Visual Monitoring of Railroad Grade Crossing

FDOT Contract # BD-542

FINAL REPORT
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Submitted to:

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16. Abstract

According to the Federal Railroad Administration's (FRA) Railroad Safety Statistics Annual Report '98, there were 75 highway-rail grade crossing incidents in Florida in 1998, resulting in 7 fatalities. Therefore, it is important to explore the use of innovative technologies for solving railroad grade crossing safety problem. The aim of this research project is to develop a video camera based automated surveillance system that can detect moving object like pedestrians, vehicles etc. This system is able to detect, track, classify and analyze the movement and location of objects in video. It can also detect if someone is in a danger zone, trigger an audio alarm, and also relay this information through the wireless data link to log into a remote database where an operator can take appropriate action in near real-time. The developed computer vision algorithms are able to automatically handle varying lighting, weather, camera positions at different locations. The system is delivered in a portable model which is powered through solar panels and has cellular data link capability for data communication. The data from the system is also transmitted to a remote database which is can be published through internet. The performance evaluation of the system has shown very encouraging results with high detection rate. FDOT can benefit from this research project in the areas of security, surveillance, operations, survey and more.

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Executive summary

1. PROBLEM STATEMENT

From 1993 to 1998, there were 25,001 highway-rail crossing incidents (worldwide?) involving motor vehicles, an average of 4,167 incidents a year. In the United States alone, a train collides with a vehicle or person once every 115 minutes, and, in an average year, more people die at highway-rail crossings than in commercial airline crashes. According to the Federal Railroad Administration's (FRA) Railroad Safety Statistics Annual Report '98, there were 75 highway-rail grade crossing incidents in Florida in 1998, resulting in 7 fatalities. Therefore, it is important to explore the use of innovative technologies to solve railroad grade crossing safety problem.

2. OBJECTIVES

The aim of this research is (1) to use computer vision technology to automatically monitor the motion of pedestrians, bikers, animals, and vehicles at highway-rail crossings, and (2) to develop algorithms to automatically analyze video sequences obtained from video cameras installed near the rail grade crossing and detect any dangerous situation. The system should be able to detect, classify, and track different moving objects in the video and analyze their activity. This situation awareness capability of the system can raise local alarm to warn the detected party, and it can transmit the warning message to appropriate monitoring staff (e.g., FDOT, Highway Patrol) at a remote location. This mechanism should help to avert accidents on the railroad crossing and reduce the likelihood of an accident. Portability should be incorporated in the final system so that it can be deployed on a remote railroad grade crossing location with minimal setup time and work without external power supply and communication connection.

3. FINDINGS AND CONCLUSIONS

Work on this project started with the acquisition of visual data from two railroad sites located in New Smyrna Beach and Mount Dora, both in Central Florida. Computer vision techniques were used to build a visual surveillance system that can detect, classify, track, and interpret the interaction of different objects in the scene being monitored by the system. There were various problems that were faced during the course of the development of the algorithms. For example, abruptly changing scene illumination resulting from fast cloud movement causes a problem in the stage during which moving objects are distinguished from the stationary backgrounds. This problem was solved using a novel approach for background subtraction.

The classification and tracking modules of the system provide a reliable framework for understanding object interaction. The tracking module benefits from the superior model that handles the shadows of the objects, which ensures that the true features of each object are used so that reliable tracking can be achieved. The surveillance software system benefits from the trip-wire feature, which can be used to

mark off dangerous zones; hence, a warning can be raised if someone is detected in the danger zone. The software has the feature of train detection as well. It utilizes the train-zone area marked by the user upon system initialization. Thus, the software can keep a complete log of the trains detected along with the objects in the danger zone. The log maintains both object parameters (e.g., time-stamp, duration in danger-zone) and the image snapshot of the object.

The system has been tested under a variety of conditions of lighting, weather, camera position, and so forth. The performance of the system was evaluated for the detection, classification, tracking, and violation detection. The results were compared against the manually annotated ground truth and were found to be over 80% accurate.

The deliverables include a portable system that uses solar power with backup battery. The final system also includes a wireless communication module to transmit the log data and warning message to a remote location. This log information can be viewed in near real-time on a website that is accessible from any part of the world with internet access.

4. BENEFITS

The developed system performed satisfactorily and can be used by the FDOT for improved security and surveillance at any railroad grade crossing. The developed system has a useful online data logging feature that can be used for various operational purposes, e.g., traffic monitoring at a remote railroad grade crossing including pedestrian and vehicle statistics during a specific part of day, month, or year.

The portable system can be deployed at a remote location without power and communication link availability. The system can run off solar power and use cellular internet data service for communication. The setup time of the system is less than 20 minutes.

Overall, this system has produced encouraging results and can be very effective for improving security, surveillance, and operations, as well as for performing engineering studies.

