1. **Stop Vehicle Alert**
2. **Queue Length Alert**
3. **Signal Malfunction Alert** and
4. **Violation Alert.**

Along with the computer generated alerts, the ideal system would also provide historical data to support forensic and statistical evaluations in the form of:

1. **Crossings Statistics**
2. **Digitized Image Files** and
3. **Full Video Data,**

The IHS single video camera machine vision system and basic software functions were successfully demonstrated at the Main Street crossing of the Long Island Railroad in Mineola, New York on 8 April 1997. This system surveillance camera shown in Figure 1 monitored the crossing and adjacent roadways and issued predefined alert signals based on the detected events within that area. Predefined automated electronic circuits and operators at a control center could have issued corrective actions based on these alert signals if the system were fully integrated. The 8 April demonstration results were presented to the 1997 International Highway-Rail Grade Crossing Safety Conference in Seattle, Washington on 23 July 1997. The presentation has been published in the proceeding's report of that meeting. The proceeding's report was prepared by, and is available from, the Rail Research/AAR Laboratory, Texas Transportation Institute, Texas A&M University System, College Station, Texas 77843-3135.

PROJECT EXECUTION

The evaluation of system parameters during the system development, design, and demonstration along with responses to many questions are summarized in the following sections:

System Trades

The system trades were initiated by defining the requirements to mitigate at grade level railway crossing's risks independent of the system configuration. After the requirements were defined, the trade included the pro and con consideration for systems that included the individual and synergistic grouping of instruments such as: inductive and capacitive in ground detectors; road side Hall (magnetic field) probes; video and digital still frame camera systems with and without machine vision; both active and passive acoustic array systems; infrared, microwave and radar type detectors; light beam interrupt sensors; laser or line scan systems; ground positioning systems; strain gauges, piezo transducers, and vibration sensor. The weighing factor for the initial trade was to minimize risk and not cost. After that, the trade was repeated with the primary weighing factor being life cycle cost, which included the combination of real time operational cost, installation costs, and maintenance costs. Subsequently, the study was reviewed with a heavier consideration given to precluding false alert signals that would wrongly initiate an emergency stop or slow down a locomotive. In each of these studies, the IHS surveillance system was the optimum sensor for risk mitigation at the grade level railway crossing. When the study emphasized false alert avoidance, the IHS system supplemented with an optional high acuity, pan tilt and zoom surveillance system became the optimum system.

System Considerations

IHS concluded that a machine vision system capable of acquiring and processing all data from more than 100 feet of roadway data on each side of the railway tracks and both crossing gates, even when the train is in the intersection, is more then sufficient to provide the optimum signals for risk mitigation. Railway statistics show that 50% of all signalized crossings are within 75 feet of a roadway crossing. Thus a ±100 foot acquisition field of view will satisfy the majority of all installations with distortion free imagery. IHS also concluded that:

1. Lapse time video and select processed data must be retained on a continuous basis. Since VCRs are not sufficiently reliable, the data retention of surveillance imagery must be computer digitized and stored at some predetermined rate (once per second) whenever the crossing's stop signalization is not active. This rate should be increased (twice per second) whenever signalization is active.
2. If an alert does occur, then the events leading up to the alert are captured. During an alert, the data acquisition rate should be increased to at least eight frames per second. During an alert, the stored digitized data is then available for immediate transmittal to the control centers. If, however, no alerts were encountered during that period and the computer does not receive a "save" command from the console operator or locomotive engineer, then the oldest digitized files can be erased if additional memory space is required.
3. The transmission of video and data should be automated to the central office and selectively transmitted to the locomotive engineers. The transmission of the video signals and data has been demonstrated with commercially available hardware by numerous security contractors, using wireless microwave and RF systems and by solid line communication from fiber optic, coax, twisted pairs and for lower bandwidth data, modems on phone lines and wireless telephony. IHS recommends that the minimum configuration should include the dedicated phone lines with 56K or 128K data rate capability between the crossings and control center. This board rate will transmit near real time imagery with reasonable clarity and may be more cost effective than dedicated coax or fiber optic links.
4. IHS estimates that wireless telephony of video will be available prior to the implementation of full scale systems.
5. The initial project should be implemented as a non invasive and fail safe system. IHS believes that a failure mode and critical effect analysis would show that the highest system reliability is attained by an over-lay of this system to the existing infrastructure. In a few years, after the IHS system has demonstrated the statistical reliability, the integrated infrastructure may be optimum.
6. The IHS hardware will meet the requirements for an all weather system capable of full performance in rain, snow, sleet, fog, heat and cold.
7. The system must be driven by a goal of no maintenance. IHS's face down optical system, that has no motors or moving parts, provides a definite advantage over systems with windows that are near vertical and that have motor driven variable apertures that are vibration, temperature and contamination sensitive.
8. An optional auxiliary surveillance system should be used if zoom (magnified) video is required to determine detail features of the objects within the area of interest. Limiting stops can be implemented to restrict the pointing angles of the camera to avoid invasion of privacy issues.

