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Final Report

DEMONSTRATION PROJECT FOR THERMAL IMAGING SAFETY SCREENING SYSTEM

By

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16. Abstract:
This project developed a design for and a prototype of a Thermal Imaging Safety Screening System (TISSS) to be used to select commercial vehicles for safety inspections. The TISSS allows an operator to view the relative temperatures of the brake drums seen through the wheels. The contrast between component temperatures of properly operating brakes and malfunctioning brakes is dramatic. The TISSS uses commercial, off-the-shelf components, which reduce acquisition and maintenance costs and are more widely available. The TISSS was deployed at the Douglas Co. weigh station in two configurations. In the first, the camera assembly was adjacent to the entrance ramp, required a dedicated opertor, and screened all vehicles entering the station. In the second, the assembly was adjacent to the static sales, screened only those vehicles being weighed, and required no additional personnel to operate. In both configurations, a PC-based video capture system allowed viewing, storage, and printing of selected images.

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Executive Summary

The goal of this research project was to design and prototype a low cost infrared imaging system, to be installed at a fixed location, in order to screen commercial vehicles for safety problems. It can be statistically shown that commercial vehicles with a defective brake system component are likely to have other safety related problems. The 8 to 14 micron infrared spectral range is optimal for viewing commercial vehicles components, particularly in daylight conditions. Infrared imaging systems that operate in this spectral region have gained popularity in both industry and Department of Defense surveillance applications, which has resulted in a rapid reduction in cost and improved availability of this equipment. Recent advances in video image capture technology, utilizing standard PC platforms, have reduced the cost of video image capture and have facilitated the storage and/or printing of the images as required.

The Georgia Tech Research Institute has developed a prototype of a thermal imaging safety screening system (TISSS) and has deployed the system in several configurations at the Douglas Co. (I-20 eastbound) weigh station. The primary factors in the deployment configurations are percentage of vehicles screened and operator demands. The system may be deployed at a location on the approach ramp that allows for 100% vehicle screening, however a dedicated operator is currently required for operation and a means of identifying the vehicle is required. The vehicle identification may be accomplished with the use of a visible spectrum camera point aligned with the infrared camera. Further research may yield a machine vision application that could eliminate the need for this operator. The system may also be deployed at the static scales in a manner such that the scale operator can screen the brake system components while weighing the vehicle. This has been shown to add minimal operator workload; however, only a small percentage of total vehicles entering the weigh station are screened. Monitoring and recording the visible spectrum image is not necessary since the vehicle identification is obvious. During the test period, all brake system malfunctions were observed to be on trailer axels. In either deployment, if a malfunction is detected, the operator “clicks” a camera icon on the screen and the image is saved to file, and/or printed.

The TISSS utilizes primarily commercial off-the-shelf components and subsystems, which dramatically reduces the initial and lifecycle costs and yields a highly reliable system with improved maintainability and spare parts availability. An enclosure will allow the camera system to be protected from theft or vandalism when the weigh station is not occupied. The TISSS provides a valuable tool for screening commercial vehicles and can be shown to increase safety system compliance.

Demonstration Project for Thermal Imaging Safety Screening System

1.0 Introduction

This document describes the work completed on the Thermal Imaging Safety Screening System (TISSS) research project. The goal of this research project was to design and prototype a low cost infrared (IR) imaging system, to be installed at a fixed location, in order to screen commercial vehicles for safety problems. It can be statistically shown that commercial vehicles with a defective brake system component are likely to have other safety related problems. The 8 to 14 micron infrared spectral range is optimal for viewing commercial vehicles components, particularly in daylight conditions. Infrared imaging systems that operate in the 8 to 14 micron spectral region have gained popularity in both industry and Department of Defense surveillance applications, which has resulted in a rapid reduction in cost and improved availability of this equipment. Recent advances in video image capture technology, utilizing standard PC platforms, have reduced the cost of video image capture and have facilitated the storage and/or printing of the images as required. This report describes the activities completed on a task-by-task basis.

