Innovations Deserving Exploratory Analysis Programs

High-Speed Rail IDEA Program

Vehicle Detection and Tracking from a Wide Angle Sensor's Signal for Intersection Control and Intelligence

Final Report for High-Speed Rail IDEA Project HSR-02

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TRANSPORTATION RESEARCH BOARD
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Vehicle Detection and Tracking from a Wide Angle Sensor's Signal for Intersection Control and Intelligence

IVHS-IDEAS PROJECT 30

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

EXECUTIVE SUMMARY

This project successfully optimized a high resolution, distortionless, wide field of view (160 degree), all weather, optical surveillance system shown in Figure 1. The project's software development has demonstrated the potential for real-time tracking and statistically reporting the omni-directional movements from all vehicles within complex intersections and rotaries.

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 an area may include each inbound and exiting lane on both sides of a railway, entire toll plaza, complex intersection, rotary circle, divided freeway, parking lot, or storage area. Figure 2 is the video signal's digitized image from this surveillance system at 28 feet above ground level from the outer perimeter of the traffic circle in Latham, New York. The keystone distortion is from the tilt that was required to compensate for the low camera elevation. If this camera were mounted on the pole (identified with an arrow) at a height of some 35 feet, the entire rotary would be observed without distortion.

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.

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 pending). 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.

The IHS software demonstrated that all traffic in the approach and departure lanes about a point of interest can be observed, detected, and tracked, from this system. The certainty now exists that a single system, installed on the railroad's right of way, could determine if an obstacle intrudes into, or remains on, the right of way of a railway after the gate closing signal has been initiated. Figure 3a is a digital image of the vehicular trajectories of the

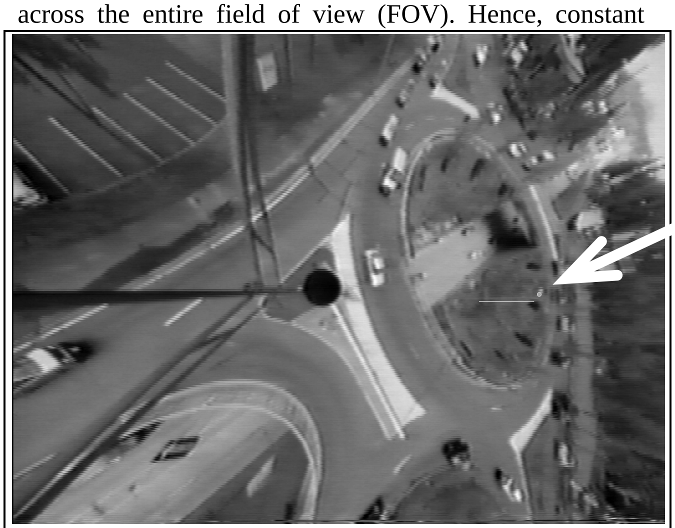

FIGURE 2 System's video image, 28 feet above roadway

Latham traffic circle shown in Figure 2.

Figure 3b is a similar image of the complex intersection in Hartsdale, New York. This video data was acquired with a low resolution, (old design) system that was 35 feet above the road bed. For both systems and intersections, the vehicular traffic is easily observed, detected and tracked (counted on a lane by lane basis).

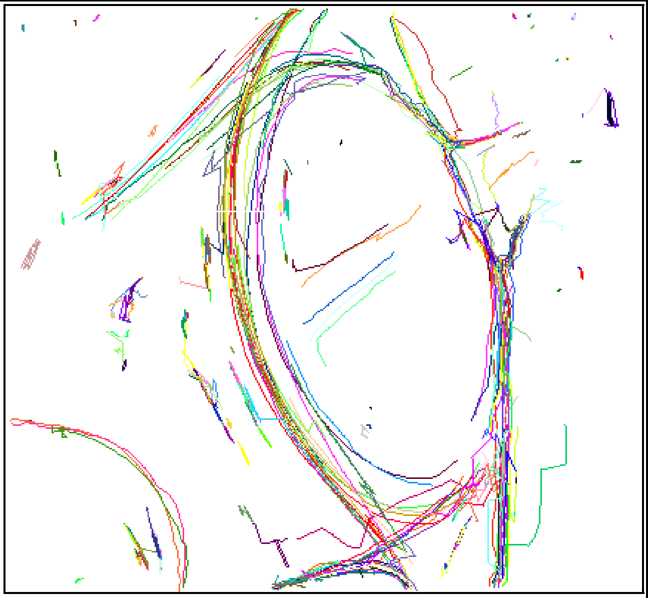

FIGURE 3a Vehicular traffic trajectories at the Latham traffic circle with camera at 28 feet

CONCLUSIONS

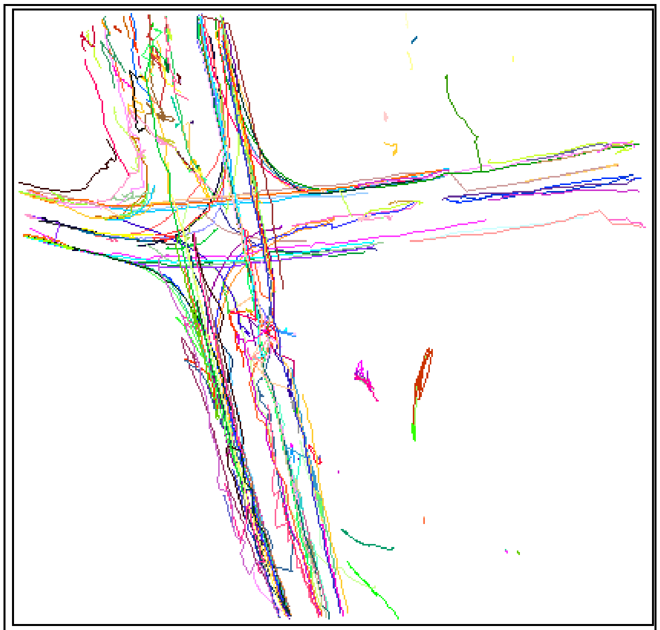

FIGURE 3b Vehicular traffic trajectories at the Hartsdale intersection, old design, camera at 35 feet