System Requirements

The system requirements were derived to mitigate the risk of a locomotive and vehicle accident at grade level railway crossings. These requirements were derived without regard for a preconceived system configuration. Then various systems were evaluated in terms of what could satisfy these requirements. The results concluded that the IHS surveillance system is the optimum sensor for machine vision observation of the crossing gates, adjacent roadway and railway tracks.

IHS also concluded that the proper response to only four machine vision signals will minimize grade level railway crossing risks and accidents. These four signals are:

1. **Stop Vehicle Alert:** object in a critical zone (on tracks) for an extended time (e.g., greater than ten seconds) implying that a vehicle is stalled or disabled;
2. **Queue Length Alert:** last of several vehicles in traffic light control queue implies that the signalization should be preempted to prevent backup of the queue onto or across the railway tracks;
3. **Signal Malfunction Alert:** a train is passing through a crossing with inactive signalization. A separate lower level alert may be initiated if preset time limits are exceeded for the conditions of "start of crossing signalization to train arrival" or "train departure from the crossing until crossing signalization stops"; and

4. **Violation Alert:** a vehicle (or other object) is trespassing the railway during active "stop" signalization.

Along with the computer generated alerts, the system provides:

1. **Surveillance to** retain historical data to support forensic and statistical evaluations in the form of:

- **Wide Area Video Surveillance** of the railway and adjacent roadway for real time observation at a control center or in the locomotive; and
- **High Acuity Surveillance** from an auxiliary surveillance system with automated pan, tilt and zoom capabilities of the distinct area that initiated the alarm.

2. **Crossings Statistics** that are computer time tagged, stored and selectively transmitted data for each alert, plus elapse time from start of the crossing's stop signals to the train's arrival, elapse time of train in crossing and the elapse time from the train's crossing departure to the end of the crossing's stop signal, plus average delay, speed, volume, stops and queue lengths of vehicles;
3. **Digitized Image Files** of the railway tracks and adjacent roadways prior to, during and after an event based on one or more of the above alerts. The system automates the archival or transmittal of these files to other remote sites based on the criteria of the above alerts; and
4. **Full Video Data** selectively stored or transmitted to remote sites, including the locomotive cabin, on a continuous basis or as determined by the above alerts and control room operators.

System Description

The significant discriminator between this and other proposed systems is the use of IHS's 160^0 degree, distortionless, panoramic surveillance system that acquires more than 100 feet of roadway and the crossing gate arms on each side of the railway's tracks, even when the train is in the intersection, from an elevation of only 27 feet. The second discriminator is an optional high-resolution surveillance system integrated to automatically track, focus on and display an alert's cause with optimum resolution. When an alert is not present, the camera will focus on and display a predefined critical zone, which is normally the center of the railway's crossing. Naturally, the auxiliary surveillance system also may be positioned in azimuth and elevation by either preprogrammed scan control or manual operations. The auxiliary surveillance system's focus and exposure control are automated for the optimum imagery.