2.0 Consultant Tasks

2.1. Develop System Requirements

The system requirements necessary to perform thermal safety screening have been developed and are described in this report. This includes technical performance requirements, operator requirements, and system integration requirements. Primary areas of interest were the technical performance of subsystem components and the operator performance requirements (human factors). Of particular interest was the minimum resolution required of both cameras as this affects camera costs, display costs and recording costs. A resolution of 320 by 240 lines has been determined to be adequate and cost effective.

A trained, dedicated operator is required to accomplish the screening function since the operator determines the threshold for out of tolerance wheel/hub temperatures (either too hot or cold). Operator workload is important, as time-sharing between TISSS and other tasks is desired. Operator time-sharing has been demonstrated to potentially eliminate the need for a separate TISSS operator.

The deployment of the TISSS required the merging of IR imaging technology, weigh station physical constraints, and operational methods. This required a system design based on the application of technology and human factors engineering.

Due to the lack of infrastructure (conduit between the weigh station and the camera system) the TISSS was designed to be remotely operated via wireless radio links. In the event that cables could be connected between the weigh station and the camera system, a wired version specification was developed (basically, the wired version is a subset of the wireless version). The System requirements are included in Appendices A and B.

2.2 Develop TISSS Design for Stationary Application

GTRI has designed a stationary TISSS which has utilized commercial off-the-shelf components and has utilized technological advancements in image acquisition, processing and storage. The design has incorporated a systems approach in order to blend the TISSS process with the other processes at the weigh station. Commercial (non-developmental) hardware and software has been incorporated to minimize development costs, to minimize documentation costs, and to facilitate maintenance and spare parts availability. The TISSS design requires an operator for system operation, however, it has been shown that the static scale operator can simultaneously screen for brake problems using the TISSS.

The interface between the remote unit and the base unit is two 75Ω coaxial cables. In this demonstration system, three radio links; two at 2.4 Ghz and one at 900 Mhz replaced the coaxial cables.

2.3 Build Demonstration System

GTRI has acquired all of the necessary components to construct a demonstration TISSS. The demonstration system was deployed at an operational weigh station. The demonstration system has been constructed such that it will have a substantial life expectancy and may be used as the primary TISSS, for that location, at the end of the demonstration program.

A considerable effort was expended in developing a subsystem specification designed around a modification of a remotely operated infrared imaging system built by Catamount Corporation. The subsystem utilizes an industry standard pan and tilt unit with controller. The Catamount subsystem was integrated with a visible spectrum camera, 2.4 Ghz wireless video system, and an Intel based computer which provides the system displays, image recording capability, and image printing capability.

The system design incorporates wireless remote control and data exchange, such that only primary power is required at the remote unit. The wireless link can be replaced with two coaxial cables if deployed at a fixed site with the proper conduit installed. The hardwired version is a subset of the wireless version. The hardwired version would reduce acquisition costs as well as maintenance costs.

Analysis of image capture techniques has lead to the conclusion that two monitors are required, if separate visible spectrum video is necessary for vehicle identification. The image capture is applied only to the infrared camera, however a split screen can be generated to display and capture both images, but at the expense of video resolution.

2.4 Demonstration System Test and Development of Operation Procedures

GTRI tested the infrared screening system for a period of four weeks after deployment. A test plan was developed and presented to GDOT for review prior to system test. Data collected during this period was used to develop/refine the test procedures. A test report is included in section 5 of this report.

3.0 Test Results/Deployment Plan

The system was deployed at the Douglas County weigh station. During the test period, the only failures were related to accidental disconnection of the controller power cord on several occasions. Three different deployment locations were configured in an attempt to optimize the effectiveness and ease of operation. The different deployment locations are shown in Figure 1.