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1. Introduction

According to the U.S. Department of Transportation, a motorist is 40 times more likely to be killed if involved in a vehicle-train crash than in any other type of highway collision. There are approximately 261,000 highway-rail and pedestrian crossings in the United States according to the studies by the National Highway Traffic Safety Administration (NHTSA) and Federal Railroad Administration (FRA). From 1993 to 1998, there were 25,001 highway-rail crossing incidents involving motor vehicles-averaging 4,167 incidents a year. In the US alone, a train collides with a vehicle or person once every 115 minutes, and in an average year, more people die at highway-rail crossings than in commercial airline crashes. According to the FRA's Railroad Safety Statistics Annual Report ('98), there were 75 highway-rail grade crossing incidents in Florida in 1998, resulting in 7 fatalities. Therefore, it is important to explore the use of innovative technologies for solving railroad grade crossing safety problem.
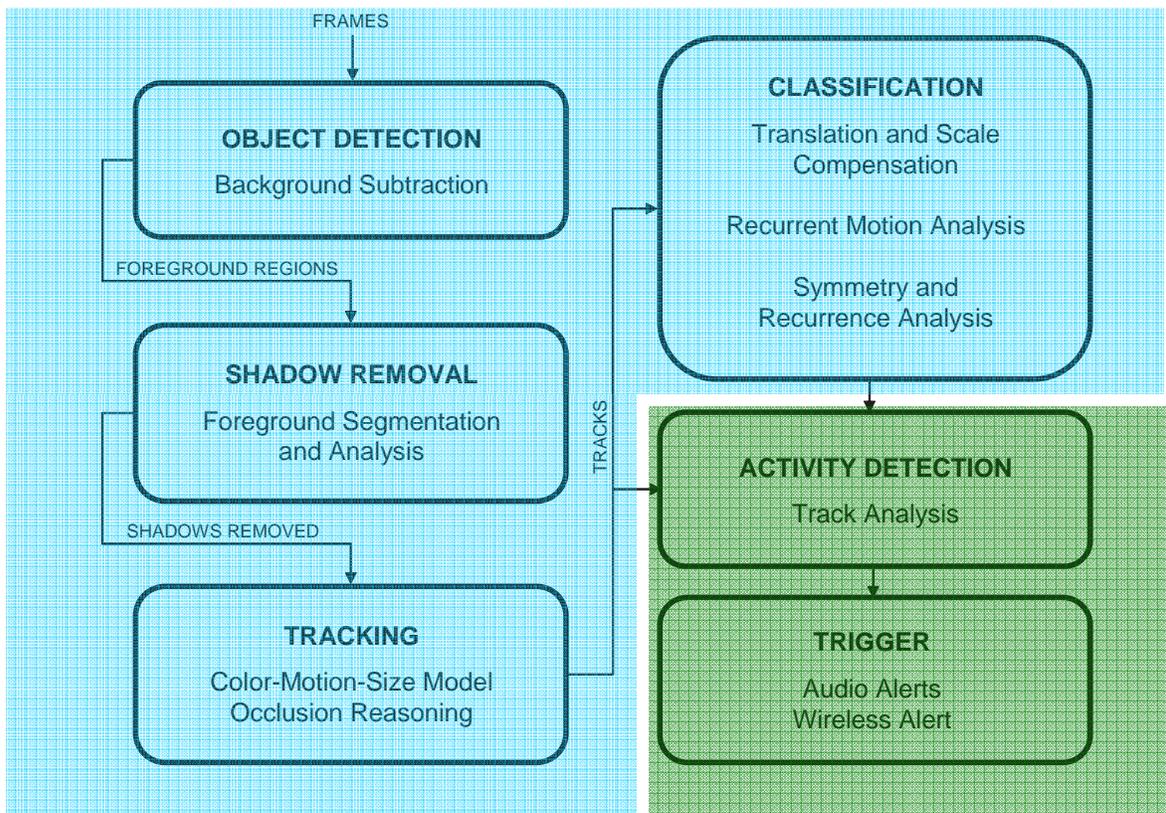
This problem can be addressed by introducing an automated surveillance system that can monitor a railroad grid crossing and react to a dangerous situation. This reaction can include a local audio/visual warning alarm and automated transmission of alert to the concerned officials at a remote location. We have developed a visual surveillance system which is based on computer vision technology and is capable of successfully carrying out the above mentioned tasks. Our algorithms can automatically analyze video sequences obtained from video cameras installed near the rail grade crossing. Based on this analysis, an active warning device can be triggered that can sound a warning alarm for the safety of the individuals. Due to the availability of low cost, low power, and high quality video cameras, increased computing power and memory capacity, and recent success in developing computer vision algorithms the proposed approach provides a cost effective solution to this important problem. For sometime now we, at the UCF computer vision lab, have advocated a motion-based recognition approach. Motion-based recognition consists of the recognition of objects and/or motions using the motion information extracted from a video sequence. Motion-based recognition is relatively easier than object recognition from a single or multiple images; this is because video provides multiple temporal constraints, which make it easier to analyze a complex and coordinated series of events that cannot be understood by just looking at only a single image or a few frames. One important motivation for the motion-based recognition approach is the fact that motion also plays an important role in the human visual system. Humans have the ability to recognize a distant walking person by his/her gait, particular hand gestures, dance steps, birds, all of which are made up of complex sequences of movements. Motion perception helps us recognize different objects and their motion in a scene, infer their relative depth, their rigidity, etc. Our visual system is very sensitive to motion, and human perception tends to focus its attention on moving objects. Motionless objects, in a scene, are not as easily detectable, and several camouflage strategies of the animal kingdom rely on that fact. Our ease of perception and interpretation of motion suggests that our visual system is very well adapted to process temporal information. Our research group has been very active in motion-based recognition area. We have published several papers in international journals, and refereed conferences. Several students have written

their theses in this area, and recently we published a book Motion-Based Recognition, Shah, M., and Jain, R., Kluwer Academic Publishers.

2. Video Surveillance Software

KNIGHT is a fully automated surveillance system developed at the Computer Vision Lab in the University of Central Florida. The system does not require any specialized hardware and can work on commercially available off-the-shelf hardware. It is wireless enabled and can communicate over the Internet using the TCP/IP protocol. It has been widely used for different projects in the surveillance domain, and is adaptive to change in lighting/environment, different times of day, and dynamic background regions.

Different components of KNIGHT software are shown below, where blue section represents basic surveillance software, and the green section marks the module with the domain specific activity analysis.