The basic IHS system (surveillance camera, monitor and VCR) provides wide area, distortion free, high resolution surveillance for traffic studies and traffic management centers. Distortionless viewing is acquired for an area 11 times its installed height when aligned normal to the observed surface. With a slight tilt, the camera acquires more than twice installation height on one side of the installation structure and above horizon on the other side. Final patent office action on pending claims will protect IHS from designs for similar applications and will also protect IHS for the exclusive application of an automated learn mode logic for placement and maintained alignment of detection zones on all inbound and outbound lanes. This automated process requires no (or minimal) operator intervention during installation and for subsequent data processing functions.

IHS believes that this system, with full data processing exploitation, will have the lowest installation, maintenance, and life cycle cost for many unique applications that presently require multiple video cameras and sensors. This claim is based on the fact that there is:

- only one sensor for an entire, non orthogonal, omni-directional, traffic intersection, rotary, or freeway;
- no erection of new mounting structure by the use of existing off the road support structure;
- no underground conduits when the structure mounting the power, recording and control electronics is near the intersection;
- no (or minimal) on-site detection zone programming;
- minimum training and skill required to prepare, install or replace, and check-out an entire system;
- minimal alignment at installation, e.g., tape ruler for height and eyeball alignment for tilt and reference to main flow of traffic;
- no calibration, unless the absolute vehicle velocity measurements are required;
- a single sensor that provides fixed scaling between roadway and image plane with a field of view that exceeds 440 feet along the diagonal, 360 feet along the horizontal and 270 feet along the vertical from an installation height of only 40 feet. Thus, numerous omni-directional lanes can be monitored from a nominal height;
- no requirement for fiber optics since cable length to controller is nominally less than 60 feet;

The primary IHS focus will now shift from designing an optimum all weather optical system to the integration and development of user friendly system software for real-time traffic surveillance.

IVHS-IDEAS PROJECT 02

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INTELLIGENT HIGHWAY SYSTEMS, INC., (IHS) FINAL REPORT

IDEA PRODUCT

This project focused on a wide angle optical sensor and its signal processing for omni-directional vehicle detection and tracking.

The 160^0, distortion free, high resolution, all weather surveillance sensor provides a standard high resolution black and white video signal on a coaxial cable. The optical system, when mounted from a 10 meter (32 feet 10inch) elevation, observes a rectangular area of 90 by 67.5 meters (295 by 220 feet) with a ground resolution of 166 millimeter (7inch). Real-time signal processing is feasible in parallel to the video display and VCR recording.

The omni-directional detection and tracking in all intersection approach and departure lanes by a single sensor simplifies the IHS data processing. This data processing reduction will now enable a real-time learn mode feature to automate the detection zone placement in all approach and departure lanes. From this, automated traffic reporting will provide time phased statistical reports of vehicular traffic from detection zones of the approach lane to the departure lane (including U-turns). Thus, real time DOT traffic surveys will be feasible from a portable sensor with little or no PC interaction required on the part of the operators.

This system also has application as a surveillance camera for ATMS display of complex intersections, rotaries, and interchanges that previously required several camera, or at least a camera with an interactive pan and tilt systems.

CONCEPT OF INNOVATION

There is nothing new about panoramic and hemispherical imagery. However, wide field of view, no distortion, and infinite resolution defies geometric principals in optics. But, when the resolution only has to find a vehicle within some finite distance, then a boundary may exist where the resolution, distortion, and field of view is acceptable. At the completion of that study, Intelligent Highway Systems Inc. was founded and basic patents submitted.

After minimal research, it was apparent that most DOT signal control technicians would prefer no PC interaction or need to identify detection zones for a PC. Thus, the second study defined how a computer can automate the optimum placement of traffic detection zones with no operator interaction. This "Learn Mode" is also patent pending.

The basic logic of the patent is that roadways, except rotaries, do or do not have intersections. When it does not have an intersection, it is a survey for a highway, and simple logic follows. When the roadway does have an intersection, then the logic seeks if the computer has a file for the intersection.

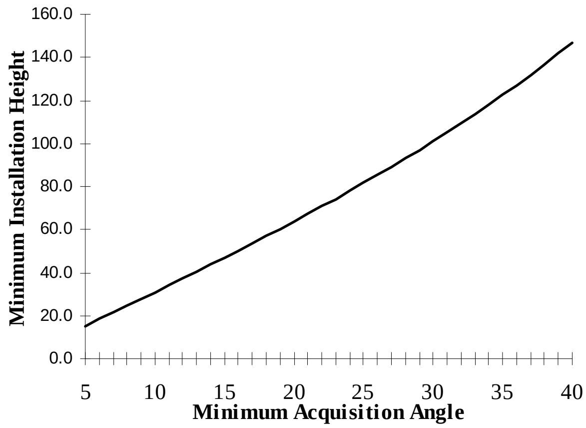
- If no file is available: [1] the intersection is scaled based on lane to lane separation, [2] detection zones are sized and placed in dimensions defined in increments of lane separation, and [3] placement is relative to the intersection of lanes and centered on each lane.
- If a file exists, [1] a matrix is computed to transform the matrix array defining the predicted traffic pattern to the matrix array derived from the observed traffic pattern. [2] This transform is applied to the matrix array that defines the detection zone boundaries (in predicted space) to set them to observed (data matrix) space. The first step iterates to maintain the optimum placement of zones.

Since software has a priori knowledge of detection zone labeling, then counting the vehicle from zone to zone is trivial, providing omni directional tracking is attainable in real time. One objective of this project was to demonstrate that real-time, omni directional tracking of multiple images is feasible.