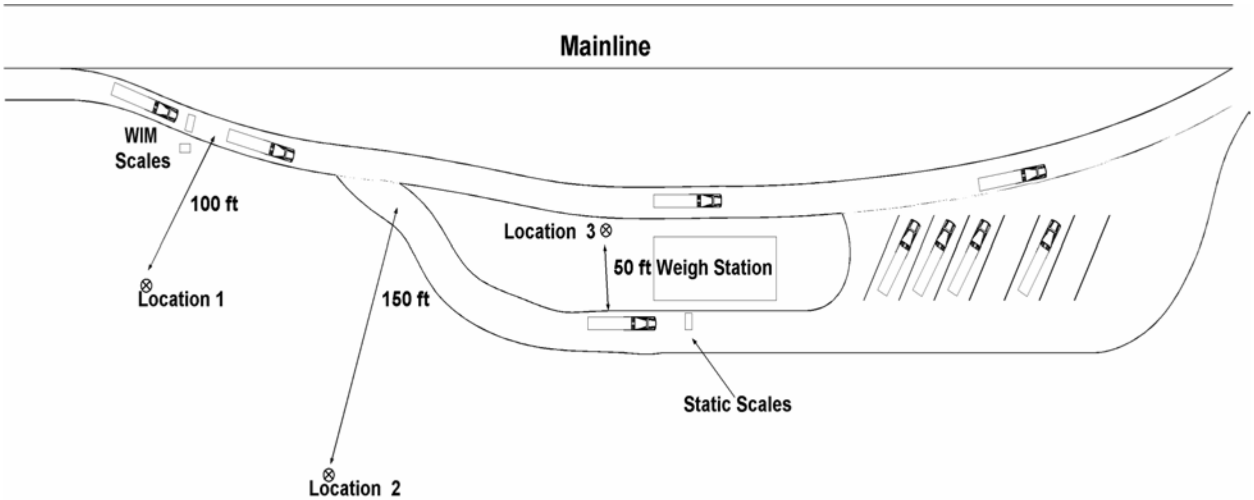

Figure 1. TISSS Deployment at Douglas Co. Weigh Station

The TISSS was initially deployed at location 1 with the cameras located along the entrance ramp to the Douglas County Weigh Station. There were two problems with this deployment. The first problem was signal interference between the data radio and the visible camera subsystem. This problem was not detected when the system was operating at the GTRI facility since the remote unit was not as far from the base unit. Camera control and IR video operated satisfactorily. The second problem with this configuration was the angular rates at which the vehicles were passing. Due to the layout of the Douglas County Weigh Station, it is only possible to place the camera system approximately 100 feet from the ramp at this location. At the typical speeds of vehicles at this location (posted at 30 mph, however most vehicles appeared to exceed this), the angular rate required was less than the 40 deg/sec specification for the azimuth rate, however it was difficult to manually follow the vehicle and observe the brake drum temperatures.

The second deployment at location 2 was at a location adjacent to the ramp "Y" to the static scales. The area is cleared further back and a distance to the ramp was approximately 150 feet. The increased distance combined with the slower vehicle speeds (vehicles must slow down as they approach the static scales) produced much lower angular rates for following a vehicle. Good data was taken from this position.

There were two problems with this deployment. The first problem was the lack of available power at the camera location. A temporary solution was to use a battery powered inverter. This portable device (approximately 40 lbs mounted on wheels with a handle) would operate the cameras, transmitters, receiver, and positioner for several hours. The battery was charged nightly. The second problem was the blockage of large trailers passing between the camera system and the base unit. The frequency band typically used for data radio transmission (and used for this project) requires line of sight between the antennas for operation. Some of the larger vehicles passing between the antennas would cause the positioner to begin moving in an uncontrolled manner. The interference problem between the visible camera and the data radios was reduced significantly due to the closer proximity to the Weigh Station. In both deployments, a dedicated operator is required to manually follow moving vehicles to screen for brake problems. A correctly operating brake system will cause the brake drums to be heated equally as the vehicle is slowing under braking action. The resulting infrared image of a properly operating brake system shows all brake drums to be hot and at approximately the same temperature. Typical images taken from deployment position two are shown in the following photos.