The basic IHS system for grade level railway crossing risk mitigation starts with the IHS 160^0 surveillance system video that is processed by machine vision (computer). The machine vision provides discrete alert signals based on predefined logic criteria for the detection of a) objects that are stopped or stuck on the tracks; or b) vehicles that are waiting in queue and that queue is becoming too close to the tracks; or c) a train passing through the crossing with non functioning signalization; or d) objects that cross the tracks in violation of crossing signals. The alert signal status of each crossing is wired to and displayed at a control center console. These machine vision alert signals initiate predefined responses and functions. The control center console also displays the live video imagery. This video imagery is annotated to identify the cause of the alert and the operator has the option to initiate other functions to acquire more information, to over-ride the predefined response, and to transmit the live or annotated video to the locomotives. As an option, IHS recommends an auxiliary surveillance system that will automatically zoom in onto the alert's cause with optimum magnification and focus.

The following is a typical outline of an automated response to the **Stop Vehicle Alert.** This alert implies that a stopped or stalled vehicle has been on the tracks for a time duration exceeding a statistically determined limit.

1. Simultaneously, a) the lapse time VCR is set to normal VHS speed and when the crossing signalization is active the VCR is set to acquire imagery in slow motion. The VCR's identification and footage counter is transmitted to the machine vision computer and the VCR video is annotated with the alert code; b) a circuit is activated (for a predetermined time, e.g., 30 seconds) that emulates a stopped train at the coordinates of the stopped object and this modifies the locomotive speed governor signals on the railway infrastructure; c) the X, Y, and Z coordinates with image size (pan, tilt and zoom/focus) commands are transmitted to the optional high acuity surveillance system. The auxiliary system automatically responds to these commands; d) the alert signal at the control center's console switches the circuitry to display the crossing's live machine vision annotated video showing the cause of the alert on the primary monitor and the extreme close up view of the alert's cause on the auxiliary monitor.
2. The control center's operator reviews the alert and, with discretion, transmits the choice video imagery and instructions to arriving locomotive cabins for their information and response to instructions. The control center's operator may also override or extend the time for the emulated stopped train signal to the railway's infrastructure.
3. Meanwhile, the computer captures and annotates the video of the surveillance systems at a predetermined rate (twice per second) and stores the images. These images are acquired until the alert is cleared. Based on the type alert, these images may be automatically transmitted to a secondary data retention center to clear the disk for additional real time data.
4. The logic also exists to always acquire the digital images, independent of the alert signal, whenever the

crossing's stop signalization is active. With this logic, the digital imagery of the events prior to the alert will be instantly available for transmittal if an alert does occur. These files also will be saved and transmitted if a "save" command is received from the console operator or the locomotive engineer. If there are no save commands and no alerts, the digital image files will be purged as required to accommodate the new files. The files are retained as long as memory capacity for these files exists.

5. After the alert is cleared, the VCR reverts to lapse time recording and the computer files are transferred.

If this were a violating alert, indicating a vehicle is trespassing the railway during active "stop" signalization, the high resolution camera could point to the predicted location of the vehicle at time T_{0+i} to attain the license plate data for subsequent processing. Other parameters must be considered if license plate data is to be acquired. License plate acquisition was not included as part of this risk mitigation subject.

Image Distortion

The IHS image quality is considered distortionless (±1 part in 500 or ±0.2%) over its entire field of view. However, as a person views the imagery from a 160^0 field of view system, the object takes on a view that one normally will never see. The average human eye only has reasonable acuity for a total cone angle of 30^0 within our 180^0 peripheral vision and the camera has a cone angle of 160^0. For that reason, our initial perception of the video is that the camera is mounted at some 8 times the actual installation height.

The upper part of Figure 2 presents a camera aligned normal to the observed surface and the lower half presents a camera aligned at an angle relative to the observed surface. The figure also represents two vehicle configurations of the same height. One with a rounded hood and the second with a squared "mini-bus" front end.

The upper figure shows the roof length "A" at a height "h_1", being a surface parallel to the image plane (I_0-I_0), projected onto the object plane O_1-O_1 magnified by $(h)\div(h-h_1)$. Where:

h is the perpendicular height to the camera from the object plane, and

h_1 is the perpendicular height of the object from the object plane.