FRAMES

OBJECT DETECTION

Background Subtraction

FOREGROUND REGIONS

SHADOW REMOVAL

Foreground Segmentation and Analysis

SHADOWS REMOVED

TRACKING

Color-Motion-Size Model
Occlusion Reasoning

TRACKS

CLASSIFICATION

Translation and Scale Compensation

Recurrent Motion Analysis

Symmetry and Recurrence Analysis

ACTIVITY DETECTION

Track Analysis

TRIGGER

Audio Alerts
Wireless Alert

KNIGHT System Modular Diagram

There are four basic modules in the KNIGHT software. These include:

a. Object Detection

The object detection algorithm assumes a stationary camera, and uses background-modeling techniques to search for moving objects in the video. A background model of the scene is incrementally built and is adaptive to the physical and illumination changes in the scene. The model consists of mean and covariance matrix for each pixel in the color space. During motion detection the difference between current frame and the background model is computed. The areas with large difference identify potentially moving objects. The first level is the pixel level processing that marks pixels belonging to objects using color and gradient information. At the second level, the object regions are detected by combining the color and gradient information. The hierarchical method described above provides robustness in detection over changes in illumination, motion of background objects, and noise.

b. Object Tracking

The object-tracking algorithm finds correspondence between objects on a frame-to-frame basis. It models each object using the color and spatial information. The color information is represented by a histogram, while the spatial information is modeled by a Gaussian distribution. Each pixel in the detected region votes for a particular object, and the object that obtains the majority vote is assigned the corresponding object label.
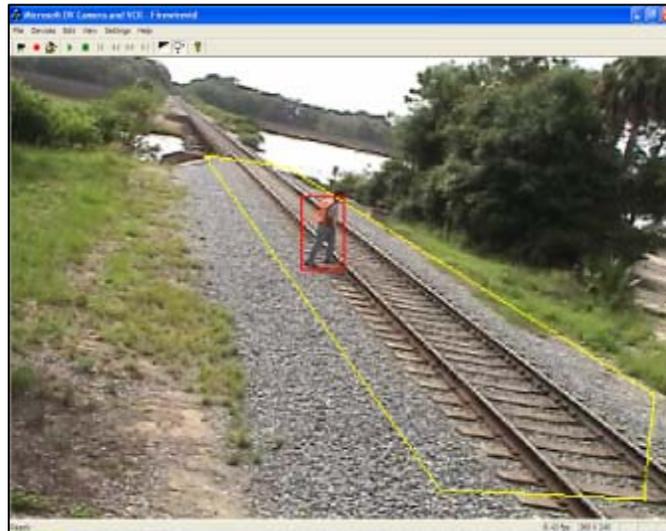
KNIGHT User Interface

c. Object Classification

The object classification algorithm performs symmetry, recurrence, motion, and aspect ratio analysis to classify the detected and tracked objects to human, vehicle, or group categories. Humans are symmetric, slow moving objects that have recurrent motion during walking and have a slim aspect ratio (i.e. taller than being wider). Vehicles are asymmetric, fast moving objects that do not portray recurrent motion and have a broad aspect ratio (i.e. wider than being taller). Groups are asymmetric, slow moving objects in which individual objects portray a recurrent motion during walking.

d. Activity Analysis

The user can mark danger zone using the KNIGHT GUI, which represents the train tracks. If a person walks inside the danger zone and if the train is approaching or had just left the zone, then an audio alert is triggered. Also, an email with an image of the person in a dangerous situation is sent to the system administrator.

3. Portable System

Our target was to eventually develop a portable system that will incorporate the functionality of the video surveillance system and provide hardware which is feasible to use on a remote site. There were various desirable characteristics of the portable system. First, it should be physically portable with reasonable size, weight, and installation time. It should not require heavy machinery to lift it on or off the carrying vehicle. Preferably, it shouldn't require major reassembling for deployment. Second, it should have the capability of being powered through solar power because a remote site is more likely to have no power supply available. Third, it should have the capability of wireless data transmission from a remote site where no phone or data cable is available. Fourth, the system should provide the performance same as that of a fixed system running on regular power supply.

Keeping these requirements in mind we designed the system which includes five main units as shown in the following figure.
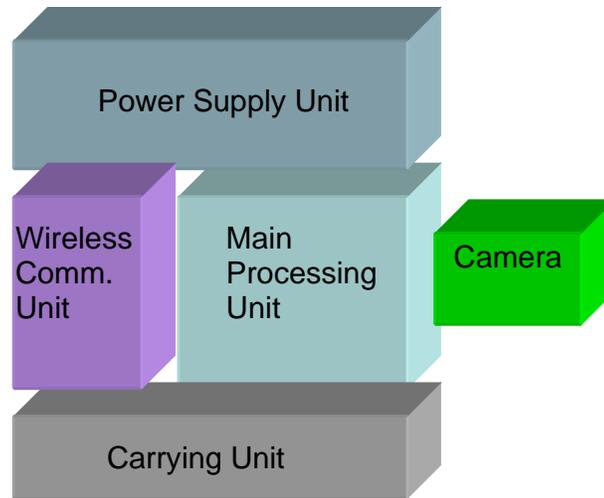
System Block Diagram