Figure 2 clearly shows a defective brake on the right-forward wheel. The hot brake drum can be seen through the wheel on the left or back wheel. On the right or front wheel, the brake drum appears to be the same temperature as the wheel. Both tires appear to be the same temperature. This trailer was inspected and the brake failure was verified. In Figure 3, the three forward axles (to the right in the picture) were equipped with electric brakes, but no braking action was evident. The hot tire on the other side of the trailer can be seen through the second wheel from the left. The temperatures of all six brake drums were measured and were found to be only slightly above ambient temperature.

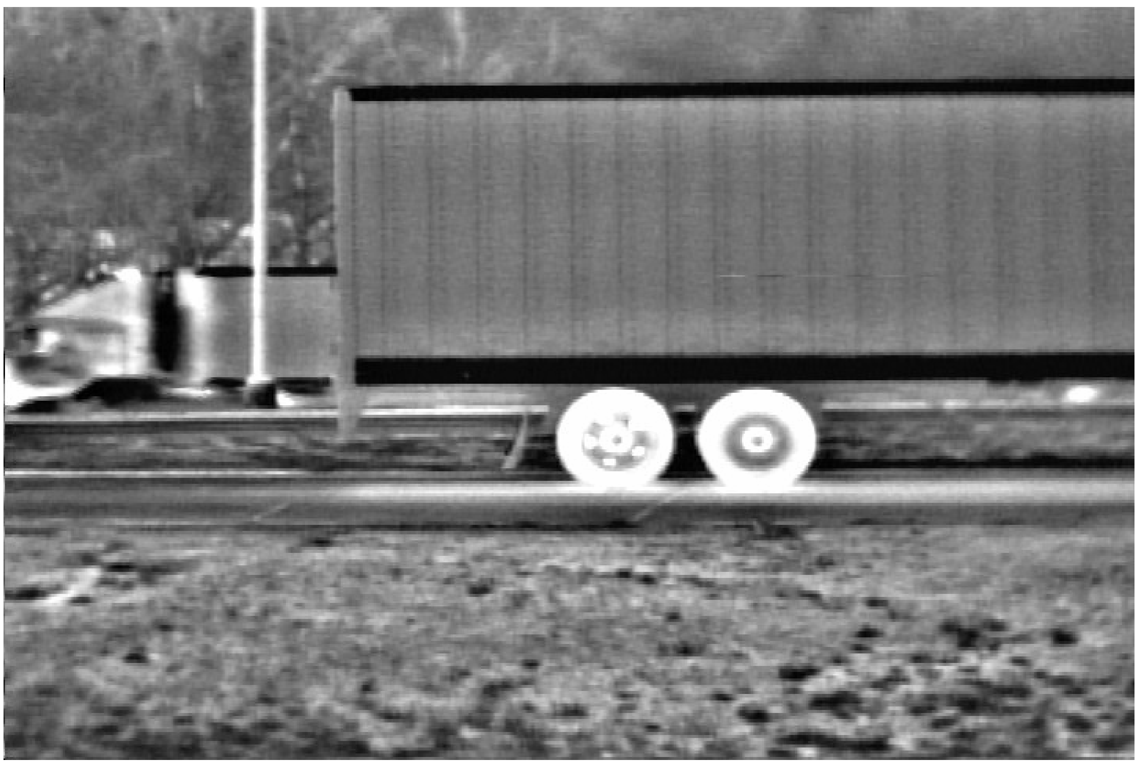

Figure 2. Location 2 - Trailer with defective brake

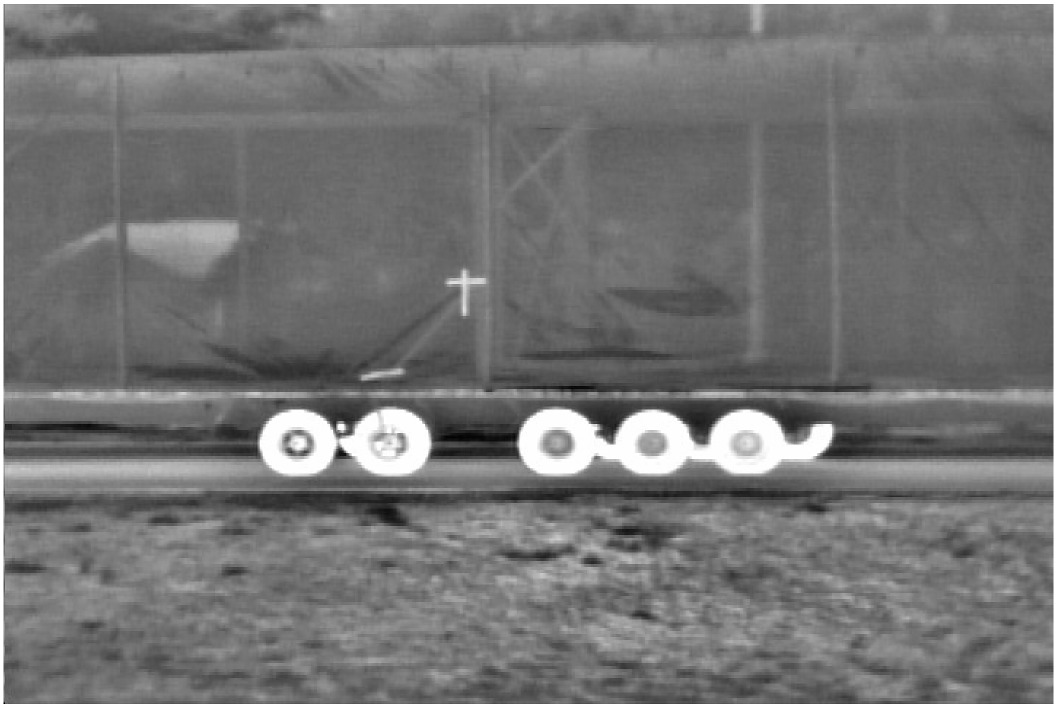

Figure 3. Location 2 - House Trailer with defective brakes

The deployment configuration for locations 1 and 2 is shown in Figure 4.