INVESTIGATION

This project was divided into three Stages:

- In Stage 1 an existing low resolution, prototype surveillance system was modified to reduce "multi-reflection" images and then used to acquired video data. This data was used for evaluation and development of software documentation (plans, requirements and detail specifications). Stage 1 also reviewed all the system parameters to define the requirements for a single video system that would be able to monitor and control the vehicular traffic for an entire intersection.
- During Stage 2, the optical design was optimized with parametric trades. These trades also included the marginal cost for a small change in optical performance. These considerations were for both limited and long term production. The electro-mechanical design was configured to maintain the optimum optical performance when exposed to all the weather and environmental conditions specified during Stage 1. Preliminary software algorithms were coded and tracking performance demonstrated.
- During Stage 3 (the last Stage), the camera design was selected, parts were fabricated and ordered, the camera surveillance system was assembled and the



system was installed for in-field testing. An additional three units are schedule for field installation during September, 1996. The long lead time parts (diamond turned optics) have been received to make additional surveillance units available within 3 weeks of order. The video data was processed and preliminary results indicate a reasonable correlation between the automated and visual counting of vehicles.

Correspondence from the US Patent office was also received during Stage 3 indicating that they will grant certain basic claims in our 1994 patent submittal. These claims will protect IHS from other systems that may attempt implementation of the weatherized wide field of view optical system or the data processing (Learn Mode) which automates the alignment of preprogrammed logic and files to the observed traffic patterns. This learn mode alignment (coordinate scaling and transform) is then used with other logic and files for optimal placement of emulated detection zones on open roadways, complex intersections and rotaries. The goal is to implement this process to eliminate (minimize) the operator intervention during and after installation of the surveillance system.

The following summary of IHS tasks within each stage explains how this surveillance system evolved. The present design is a high quality, all weather, distortion free, 160 degree optical surveillance system. The optical resolution matches the resolution of high quality surveillance camera focal plane electronics and IHS software will provide for real-time processing of the video data.

STAGE 1, TASK 1: VIDEO DATA ACQUISITION RAILWAYS AND ROADWAYS CROSSINGS

IHS established liaison with Metro-North Commuter Railroad and secured video data under their supervision. The data sets were acquired at the Virginia Road crossing in North White Plains, New York and in the North White Plains Metro-North Commuter Railroad employee's parking lot adjacent to the maintenance facilities.

Continuous recordings of the entire intersection were made from a height of 35 feet with the camera's horizontal axis nominally aligned to the vehicular traffic. It was then rotated to have the horizontal axis nominally aligned parallel to the railway tracks. In both configurations, the railway crossing gate operation could be observed on the monitor to verify proper operation. The vehicular roadway crosses the railway at a skewed angle of some 20 degrees and has a severe "S" from approaches that are near parallel to the tracks. On the far side of the tracks, the roadway has a steep drop-off in grade with a significant portion obscured by trees and shrubs. A structure on Metro-North's right of way is the only single vantage point to observe the vehicular traffic on both sides of this crossing. If a wide field of view system were not used, then two sensor systems would be required.

The parking lot data was acquired to calibrate the prototype system and to assess the system's resolution as a function of aperture size and application of colored band-pass filters.

Subsequent calibrations were made with the camera mounted to a stable tripod. Here the calibration targets were 3 inch wide white posterboard strips at two foot centers on an open roadway and then with 1 inch white posterboard strips attached to black posterboard background on a 30 foot floor space inside a building. The conclusion from the latter calibration is that the change in the camera's field angle distortion, chromatic error, and resolution as a function of aperture size and chromatic filter is smaller than, or the same magnitude as, the errors due to the setup change between measurements. The mounting changes (translations and tilt) were the result of camera removal from the tripod and the lens disassembly to change the color filters between test sequences. Likewise, the temporal stability of target illumination was insufficient to readily quantify the system's quantum efficiency or image resolution as a function of installed colored filter. While sufficient data may exist to statistically determine these attributes, the use for these results did not justify the labor intensive effort required to attain them. However, even though the analytically quantification was aborted, the visual perception provided an excellent correlation with the predicted result.

STAGE 1, TASK 2: SYSTEM STUDIES TO OPTIMIZE OPTICAL PERFORMANCE UNDER ALL ANTICIPATED ENVIRONMENTS

This trade started with the basic review of all requirements. The function of minimum installation height, in feet, to acquire 350 feet of roadway versus minimum observation angle relative to the highway pavement is shown in Figure 4.

FIGURE 4 Height, in feet, for 350 foot acquisition versus minimum acquisition angle.

The 350 feet (± 175 feet) was derived to acquire the distances of two 40 foot detection zones (emulated inductive loops) starting 10 feet behind the far side boundary defined by the intersecting lanes, four 12 foot through lanes, a 12 foot left turn lane, a 12 foot right turn lane, and a 12 foot off the road installation.

Next, the nominal 64 inch car height and a 25 foot separation between cars imply that all viewing angles under 12 degrees will occlude part of the subsequent vehicle. With 12 degrees as a lower limit for viewing traffic, the horizontal axis of the image on the array is ±(90-12) degrees or ±78 degrees. Since video camera array dimensions of vertical to horizontal to diagonal have a 3, 4, 5 ratio, the array's diagonal angle is $\pm\mathrm{Tan}^{-1}(1.25\mathrm{Tan}78^0)$ or $\pm 80^0$. A second relationship of minimum height versus FOV required to attain 350 feet with a minimum viewing angle of 12 degrees is shown in Figure 5. This figure shows that a 37 foot installation will acquire at least ±175 feet of ground coverage with a 156 degree horizontal FOV optical system.