The size of the flat roof remains constant (A_0) over the entire field of view. This is true for any surface parallel to the roadway surface! (Visualize the roof supported at h_1 by an invisible structure, the vehicle would not change size).

Now, as the leading ray traces the vehicle edge with the vehicle going to the left from the vertical ray, the leading edge will move from h_i = zero to $h_i = h_1$ as a function of field angle. This ray intersect, with O_0-O_0 relative to a square front profile, will produce a variant

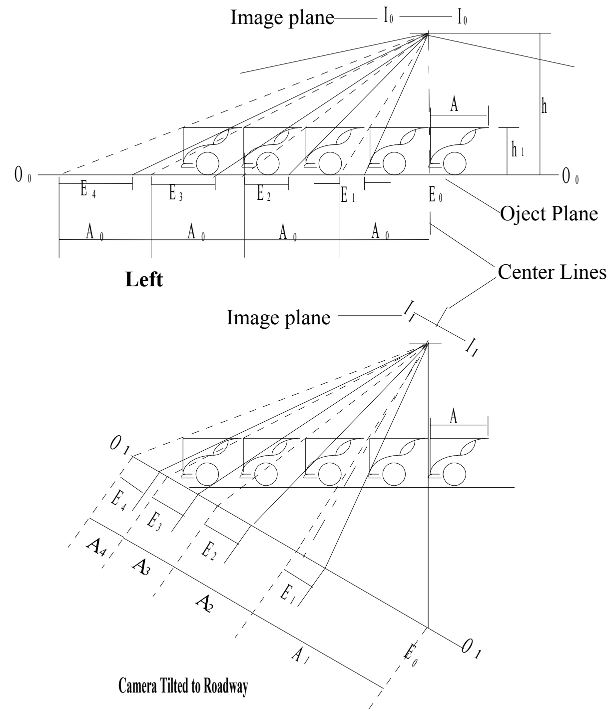

Figure 2

Camera Normal and Tilted Relative to Roadway

from E_0 to E_4 in that figure. Here we readily see image size variation is only due to the vehicle height plus shape of the leading and trailing profiles. A plot of image length versus field position will fully characterize the vehicle height and profile for vehicle classification.

Next we evaluate the imagery from a tilted camera. Here the object plane is tilted by the compliment angle of the camera's tilt relative to the road surface. This tilt between the road surface and the object (and image) plane generates a variable magnification of "A" as a function of the field angle to yield A_1 to A_4. Here, the length's change rate has the additional variable of camera tilt that usually predominates the height and profile variables (E_0 to E_4).

IHS has concluded that a system with its optical axis normal to the road surface provides the video data in the purest form for mathematical treatment by machine vision for the purpose of vehicle classification. In addition, if the imagery were compared between the narrow and wide field of view systems suspended at the exact same heights, the "distortion" as a function of field angle would be identical. The major difference is the larger field of view provided by the IHS surveillance camera system.

Resolution

The term resolution is often improperly applied in the discussion of electro-optical system. The ability to detect the differential or relative shift of an object (it's energy centroid) has been proven to be significantly smaller than the distance subtended by a single detector element. However, that is detection of image motion and not optical resolution. Optical resolution is the separation distance required by high contrast parallel line pairs to appear as distinct and separable objects. This separation distance is usually defined when the signal modulation between the successive images relative to full scale modulation exceeds 10% to 20%. Thus, the lines per aperture resolution of a video camera system is usually about 75% of the detectors per aperture.