A physical snapshot of the portable system is shown in the figure below with the details of the individual units in the following.
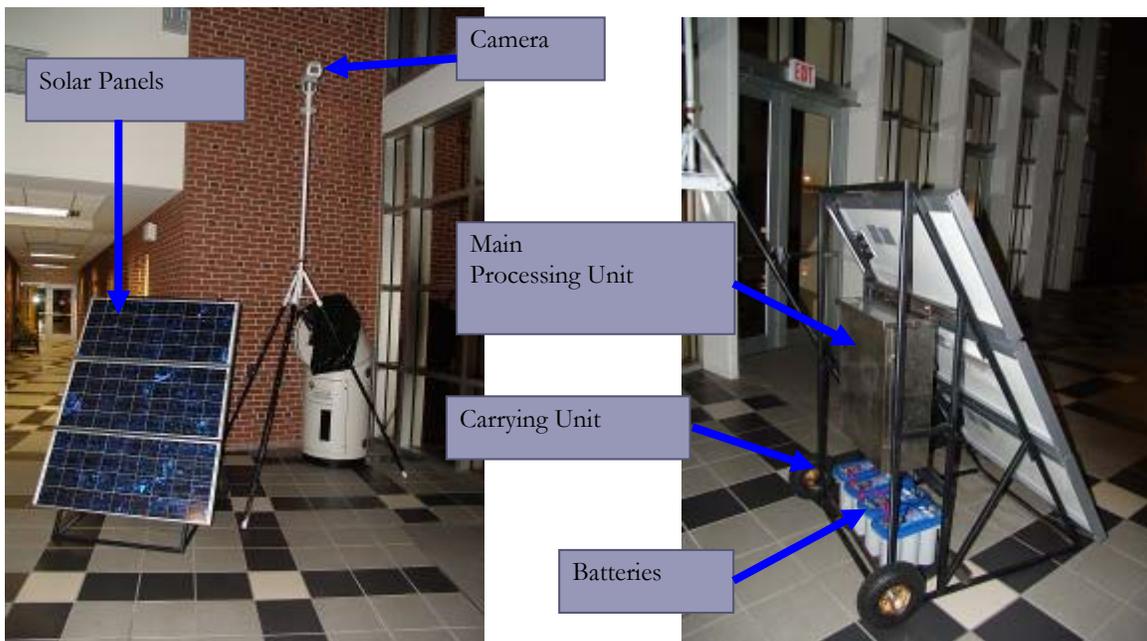
Snapshot of system components

a. Main Processing Unit

Main processing unit contains the computer system which has sufficient processing and storage resources to smoothly execute the software. Main features include

- Intel P4 2.4GHz CPU
- 400 MHz FSB Motherboard

- 1GB memory
- IEEE 1394 interface (Firewire port)
- 20GB Hard drive

This computer system is enclosed in industry grade waterproof casing. This casing has special ventilation fans for cooling during operation in the outdoor environment.

b. Camera Unit

The camera used is IEEE1394 compatible firewire camera which can give up to 30 frames a second. It is mounted in a waterproof camera casing on top of a custom made trip-pod stand that can go about 13 feet high. The software needs a very stable video and the camera should be completely stationary even in presence of strong wind in an outdoor environment. This problem was experienced in the earlier stages of the project, so it was decided to use a custom made tripod stand that can easily be assembled or disassembled by one person.

c. Wireless Communication Unit

Wireless communication unit contains the hardware that makes data communication possible from a remote site back to the central server system. Different options were considered for this problem including the IEEE 802.11 and cellular internet (GPRS, CDPD) based solution. The solution is targeted for a scenario where no data cable is available for more than a mile, therefore, the IEEE 802.11 based solution are not feasible because of limited transmission range. The only viable option was to use the cellular internet access as the solution. This solution is dependent on the availability of the cellular coverage in the area of deployment. This is one of the reasons that communication units from two different service providers were used and tested.

T-Mobile AirCard

Motorola V-180 with
T-Mobile service

Hardware in T-Mobile solution

T-Mobile and Nextel cellular internet service has been used for this task. Initially there were compatibility problems between T-Mobile's Aircard and our system. The problem was solved by using Motorola V-180 cell phone as an external modem for the system. According to our tests it is giving satisfactory performance inside the area of coverage.

Nextel's service comes with a rugged external modem which has additional features than T-Mobile's service. Those include remote location retrieval through the built-in GPS receiver and static IP-address availability, which provides remote access for controlling the system from a base station. One drawback in Nextel's service is that it provides smaller data bandwidth as compared to T-Mobile. However, intelligent video transmission service built into our system helps to overcome this limitation. We have tested wireless data transmission from both remote sites to the central server.
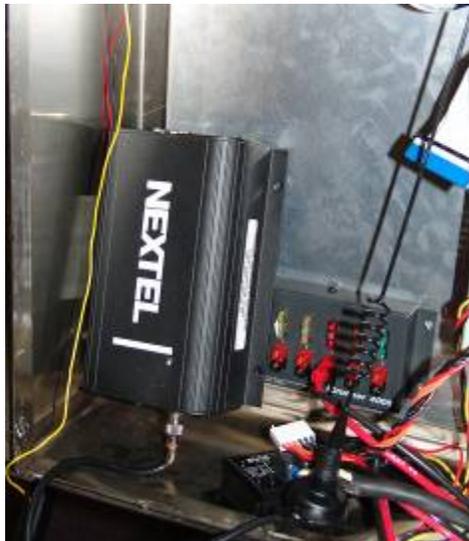
Hardware in Nextel solution

d. Power Supply Unit

Power supply unit includes the solar panels, backup gel-cell batteries and the battery charge controller. System power consumption was first tested during the full operation and was found to be in the range of 75-85Wh. Based on this power consumption rate and allowing some power loss from the solar panels, we found that we needed:

- Solar panel generating 240W power

    o Sharp NE-80EJE Solar Panel (80W power output, quantity: 3)

- Backup battery capacity up to 300Ah

    o Optima Bluetop (gel-cell) batteries (75Ah per battery, quantity: 4)

With this configuration the system can run for about two days without full sunshine.

e. Carrying Unit

The carrying unit is a metal frame that carries all other units on top of it. It has the capacity to carry about 600lbs and currently they current load weighs about 300lbs. The load can be transferred on two tires by just tilting the frame and can be pushed or pulled by one or two persons. There is no need of disassembling or reassembling any of the unit on this carrying unit. Only part that has to be assembled on site is the camera tripod stand and that only takes about 10 minutes by one person.