The third study addressed the ghost images of bright objects (head lights at night) in the prototype system. The initial proof of concept system used a clear quartz cylinder with MgFl anti-reflection coatings to provide the structural support and environmental enclosure between the camera's imaging lens and convex mirror. Thus some 4% of the incident energy of the bright objects was reflected from the far side wall of the cylinder to form a second image 180 degrees from the primary image. During stage 1, the cylindrical enclosure was replaced with a 155 degree conical window as the support and environmental enclosure. However, a unique angular range still existed where a bright object reflected from the primary mirror could, after reflection from the cone and after a second mirror reflection, enter the aperture of the system and form a ghost image. Since the mirror is more than 90% reflective, this ghost image could be more than 3% of the primary image. Even though this region is well understood and the secondary image could be eliminated by software, a design was prepared to eliminate secondary reflection from entering the aperture of the system. The shape of the enclosure, where the energy of all secondary reflection will miss the primary mirror, approaches that of a hemisphere. An enclosure design that eliminated secondary reflection from the aperture has been incorporated into the latest design. The enclosures ordered during stage 3 were not formed to that exact prescription but the stray light images are not expected.

The fourth study evaluated the resolution of the old design at ten radial positions (field angles) from a 10 meter installation height. This evaluation varied aperture size and spectral bandwidth. The average and worse case spot sizes for 4 aperture sizes for each of 5 spectral filter bands are shown in Figure 6. This is a typical plot for an optical design and specifically relates to the old design used to acquire data during and prior to Stage 2.

The spot size, expressed in millimeters, is defined as the minimum diameter for 80% of all incident energy at the

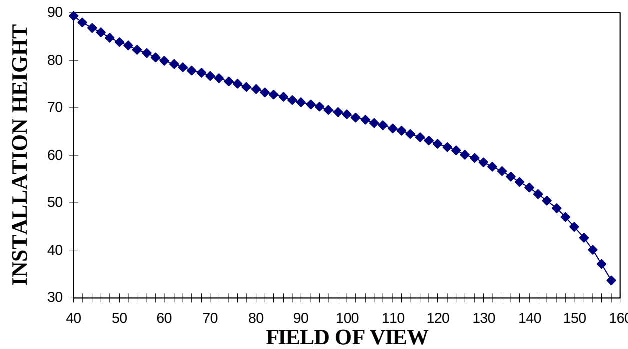


FIGURE 5 Minimum height, in feet, versus FOV to attain 350 feet with a 12 degree minimum viewing angle

object plane from a focal plane point source. The evaluation of the calibration video, of two aperture sizes at each of three spectral bands, has good visual correlation with Figure 6.

The fifth study optimized both the afocal and the imaging systems for configurations that only used spherical elements and for an afocal system that employs aspherics as well. Each of these optimizations maintained an aperture of 6mm, a focal plane compatible with a 1/2 inch CCD Camera, and used the visible spectrum for the performance assessment. As was shown in the fourth study, we know that this performance can be improved by reducing the aperture or by using optical filters to minimize the chromatic aberrations. The result of this study is summarized in Table I. In the above study, the aspheric design was used to bound spot size performance

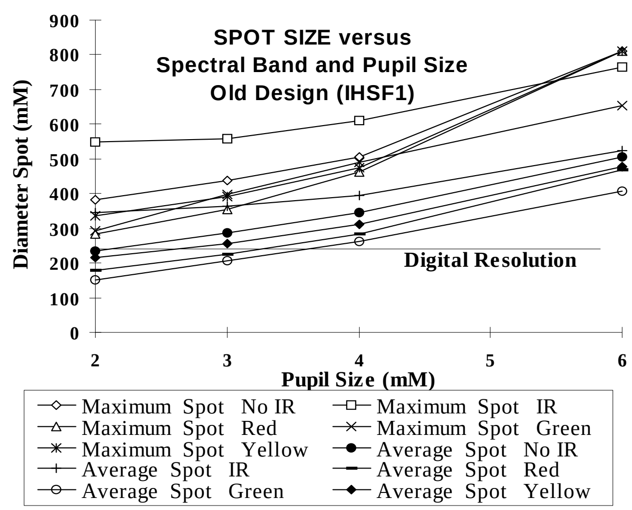


FIGURE 6 Spot diameter (mM) versus aperture for 5 spectral bands. Installation is at a 10 meter height.

of the four element afocal system if cost was not an issue. In this optimization, two designs had spot sizes less than 150 millimeters in diameter for the first 3/4 of the field of view.

Design	Max. spot	Avg. Spot
Nominal	715	473
Afocal Aspheric	843	217
Afocal Spherical	524	252
Focal 7 Spherical	308	135
Focal 6 Spherical	241	160

Table I
Spot size in millimeters, elevation at 10 meters

The 6 and 7 lens focal designs, that combine both functions of the afocal lens adapter and the commercial imaging lens of the existing nominal design, showed considerable improvement. Most of this improvement was due to the additional surfaces available for geometric corrections (the old design had only four elements in the afocal lens) and some of this improvement was due to selection of lens element designs that may not be readily available. Comparing these results with the existing old proto-type design, the maximum spot size was smaller than the previous average spot size and the new average were significantly smaller that the focal plane's detector resolution of the standard video camera.

STAGE 1, TASK 3: FORMALIZE SOFTWARE, ARCHITECTURE AND REQUIREMENTS COMPATIBLE WITH THE ULTIMATE GOAL OF ONSITE PROCESSING OF RAILWAY AND HIGHWAY CROSSING PARAMETRICS

IHS contracted Rochester Institute of Technology Research Corporation (RITRC) for development support of robust tracking algorithms for multiple omni directional objects and for algorithms that may detect gate functions or other features that may be of interest to the railway and DOT industry. These algorithms are to function well in the presence of low contrast and non symmetrical targets, and with omni directional trajectories in the presence of significant noise. The algorithms that IHS previously considered would not meet these requirements.

RITRC prepared the software design specification in response to the IHS's software plan and requirements.

RITRC was not informed of, nor contracted to work on, the patent pending learn mode.