1. Many monochrome CCD video cameras have a detector array that is typically 768 elements horizontally and 494 elements vertically with a resolution of 570 by 350 lines.
2. Most DOTs require that a traffic detection system acquire all licensed vehicles including motorcycles;
3. The probability of object detection is a function of many factors such as signal to noise, contrast, lighting, spectral color, brightness and weather, plus object size, and rate of motion. It is obvious that a slow moving and low contrast object that only stimulates one or two detectors in the above detector array will probably remain undetected. However, as the object stimulates larger clusters of detector elements, the probability of detection increases rapidly until stimulated detector clusters that have correlated patterns of about 16 elements. Even though IHS has not resurrected the documentation for the above fact, it was used to conclude that the system magnification must be such as to have a motorcycle (3' by 5') simulate about 16 pixels. From this, the 1 foot per element scaling was applied to conclude that a motorcycle could be detected in a PC monitor's field of view that is about 640 by 480 feet and would be well resolved in a 570 by 350 foot field of view.
4. A motor cycle at 90 mph has a correlation length of 4.4 feet when processing acquires new data at 30 frames per seconds. The 90 mph motorcycle image blur is some 2.5 feet when acquired at the worst case longest exposure time of 1/50 second.
5. The automatic shutter speed for the standard camera ranges from 1/50 to 1/30,000 of a second which is equivalent to a 25:1 range in setting "aperture" or "f-number" (where f# = focal length ÷ aperture diameter). Very few systems have an F# smaller than 1.0, so an aperture change of 25 yields a minimum f# of 25. The image blur is defined as 1.22 λ f# where λ is the wave length of light. Thus an f-25 system has a focal plane spot image from a smallest bright spot object that is more than 6 detector elements in size and a blur larger than the blur from a 90 mph motorcycle captured with a 1/50 second exposure. Thus, the image blur of an aperture controlled system is worse during bright illumination that the shutter's blur under any lighting conditions. This is one compelling reason, along with better reliability, less cost and less complexity, to choose a variable speed shutter instead of a motor driven aperture.
6. The IHS system acquires a distortionless field of view that is 9h (±4.5h) by 6.75h (±3.37h) where "h" is the installation height.
7. A single camera mounted at 40 feet acquires a distortionless object field of 360 by 270 feet and should have no problem detecting and tracking a motorcycle since it has a correlated tracking cluster exceeding 40 detector elements.

Field of View versus Installation Height

The useful range of a machine vision system is usually limited by the ability to distinguish between sequential vehicles. As the field angle approaches $\pm 80^0$, or 10^0 from the horizon, two cars that are five (5) feet tall will appear as one vehicle if separation is less than $5\tan(80^0)$ or 28 feet. Thus angles less than 10 degree from horizon have little value if individual vehicle must be defined near the edge of a surveillance system's field of view.

1. The IHS camera's 9h by 6.75h field of view is extended to infinity ($\propto$) on one side of the mounting pole and decreased to >2h on the other side of the pole when the camera is tilted by some 12 degrees. However, tilting the camera is seldom required since ±100 feet is acquired from a height of only 22 feet and the tops of the cars are acquired for that area from an installation height of only 26 feet.
2. There are very few commercial lens systems that are distortionless beyond $\pm 60^0$. These systems acquire $\pm 54.2^0$ by $\pm 46.1^0$ on the focal plane's detector array since the $\pm\ 60^0$ is across the diagonal of the focal plane array.
3. Imagery from an elevation angle that is less than 10 degrees from the horizontal obscures more than 28 feet behind a 5 foot high car and is seldom useful for a vehicular vision system. (IHS normally limits the horizontal field of view to 12.5^0 from the horizon.) Thus the maximum range of a $\pm 54.2^0$ system, limited by the 10^0 angle, is [+(h)tan(80)+(h)tan(28.4)] = [+5.67h +0.54h] or 6.21h. This 6.21h would be 5.1h if the 10^0 angle were limited by the safer IHS angle of 12.5^0. To acquire 200 feet, the minimum installation height must be at 200÷6.21 or 32.2 feet and positioned at (32.2')(5.67)-100' or 83 feet from the railway. This implies that a 37 foot installation height is required to observe the top of the vehicles over that entire area. Limited by the maximum IHS viewing angle of 12.5^0, the conventional 60^0 camera requires the elevations of 44 feet.
4. The angular deflection of a pole tip is a function of $(h)^2$ for a unit load at the end and a function of $(h)^3$ for uniform loads. Thus, angular deflections for the 37 versus 26 foot installation will be 2 to 2.8 times that of the IHS installation. The ground image motion at the edge of the camera's field of view is additionally increased by tan(80) versus tan(77.5). The net result is a ground image motion at the camera's edge of 2.5 to 3.5

times that of the IHS camera.