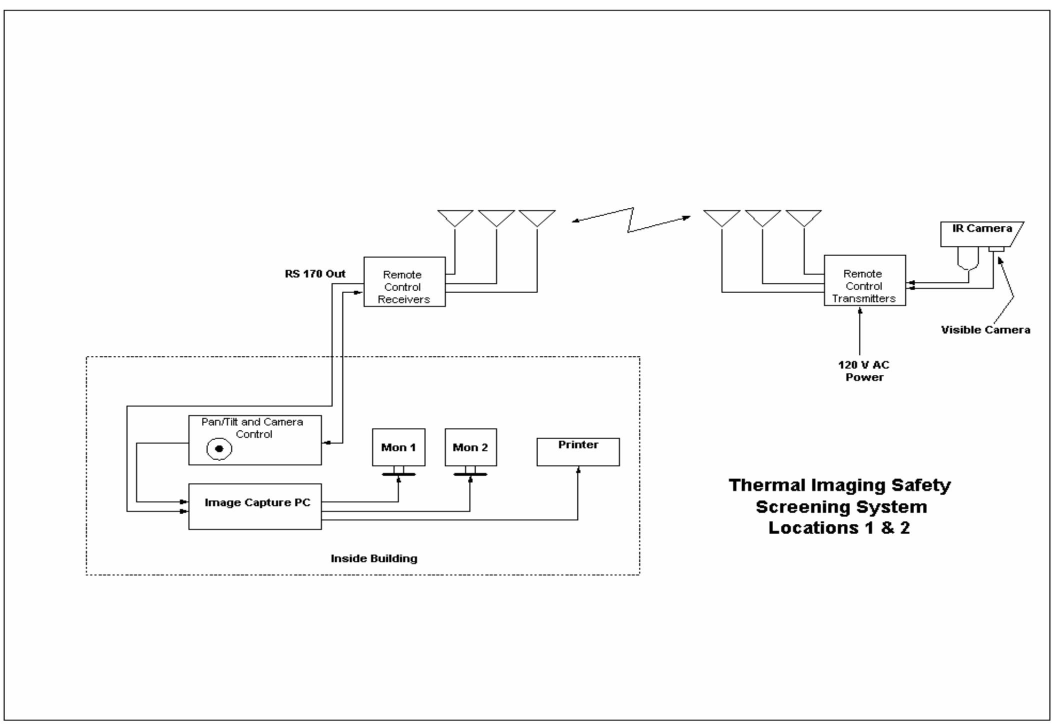

Figure 4. TISSS deployment with wireless link

The third deployment at location 3 was near the weigh station at a location adjacent the point at which the trailer axles are located when the tractor's drive axles are on the static scales. Figure 5 shows the camera system deployed as far back from the static scales as possible. Figure 6 shows a truck approaching the static scales. When the drive axles are on the scales, the camera is directly in-line with the trailer axles. A single coaxial cable is used to transmit infrared video to the image capture computer and to provide positioner and camera control. An extension cord provided the 110V AC.

Figure 5. Location 3 camera deployment – view A

Figure 6. Location 3 camera deployment – view B

The deployment of the equipment in the weigh station was modified to allow the officer operating the static scales to view the infrared display while operating the static scales. Occasionally a minor change in camera position is necessary, however there is time for the scale operator to accomplish this since several seconds are normally required to allow the scales to dampen. Figure 7 shows the infrared image of a trailer axle on the monitor just to the right of the officer. The joystick, the mouse, and the printer are all on the table just to the right of the monitor.

Figure 7. Location 3 – Weigh Station Video Capture System Deployment

In this deployment, only the infrared camera is displayed since vehicle identification is not an issue. The image is shown on a LCD computer monitor. By clicking on a camera icon on the screen below the image, the infrared picture is automatically printed on an HP InkJet printer. The major advantage is that no additional operators are required. The disadvantage is that only those vehicles that are routed to the static scales are screened. At the Douglas County weigh station, that is not really an issue since a deployment on the ramp does not allow enough time for scanning the truck, making a decision, and routing the vehicle to the static scales. The Douglas County weigh Station is not open around the clock. Due to the potential for vandalism when the weigh station is closed and unmanned, the officers returned the camera assembly to the station nightly. This is a cumbersome process at best and hazardous to the equipment at worst. The system configuration for deployment in location 3 is shown in Figure 8.