STAGE 2,TASK 1: DESIGN OPTIMIZED

The project evaluated and defined the system requirements for a single video surveillance system used for traffic surveys, management and control of entire intersections, rotaries and freeways. The major refinements to the system requirements include:

- the "environmentally sealed" unit maintains an air tight system to avoid internal condensation of moisture and non volatile residues;
- a $\pm 80^0$ field of view optical system satisfies or exceeds all requirements for every operational scenario studied. The linear scaling of the object plane (ground) as a function of installation height (h) relative to the video monitor is:

  Diagonal = 11.25(h),
  Horizontal Axis = 9(h), and
  Vertical Axis = 6.75(h);
- the optical resolution is less than 0.015 times the installation height. The distortion and resolution of the present optical design is now equal to, and better than, the electronic resolution of high quality surveillance cameras;
- the camera system displays a non mirror image when using a standard VCR or monitor. Previous configuration presented mirror images;
- fixed, rather than electro-mechanical, focus and aperture control are implemented for improved reliability, interface simplification, and less operator intervention.
- the surveillance system is suspended (mounted from above) rather than supported from underneath. A simple three axis, cam locking, swivel joint is provided for initial installation. After an operational alignment verification, a solid spacer could provide the angular transformation between the solid mount and the camera interface,
- auxiliary heaters for extreme cold environments are self regulating and easily enabled. The conical shield is coated to optimize the thermal balance;
- a toroidal bladder maintains a near zero differential pressure. The toroid is sized to accommodate the volumetric change of $\pm 100^0$ F in temperature and ±75 millimeter (3 inch) in barometric pressure;
- an acrylic primary mirror, enclosure, and primary structure maintain a consistent match of thermal expansion coefficients;
- a significant weight reduction is attained (relative densities; acrylic @ 0.043 pounds per in^3, Aluminum @ 0.10 pounds per in^3, and Steel @ 0.28 pounds per in^3) while still retaining large design safety margins, structural stiffness, and a high first mode resonant frequency;

The optical design optimization continued until the two mirror design (designated D2) was selected. Here the refractive imaging lens group and camera are behind (above) the larger primary mirror as schematically shown in Figure 7. This configuration satisfies each of the above requirements and also provides for the following features:

- low stress loading of the transparent environmental enclosure;
- the optical design eliminates (minimizes) stray light and multi reflected images;
- simpler adaptation to existing DOT structures;
- the conical shield, and extreme light baffle, protects the optical enclosure. Precipitation at angles greater than 15 degrees from the horizon will not reach the optical window;
- the increased optical complexity, to eliminate or reduce the present 0.25% central obscuration, is not warranted since there were no operational scenarios where the obscuration precluded a useful and practical

application. Designs (patent pending) using axicon elements and or prismatic enclosure shells were considered;

- a camera, mounted at a height of 10 meters (32’10”), with a detector array of 768 horizontal pixels by 494 vertical pixels and perfect optics has an RSS ground resolution of 248mm (156mm horizontally by 192mm vertically). The average optical resolution for the new design is 166mm. The RSS of the optical and electronic resolutions (298mm) implies that a checker board pattern of 11.74 inch squares over a 65,275 Sq.Ft. area will be fully resolved into black and white squares. See Table 2 for optical resolution and distortion as a function of field position from the optical axis. At a 10 meter height, 1.00 is equal to ±56.2 meters (±185 feet);
- the simultaneous use of an optical element as the only structural member between optical elements and as an environmental enclosure is one of the basic pending patents.

The optical performance for the old prototype design (IHSF1) and the new design (D2) is summarized in Table 2. The installation height is 10 meters and all distortion and spot size dimensions are given in millimeters. (25.4 millimeters (mm) equals one inch).

	Old Design (IHSF1)		Present (D2)	
Increment of Full Scale	Distortion	80% Spot Diameter	Distortion	80% Spot Diameter
0.05	29	347	24	125
0.10	31	317	13	130
0.15	-2	267	-33	136
0.20	-58	205	-86	144
0.25	-111	189	-112	155
0.30	-138	212	-96	169
0.35	-127	320	-47	177
0.40	-77	441	12	185
0.45	0	553	60	188
0.50	85	643	79	186
0.55	160	702	68	182
0.60	204	715	34	179
0.65	202	694	-7	179
0.70	148	329	-41	182
0.75	49	522	-59	173
0.80	-71	459	-57	168
0.85	-175	456	-43	155
0.90	-215	512	-20	143
0.95	-142	629	12	164
1.00	122	652	81	209
	Max. Spot	715	Max. Spot	209
	Ave. Spot	473	Ave. Spot	166

Table 2
Distortion and spot in millimeters, elevation at 10 meters

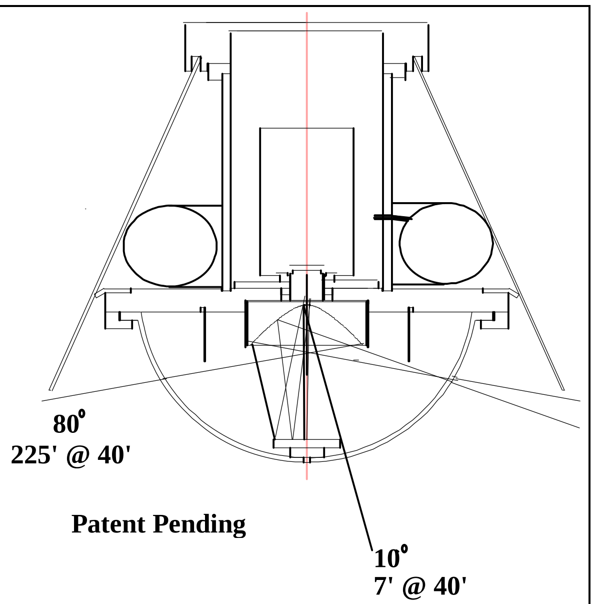


FIGURE 7
Optical configuration for two mirror design

STAGE 2 TASK 2: VIDEO ACQUISITION AND DEMONSTRATION

Software modules were integrated and tested using existing data from the low resolution surveillance system. The detection software modules, for the tasks described in Table 3, were demonstrated and documented. These modules are to be optimized with the higher resolution data of the new optical system as more time and funding is made available.