4. Field Testing

We have used two sites for initial data gathering and final deployment and testing of our system. First site is located on Florida Central Railroad at the West Third Avenue rail-highway grade crossing, Crossing No. 621810-G at Mount Dora, Lake County, FL. Second site is located on Florida East Coast Railway adjacent to Turnbull Bay Road in New Smyrna Beach, Volusia County, FL.

In the earlier stages of the project these two sites were used for recording video data for limited time. This data was processed in the laboratory and the performance of surveillance algorithms was evaluated. This was followed by the installation of power supply and pole on the second site. After that our system was deployed there inside a waterproof casing which was secured with the pole. This provided us with the test-bed to analyze the system performance over longer periods of time. The algorithms were tested and improved over time under a variety of different environmental conditions, field of views etc. Our system has been currently deployed at the second site for 24/7 monitoring and transmits the data through wireless data transmission. The first site at Mount Dora was only used for recording small amount of video data or testing the portable system.

5. Performance Evaluation

The automated surveillance system was installed on two sites, and evaluated for over two weeks of data. The system was tested under various conditions such as different views, time of day, lighting conditions, wind conditions, pedestrian and traffic density. The system was tested under the following criteria:

- Object detection error
- Tracking error
- Classification error
- Violation detection error

a. Object detection error

Error in object detection occurs if the system is unable to detect a person or a vehicle in the camera field of view. The object detection error is calculated by:
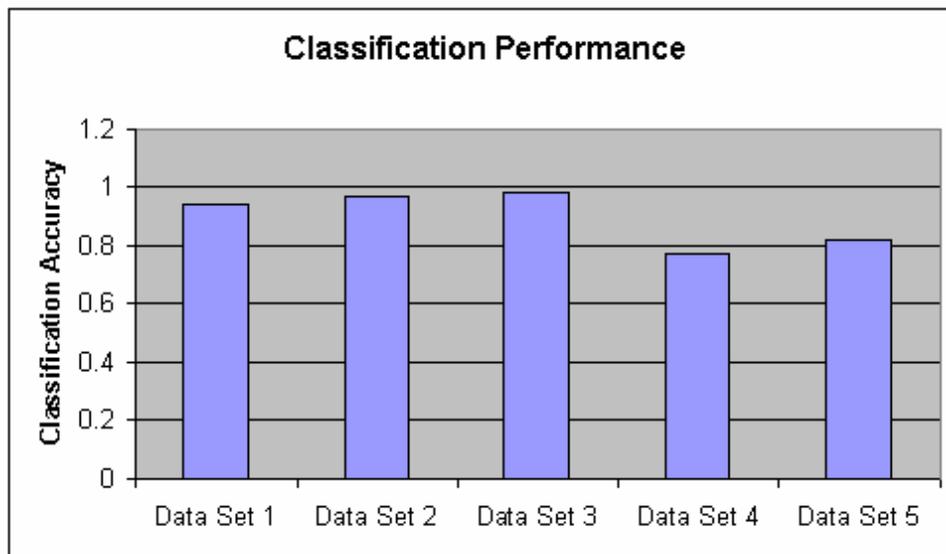
$$\text{Detection Error} = \left(1 - \frac{\text{Number of Correct Detection}}{\text{Total Number of Objects}}\right) \times 100$$

Detection Performance

Detection Performance
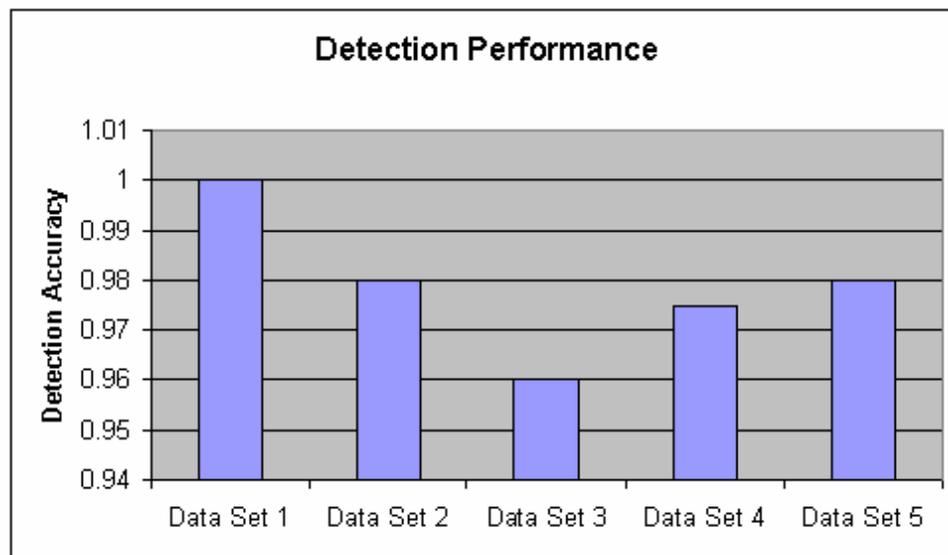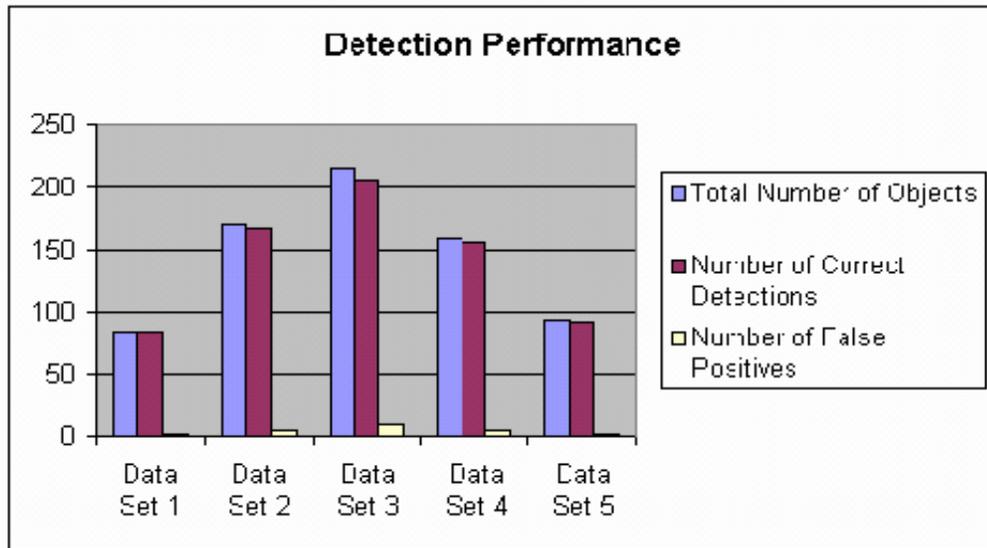
b. Object *tracking error*