5. The non IHS camera also must be located at least 80 feet from the railway. This distance and the shallow view angle precludes the observation of the crossing gate arm and a minimum of 30 feet on the track's far side when a train is in the intersection. Likewise, 80 feet from the railway crossing is normally not on the railway's right of way nor near an existing mountable structure or pole.
6. There is a fallacy in the concept that the system's machine vision range and resolution can be improved by mounting two non IHS single cameras on the railway's right of way."

When multiple cameras are considered:

- The project doubles the system's "back-end" requirements for twice the video recording, processing, video transmission links, and data displays capabilities. The system's "back-end" cost dwarfs the cost of the IHS optical surveillance system.
- The control room observer must now monitor two screens or split a monitor screen for the two cameras. In the latter case, the resolution is poorer and more confusing to interpret than a single image of the entire area from one camera;
- Two camera systems, with motor driven mechanical parts, require more maintenance and environmental control than a benign single camera system with no moving parts.

Video Data for Security

The dual use of a camera systems for machine vision vehicle detection and for a pan, tilt, zoom, security surveillance application is not practical. The conflict is driven by two considerations. The first consideration is that the detection zone boundaries of existing machine vision systems are programmed in the spatial domain of the focal plane and not in the domain of the observed imagery or object surface. As such, any change of the camera in magnification or pointing angle will move the selected zones relative to the object space and deteriorate the machine vision processing. The second consideration is that the machine vision alert system is rendered inoperable whenever the camera is moved for security surveillance. A condition where such a system is not reinitialized after the surveillance operation would be an unacceptable failure mode. (the IHS patented learn mode process automates detection zone alignment and maintenance relative to the observed traffic pattern and object scene. Thus, the machine vision performance will not degrade if the camera's pointing were misaligned after installation, e.g., the camera moved by command or from actions by vandals.)

Thus installers recommend the installation of a separate surveillance camera, with a pan, tilt, and zoom capabilities, to acquire different areas of interest with the optimum resolution. A 200mm lens will resolve fractional inch features from 300 feet. IHS is presently qualifying software to automate auxiliary camera pointing to a precise coordinate within the IHS field of view with optimum magnification and focus. This coordinate may be defined by either the machine vision's computed position, the alarm's detection zone, a keyboard or mouse key click, or the location touched on the monitor screen.

Machine Vision

IHS evaluated several systems prior to committing the LIRR demonstration to Econolite. Without any rebuttal, the Autoscope™ System from Econolite Control Products, Inc. has the most documented performance record. The evaluation, conducted with prerecorded video tapes, found that other systems did extremely well with the detection required for this system. However, in every case and with the exception of IHS's software, gate motion detection was not evaluated. It is not that the suppliers could not detect gate motion in the future, but that they are only willing to develop that capability when they perceive a ready market or when such an effort is externally funded. During this evaluation period, Autoscope™ also did not demonstrate a capability to detect gate motion.

After committing to the LIRR demonstration, IHS learned that Econolite has a strategic alliance with a camera manufacturer for the use a proprietary design that only works with a motor driven shutter for light control. As previously stated, the IHS optical system must use an Automatic Electronic Shutter Control (AESC) camera which is not available from that camera manufacturer. This is not a significant technical issue, since the manufacture does have manual shutter speed switching and Econolite's adaptive loops could drive an automated shutter speed circuit instead of the motor driven lens aperture. However, due to the strategic alliance, the Econolite Company provides a disclaimer as to the performance of any IHS demonstration being representative of performance with their preferred system configuration, and did not allow any permanent media recording of IHS performance with their system. They also will not provide any pricing or near term solution for the sale or lease of a system to, or through, IHS.

At present, and as shown at the LIRR demonstration, the IHS software is able to detect and track every moving object within the field of view, including the gate motion. That software, has the real time keyboard select options to: only display detected objects; display the instantaneous tracking vectors assigned to each detected object; color and superimpose the tracked objects on the live video; display and overlay the video with the history of the image vectors; and to provide a count of objects on a per lane or per zone basis. This process is performed on a commercial Pentium Pro 200 NT with the advantage that a customer will only have to license the software to execute these functions on their own equivalent PC. Subsequent studies have shown that lower priced MMX and newer Pentiums can execute this process in real time in the control room if the video is hardwired (coax or fiber optic) to that location. At present, IHS has ceased all self funding of this software.