Module/Activity
1. Background Estimation: adaptive estimate of scene background
2. Segmentation: extraction of features, clustering of vehicles
3. Velocity Estimation: calculation of velocity from object positions in successive frames
4. Trajectory Estimation: interpretation of trajectories from object position and motion
5. Traffic Summaries: categorization of trajectories in traffic statistics
6. Process and Testing: existing baseline traffic patterns
7. Output Image Displays: road labels (input), vehicle identification (output)
8. Design Documentation
9. Video Production: vehicle labels, output to videotape
10. Design Review

TABLE 3 Software modules: activities

The results demonstrated that the relatively simple approach taken is a promising candidate for real-time implementation. With a few improvements in low-level processing and trajectory analysis, it should be able to produce usable traffic statistics on the stable video sequences. This effort, in addition to further testing on longer, more variable image sequences (dawn, daylight, dusk, night, with and without street lamp, fog, rain, etc.) are needed to determine the performance of the background estimate, and to confirm the accuracy of the aggregate trajectories in counting vehicles. These efforts are now in progress but do not form part of this IVHS-IDEAS project or report.

The code base, with the scheduled upgrades based on the processing of the new data, will be converted to a real-time mode. This conversion will enable more extensive tests, and a quicker determination of the changed performance as a function of tracking algorithm modifications.

Prior to acquiring the latest data, tests were run using 700 consecutive 640x480 gray-scale images acquired from a sample video tape (from the stage 1, low resolution camera) using a Matrox Meteor card and a Panasonic VHS VCR. A custom program was written in Microsoft Visual C++ 2.0 using the Matrox MIL library for this task. A frame rate of 5 frames/second was used, yielding 2 minutes and 20 seconds of elapsed time. The images were cropped uniformly to 416x400 to eliminate most of the empty boundary region, and saved to disk as PGM files (8 bits/pixel raw data with a simple header). It should be noted that the sample video was acquired using the first version of the IHS lens mounted on a soft boom, so the resolution is somewhat low, and there is noticeable movement in the camera. Likewise, to understand the full field of view performance of the optical system, the image was scaled for the diameter to fit within the vertical axis of the CCD camera array (monitor). For this reason, RITC cropped the data array. Thus it was anticipated, and in fact recently demonstrated with the new data in stage 3, that performance is significantly enhanced by the new optical system. In the new system, the entire 640x480 gray-scale image array is useful, and the camera is mounted on a secure platform. However, since the initial stage 3 data was acquired with a tilted camera, RITC also cropped these arrays to eliminate the non rotary information. (Compare Figure 3a to Figure 2).

The background image for the low-level processing of the stage 2 data was established by a median filter applied to the first half (350 frames) of the sample data. In that test data, the adaptation changed the background estimate very little. Longer test sequences with the new data will test the adaptive background estimate. Subsequently, the images of interest were obtained after subtracting the background from each frame, thresholding and averaging N consecutive difference frames. A blob analysis was applied to the averaged frames.

These blobs were then labeled and tracked for velocity estimates, trajectories, traffic lane estimates, and traffic counts of all traffic entering and exiting the intersection. The comparison of manual counting and automated counting had reasonable correlation.

Once the software was operating with reasonable confidence and accuracy, the timing performance was evaluated to assess if this software structure would support real-time processing. In general, it took approximately 60 seconds for 100 frames of 416x400 images on a 75 MHz Pentium, or about 1.6 frames per second. Assuming we can use lane estimates to reduce the portion of the image analyzed by 50% and that we can optimize key segments of the code to improve efficiency by a factor of two, the software will run real-time on a 150 MHz Pentium. A review of the algorithms, considering assembly language and basic improvements, implies that a factor of two is feasible and real-time omni-directional tracking and parametric reporting will be achieved.

This project demonstrated that all traffic in the approach and departure lanes about a point of interest can be observed, detected, and tracked, from a single wide field of view surveillance camera's video signal. The certainty now exists that a single system, installed on the railroad's right of way, could determine if an obstacle intrudes into, or remains on, the right of way of a railway after the gate closing signal has been initiated.

Figure 8a (a copy of Figure 3a) is a digital image of the vehicular trajectories of the Latham traffic circle shown in Figure 2. The Latham data was acquired with the new high resolution camera system but processed with the stage 2 software.

Figure 8b (a copy of Figure 3b) is a similar image of the complex intersection in Hartsdale, New York. This

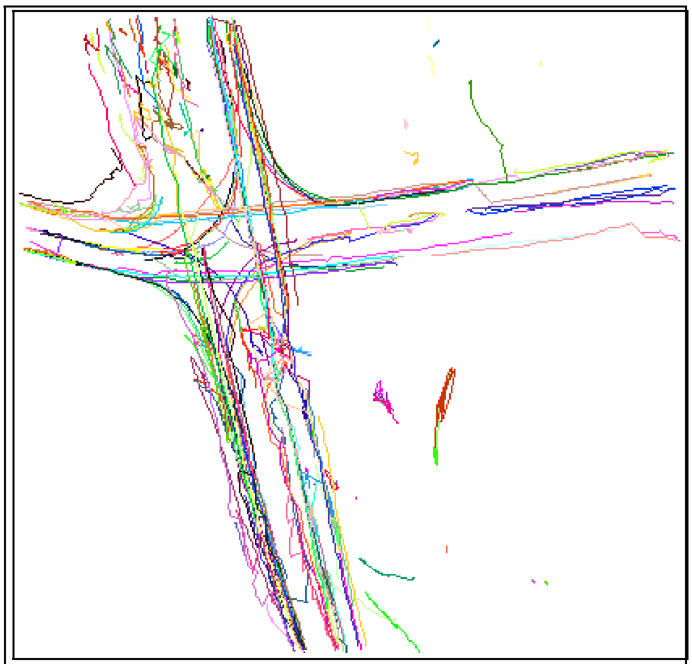


FIGURE 8b Vehicular traffic trajectories at the Hartsdale intersection, old design, camera at 35 feet