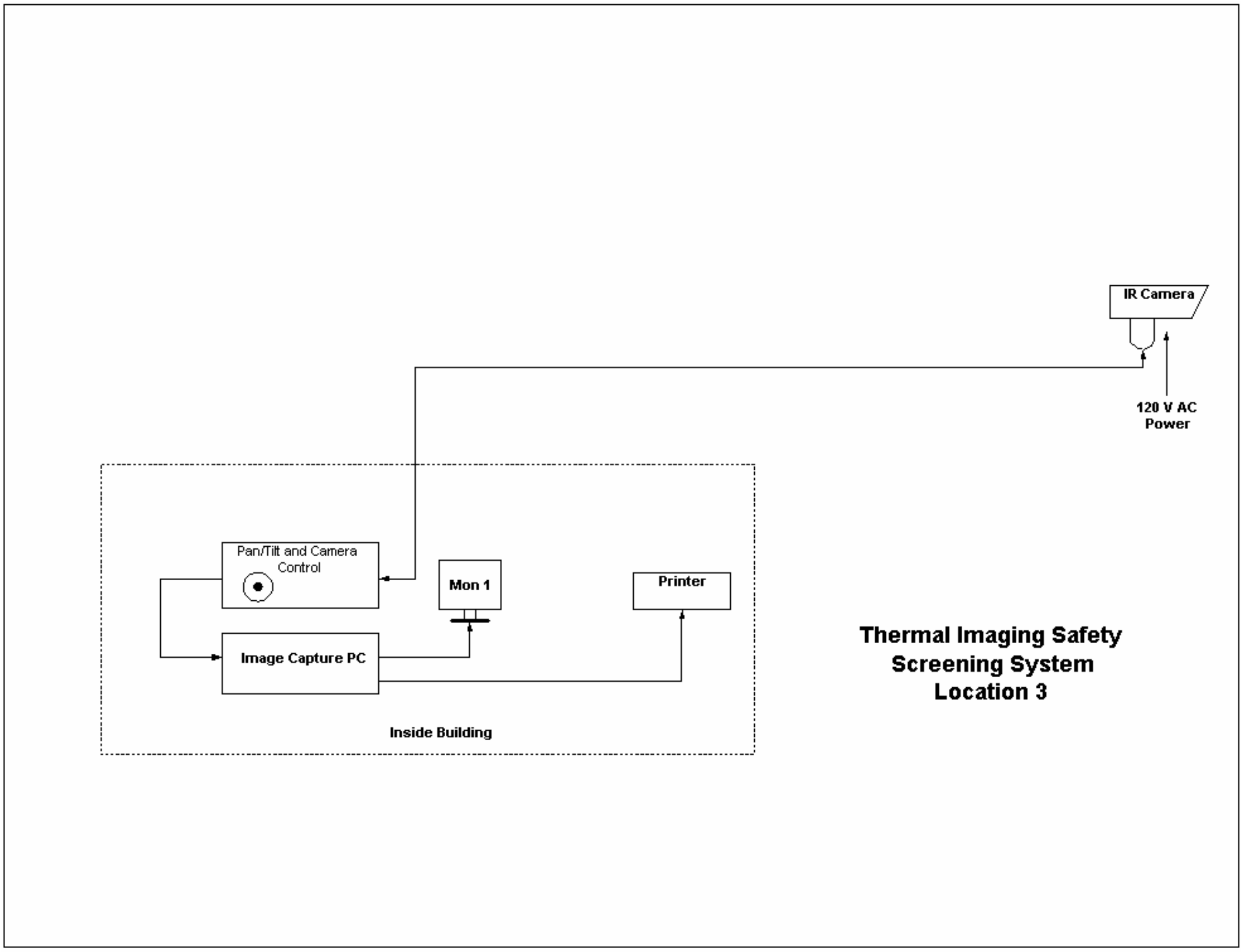

Figure 8. TISSS Deployment with wired link

A typical image at this deployment location is shown in Figure 9. This trailer had both brakes operating properly and the hot brake drums can easily be seen through the wheels.