Error in object tracking occurs if the system is unable to correctly label a detected person or vehicle in the camera field of view. The object tracking error is calculated by:

$$Tracking\,Error = \left(1 - \frac{Number\,of\,Completely\,Correct\,Tracks}{Total\,Number\,of\,Objects}\right) \times 100$$
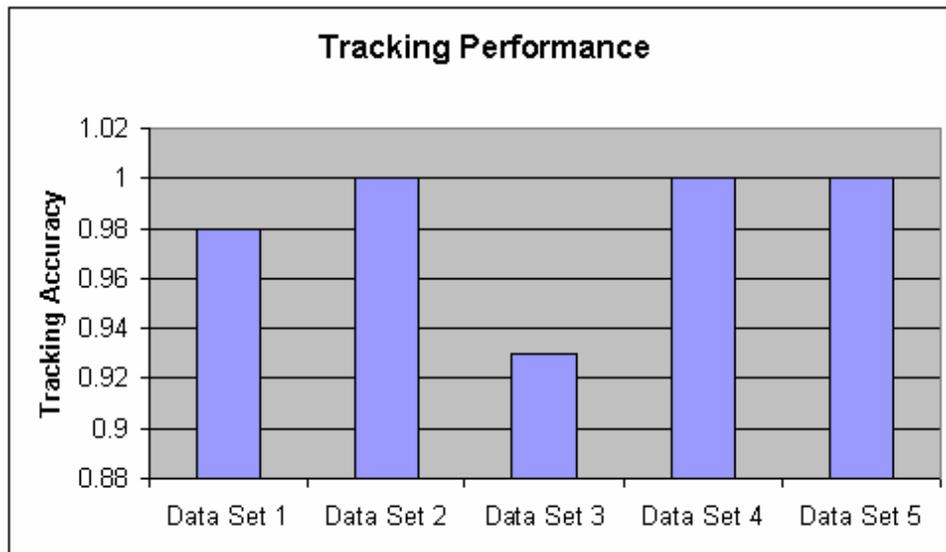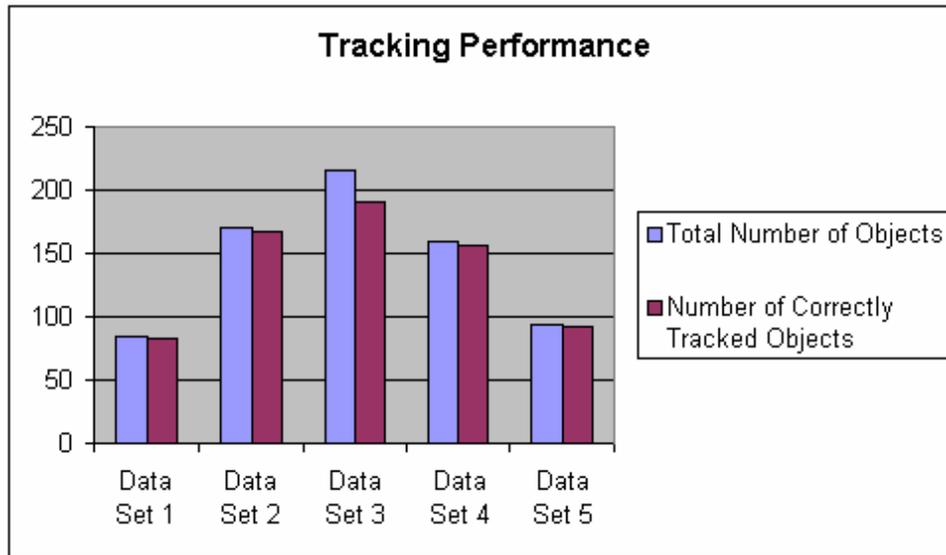
c. *Object* classification *error*