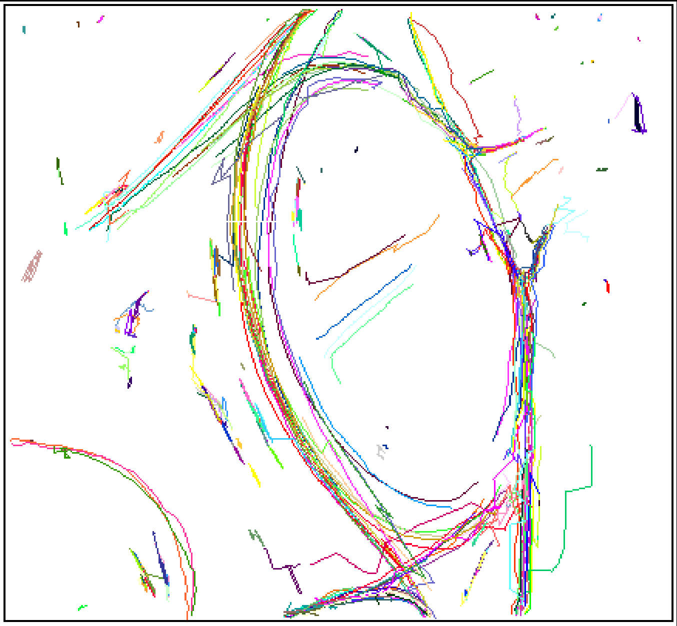


FIGURE 8a Vehicular traffic trajectories at the Latham traffic circle with camera at 28 feet

video data was acquired with a low resolution, (old design) system that was 35 feet above the road bed. For both systems and intersections, the vehicular traffic is easily observed, detected and tracked (counted on a lane by lane basis).

Similar data was acquired with the same low resolution (old design) camera at the intermodal intersection of Virginia Road and Metro North Railway in North White Plains, NY. The railway crossing data was acquired to determine if automated railway gate motion detection is feasible (while visually detectable) with simple detection algorithms similar to that used to detect stationary and moving vehicles. The evaluation of data arrays from the video's frame to frame differences found that the 2 inch wide gate arm significantly under filled the width subtended by the camera electronics' resolution and single detector element (pixel). Thus, the gate's straight line within that difference array had nearly the same gray tone noise as the surrounding areas and was therefore non-detectable with our available algorithms. The effort to detect a moving straight line in the presence of noise was temporally abandoned for higher priority efforts

The RITRC contract was completed at the close of stage 2 and the submittal of the Final RITRC Report for the software development and testing was previously distributed as part of IHS's Stage 2 Progress Report.

Dr. Rob Gayvert, formerly the RITRC project manager, and Mr. Troy Toffolo, principal of Apt Technologies Inc., are now continuing the effort. AptTech is a significant software developer and integrator for real-time SONAR development systems.

STAGE 3: FABRICATED NEW DESIGN AND DEMONSTRATED SOFTWARE WITH DATA ACQUIRED BY THE SYSTEM

A critical design review was conducted immediately after the design optimization process in stage 2. The design was specifically reviewed for all tolerances, mechanical and thermal stability of the optical elements, the optical performance and the structure, ease of fabrication, special tooling and fixtures, reliability, maintainability, long term environmental compatibility, analysis of critical part for stress, resonant frequency and stiffness estimates, the assembly and testing procedure, and cost. The review continued as vendors responded and delivered parts.

Unexpectedly, the schedule for the diamond turned mirror elements took an additional 8 week until the first lot of 10 optical elements was received. This delayed the stage 3 data acquisition and project completion. There were no other schedule delays.

The assembly process was flawless and the optical subassembly testing was as predicted. The first assembly was delivered for installation at the Latham traffic circle on July 12, 1996. The delivery was made to the NYS DOT signal division's motor pool where the installation crew and the principal investigator from RPI conducted a preliminary acceptance test in the laboratory. The installation crew then fabricated and painted an adapter for the existing pole, drove 10 miles to the site, installed the new camera at an elevation of 28 feet, powered the unit, aligned the camera's tilts, initiated the recording of the video signal, and then left for another assignment within 3 hours of the initial arrival at the motor pool. The total on-site time for the DOT crew did not exceed 45 minutes and part of that time was a discussion of other applications they would like to try. At 1pm, the 2 hour video tape was removed for playback, reproduction and mailing to Rob Gayvert for data processing.

The object was to test the existing omni-directional software, with this rotary traffic data, with no software modification from the software configuration that processed the near orthogonal intersection data during stage 2. (see Figure 8a). Two quick counts were made to verify if the software was operational. The first counter reported 16 vehicles versus the manual count of 19 and the second counter reported 25 of 27 vehicles. These errors are most likely due to the automated counting of two vehicles as one (single blob). This error will be corrected and the software will continue as originally planned.

PLANS FOR IMPLEMENTATION

From an immediate perspective, IHS will now agree to supply video systems for evaluation and testing. These optics were seldom mentioned and previously withheld to avoid a preconception that IHS fabricates low resolution systems. As the software develops the systems will be used to monitor, acquire, detect and track all omni-directional traffic within an entire intersection, rotary, railway crossing, divided highway, and parking or storage area with this single video surveillance system.