PROJECT DEMONSTRATION, 8 APRIL 1997

Prior to the demonstration, LIRR mounted the IHS surveillance camera on an existing wooden power line pole adjacent to a switching tower at the Main Street Crossing in Mineola, NY. The camera was about 25 feet from the nearest track and at a height of some 35 feet to clear lines above and below the camera. The camera's power and Econolite's (traffic machine vision) Autoscope™ System display area was provided at a desk in the switching tower. IHS pre recorded 6 hours of video data and, a week prior to the demonstration, provided copies to Traffic Control Equipment Corp. (Econolite's local representative), Econolite Corp., Image Sensing Systems, Inc. (The provider of AutoScope's software) and an IHS software consultant.

The real time on-site 12 inch monitor demonstrated clear observation of gate motion and all pedestrians and vehicles within a 250 by 340 foot area. The on-site machine vision demonstrated the 'stop vehicle' and 'green light' alerts in pre programmed detection zones. The local representatives also explained how Autoscope could be programmed to detect the 'violation' alert by the logic of lane changes and wrong direction traffic within discrete detection zones. Unfortunately, the machine vision gate motion detection was not feasible during the demonstration with the Autoscope software.

To show the promised gate detection feasibility, an IHS tape was retrieved for playback. This playback, although not planned for the meeting, demonstrated IHS's real time PC based machine vision software detection, tracking and statistical recording of all motion, including both gate functions, within the entire field of view. A pre recorded VCR tape from the local representative also showed the success of an earlier wireless (microwave) video signal transmission to a locomotive cabin while the train was traveling at 100+ MPH.

Since the Demonstration

IHS, Inc. has established a limited teaming arrangement with Nestor, Inc. for certain railway applications since:

1. TrafficVision™ System is the only other provider of traffic machine vision with omni-directional detection and tracking of all objects within the entire field of view.
2. After just 2 years from market entry, their system out performs all other systems in the critical areas of IHS interest.
3. They have the potential to execute the important IHS features which "detection zone" machine vision systems cannot handle.
4. Nestor's patented classification processing provides additional levels of false alarm mitigation without sacrificing detection sensitivity.

This arrangement has allowed both IHS and Nestor to focus on core competencies; IHS, on system optimization capabilities and Nestor, for machine vision software development for auto-configuration and object detection, tracking and classification. The synergism of this agreement provides a very low cost, off-the-shelf PC based system, for immediate integration and qualification.

The Discriminators Between Systems

The significant discriminator between this and any other potential machine vision systems is the use of IHS's 160^0 degree, distortionless, panoramic surveillance system and TrafficVision's full field of view omni-directional detection, tracking and classification of all moving objects by a patented neural network system.

IHS's Surveillance System acquires more than 100 feet of roadway and the crossing gate arms on each side of the railway's tracks, even when the train is in the intersection, from an elevation of only 27 feet. As an option, the system may be augmented by a high resolution surveillance system to automatically track, focus on and display an alert's cause with optimum resolution.

Nestor's TrafficVision System detects, and tracks every moving object within the system's field of view. This system easily differentiates between vehicles and shadows at full video speeds. Maintained performance has be demonstrated even under environmentally difficult conditions.

The system provides classified counts and derives statistics of each vehicle traveling along the roadway. This classification is a significant feature to automate the identification of the type object or vehicle initiating the stopped vehicle alert. A different automated emergency logic may exist for a stopped bulldozer or bus versus an abandoned shopping cart.

The exact coordinate of the object, which initiated an alert, can also enable automated tracking and evaluation of that object by an optional high resolution surveillance system.

The processor and PC also digitize and store the live video and statistical vehicular data to local memory on a continuous basis. Automated transmittal of this data for control room display or storage may be initiated by predefined logic based on the detected alerts or by external command.