Error in object classification occurs if the system is unable to correctly classify a detected person, vehicle, or group into the correct object category. The object classification error is calculated by:

$$\text{Classification Error} = \left(1 - \frac{\text{Number of Correct } \textit{Classifications}}{\text{Total Number of Objects}}\right) \times 100$$
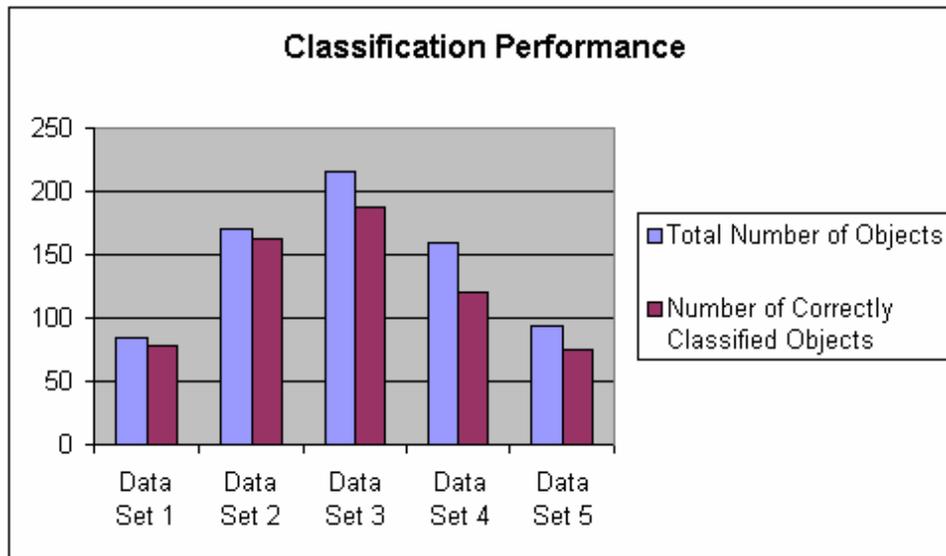
d. Violation *detection error*

Error in violation detection occurs if the system is unable to correctly detect a violation of danger zone. The violation detection error is calculated by:

$$\text{Violation Detection Error} = \left(1 - \frac{\text{Number of Correct Violation Detection}}{\text{Total Number of Objects}}\right) \times 100$$

Detection Performance

Detection Accuracy
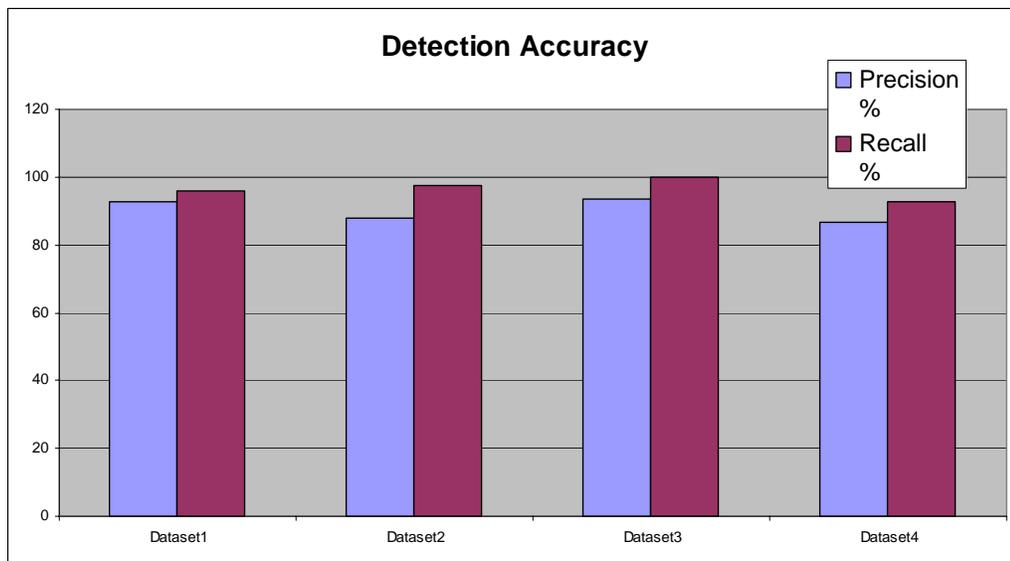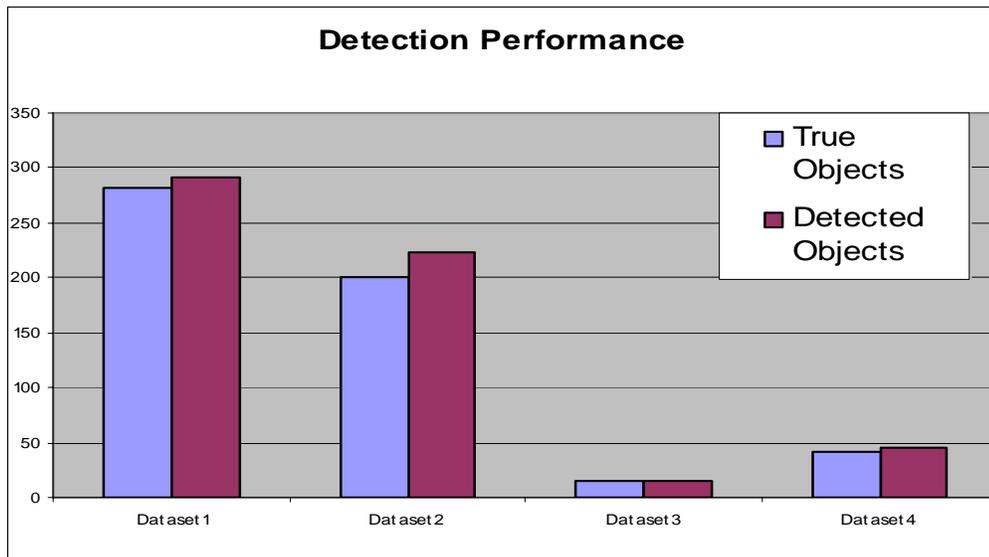
The railroad detection statistics are summarized below:

	Number of Objects	Average Duration in Zone (frames)	Number of Trains	Average Train Duration (frames)	Dangerous Situations
Dataset1	282	23	2	355	2
Dataset2	201	27	1	310	1
Dataset3	15	42	2	308	1
Dataset4	42	41	6	311	3