Applications for this system include:

- **Traffic Surveys:** Even without software, this video system has demonstrated the simplification of a very tedious and difficult rotary circle traffic analysis. When the software is fully developed, this system will provide rapid and low cost reports in near real-time.

- **ATMS Information:** The system is ready for immediate applications. The most logical applications will be “clover leaf” intersections, rotaries, and omni-directional intersections.
- **Security Surveillance:** As a stand-alone, this system can monitor an entire parking area or security perimeter without a scanning system. A surveillance camera with a $\pm 60^0$ field of view must be installed at 3 times the IHS system height to acquire the same distortionless area.

From the marketing (long term) perspective, IHS will continue the support of Rensselaer Polytechnic Institute’s (RPI’s) video data acquisition, processing and evaluation of the traffic data at the Latham Traffic Circle.

Plans are in process to also supply a system to acquire and process the railroad data to be acquired at a High Speed Railway Ground Level Crossing Test Site. This site has been visited with the NYS DOT engineer in preparation for the IHS camera installation. In that project, the video camera image will be transmitted to the train engineer’s video monitor via a microwave carrier

IHS will now apply a major effort to acquire grants and funding. This project has proven successful and the next phase will also prove to be the most cost-effective investment. This system, with full data processing exploitation, will have the lowest installation, maintenance, and life cycle cost for applications that presently require multiple video cameras, a gimbaled camera, or multiple sensors.

Grants and studies are also recommended to develop the data processing software to meet all DOT requirements. Such studies could be a cooperative or joint effort with universities or a government laboratory such a JPL. At these facilities, studies and evaluation projects should use this system with data processing and software from other projects and systems.

CONCLUSIONS

This project has demonstrated two novel concepts:

1. A distortionless, high resolution, 160^0 field of view, all weather, optical surveillance system, and
2. Omni directional detection and tracking of all vehicles within an entire intersection from a single video signal and a low cost PC.

The synergism will be a system providing automated traffic surveys and reporting from a portable system. That basic system would only require the camera, cable, and lap top PC. The VCR and monitor being optional and not required.

When funding provides the completed software exploitation of these patent pending features, this simple system will be a most cost effective traffic engineering tool, surveillance system, and traffic control product.

Joint ventures (government agencies, laboratories universities, etc.) are encouraged to explore the unique features that can be applied or developed.

INTELLIGENT HIGHWAY SYSTEMS, INC.

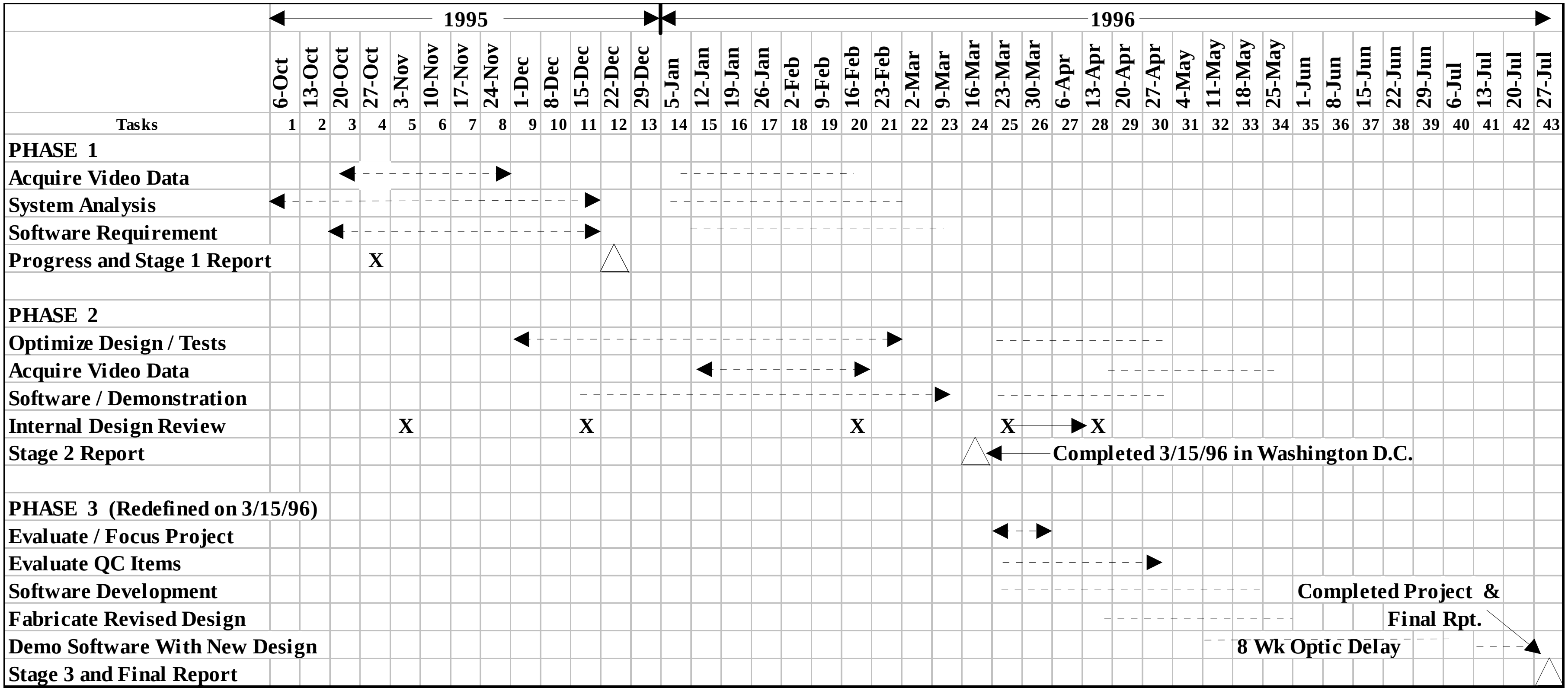


FIGURE 9 Project schedule for contract ITS-02