Since Seattle Conference

A railway representative, after the Seattle conference, requested a proposal for a complete railway crossing system that would have a zero interface with the existing railway infrastructure. The system would be installed and qualified by the railway and then turned over to the local

DOT. They believed it would be cost effective by eliminating their future maintenance costs and by minimizing product liability. Such a system was then documented by IHS and reviewed with individuals from the Volpe Center in Cambridge, Mass. While existing off the shelf equipment could implement this system, it exceeds IHS's deployment capability. Thus, the proposed specification will be retained for future reference. Dialog with the railway has continued.

Other contacts have been developed and a camera was provided for deployment and evaluation at a quad crossing in Los Angeles, CA. Another camera has been prepared for deployment at a rotary in Manhattan, Kansas.

IHS also donated or provided cameras for all weather performance assessment and software development. These installations include: the Main Street LIRR crossing in Mineola, NY, the Blue Line Quad Gate railway crossing in Los Angeles, the staggered intersection of Main Street, Mamaroneck Avenue and Church Street in White Plains, NY, the traffic circle in Latham, NY, a maintenance area for the Tri-bourough Bridge and Tunnel Authority of New York City, NY, Renseallear Polytechnic Institute of Troy NY, and locations with a security company with offices in Poughkeepsie and in Kingstown, NY.

A set of view graphs were prepared and submitted to the TRB program office for their presentation at a European Railway crossing conference.

SYSTEM STATUS

The IHS video surveillance system is currently deployed in numerous locations. Facilities exist to immediately ship about 5 units per week within 2 weeks ARO. Long lead items are on hand to sustain that rate and this rate could be significantly increased within 8 weeks if a commitment justified the effort.

The IHS software and integrated system level performance (qualification) testing is on hold while strategic alliances are being evaluated. The integrated system performance testing will resume when IHS has defined the machine vision system that will be used.

PLANS FOR IMPLEMENTATION

IHS, along with an independent review board, evaluated the core assets, technologies, installations, demonstration projects, contracts and presentations. Based on this review, and without additional funding

1. IHS has now limited, focused, and directed all internal investments to the patent and its imminent issuance. IHS has been notified that all of the claims have been granted and final supporting artwork has been submitted.
2. Once the patent is issued, IHS will introduce an "Rα" optical system to supplement the existing "RTan(α)" design.

The "Rα" imagery appears conventional to the viewer and other machine vision systems. In addition to the desired imagery for security applications, the "Rα" will provide a larger field of view (horizontal axis acquires 12, versus existing 9, times the installation height).

The "RTan(α)" design is retained for applications of vehicle classification by a direct mathematical algorithm and for areas where distortion free imagery is desired.

3. IHS will then fabricate "Rα" and future "RTanα" systems using an improved design and production tooling for low recurring cost (comparable to existing security systems).

In parallel, IHS will develop the existing dialog and demonstrations to refine the system requirements for railways and roadways while deploying appropriate systems for defined applications.

The soon to be issued patent also may solidify a software venture to complete the IHS real-time software that detects, tracks, and classifies all moving vehicles and provides a quantified report on a per lane to lane basis (to define turning and straight through movements at intersections). IHS believes this software can be adequately implemented on today's low cost MMX and newer Pentiums with a standard commercial frame grabber. Hence, users only require the IHS program for full implementation with any camera. The IHS camera would enable the evaluation of a complete intersection from one camera. At the present rate of computer improvements, the IHS system could be laptop based by early 1999. Abstracts of this IHS proprietary software was used during the 8 April demonstration to show the gate motion detection and other promised features that the "world's most widely deployed" system could not show.

CONCLUSIONS

The demonstrated system concept would be in the public's interest to have developed and deployed. It is a very reliable and cost effective means to detect:

1. If an object is on the railway tracks,
2. If a vehicular queue is approaching the tracks and a traffic light control signal should receive a pre-emptive change to empty the queue,
3. If the gates and signalization are working properly, or
4. If individual or vehicles are violating the "do not cross" signalization.

In addition, the system would provide statistical, forensic and educational data that presently does not exist.

The IHS system is the only one camera system that can monitor all omni-directional traffic of an intersection from an existing 30 foot telephone or lamp pole.