Samples of the detected violations at the two sites are given below:
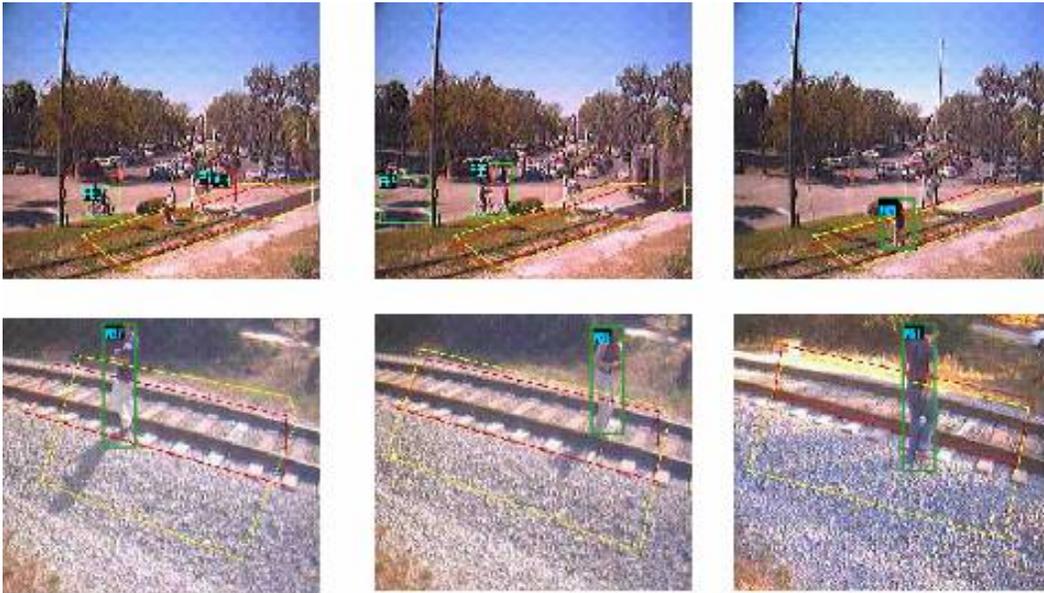
Samples of detected trains at the two sites are given below:

A dangerous situation is encountered when a person crosses the railroad track when a train is about to pass or has just passed. Sample frames of the detected dangerous situation are given below:

6. Project Schedule

This section covers the details of the project schedule followed through the lifetime of this project.

Phase I: Months 1-6,
 Technical: Literature review, initial design, complete motion detection in presence of shadow
 Filed Testing: Collect several hours of video near 2 crossings in Orlando area.
 Demo and report
Phase II: Months 7-12,
 Technical: design modifications, implementation and testing of object detection and tracking. Performance evaluation of basic surveillance software.
 Field testing: First model of the portable system developed.
 Demo and report.
Phase III: Months 13- 18,
 Technical: design modifications, implementation and testing of classification framework using AdaBoost. Implementation and testing of intelligent video transmission
 Field testing: integration of Web-Cast, system setup at New Smyrna Beach site.
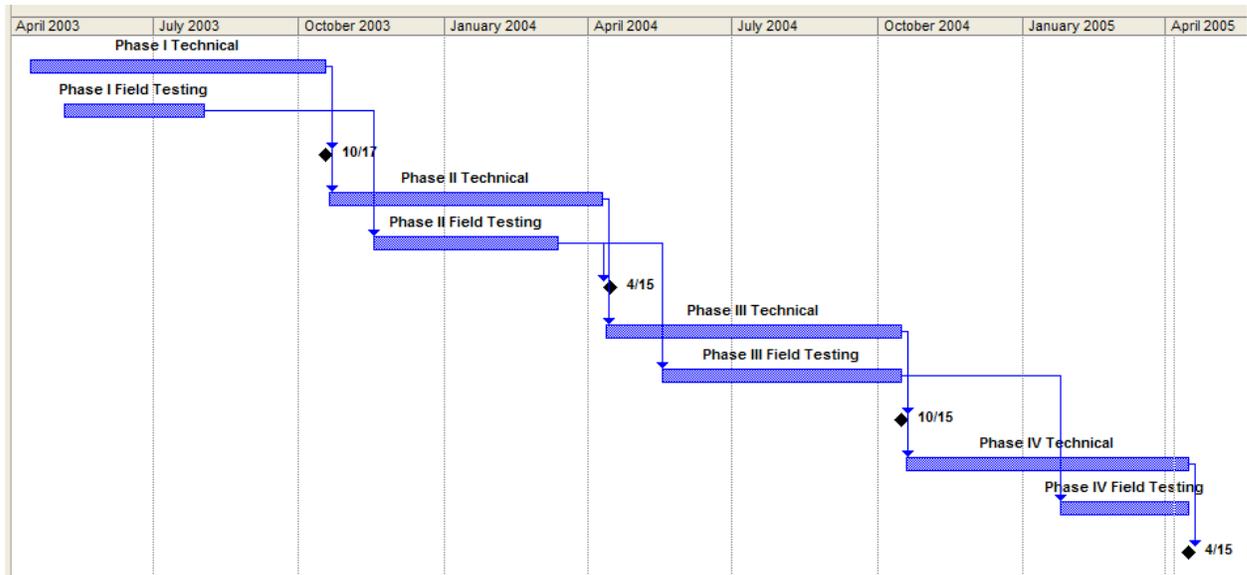 *Demo and report*.
Phase IV: Months 19-24,
 Technical: activity analysis implementation, integration, testing, and evaluation of all modules
 Field testing: Integrate computer system, video camera, wireless modem in final portable system, and testing of solar power unit.
 Final demo and report.

Project Timeline