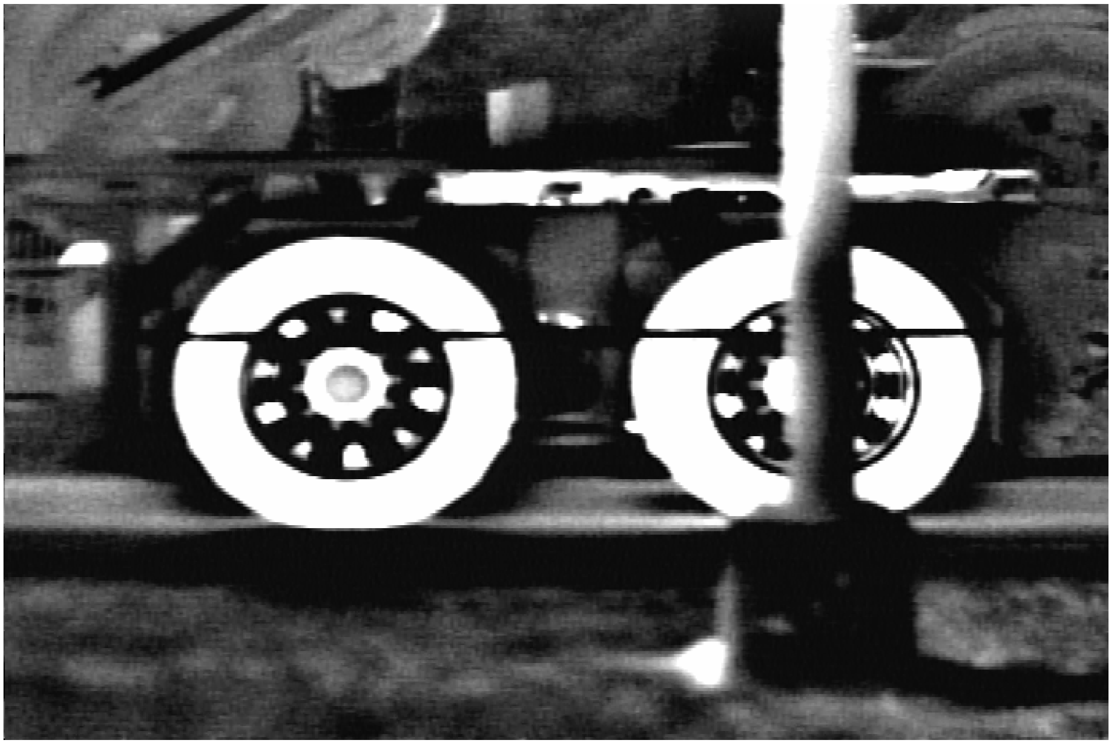

Figure 9. Location 3 – Typical trailer brakes image

4.0 Conclusions and Recommendations

The TISSS is very effective in detecting brake problems. The intent of the system is to screen vehicles to determine which ones should receive a safety inspection. The system performs this role very well and operator training is minimal. As an operator views a large number of vehicles, a normal temperature balance (white level in the image) is easily recognized. The contrast between an operational brake drum and an inoperative one is fairly dramatic. The average operator was able to operate the system satisfactorily within 30 minutes or so. As parenthetical evidence of the system's effectiveness, weigh station personnel noted that once the word got out that brake system screening was being conducted with an infrared system, an increase in the percentage of house trailers with operational brakes was noted. Improved safety compliance is the desired goal. During the test period, all malfunctioning brakes were found to be on trailer axles. Apparently the tractor brakes are serviced and inspected with more regularity and care.

Location 3 at the static scale and weigh house is GTRI's recommended deployment position for this site. This configuration has the infrared camera on the pan and tilt positioner located in a position where the trailer axles can be viewed when the tractor is on the static scales. Due to the variation in weigh station configurations, each different configuration should be evaluated for proper placement of the camera and user interface equipment. Screening trailer axles when a vehicle is at the static scales does not appear to be a problem for the scale operator. The few seconds required to observe the infrared image for each vehicle are available during the required wait times when the scales dampen to provide an accurate weight measurement. This deployment obviously screens a smaller percentage of vehicles, but the elimination of a dedicated operator will change the system utilization from intermittent to constant. Therefore, the total number of vehicles screened in the period of one week may be higher than if deployed with a dedicated operator at the entrance ramp.

A shorter focal length would give a wider field of view. The IR camera currently has a 75mm lens. A 50mm lens is available and would probably be optimal for a close deployment (50 to 75 foot range).

One issue that the author did not anticipate is vandalism. The camera needs to be mounted near the ground in order to be able to look through the wheel holes (and under the truck/trailer to see the brake drums on the opposite side). This deployment obviously puts the camera in harms way with respect to vandals. A lockable cabinet with a hinged cover is suggested. Dimensions for the suggested cabinet are shown in Figure 10.

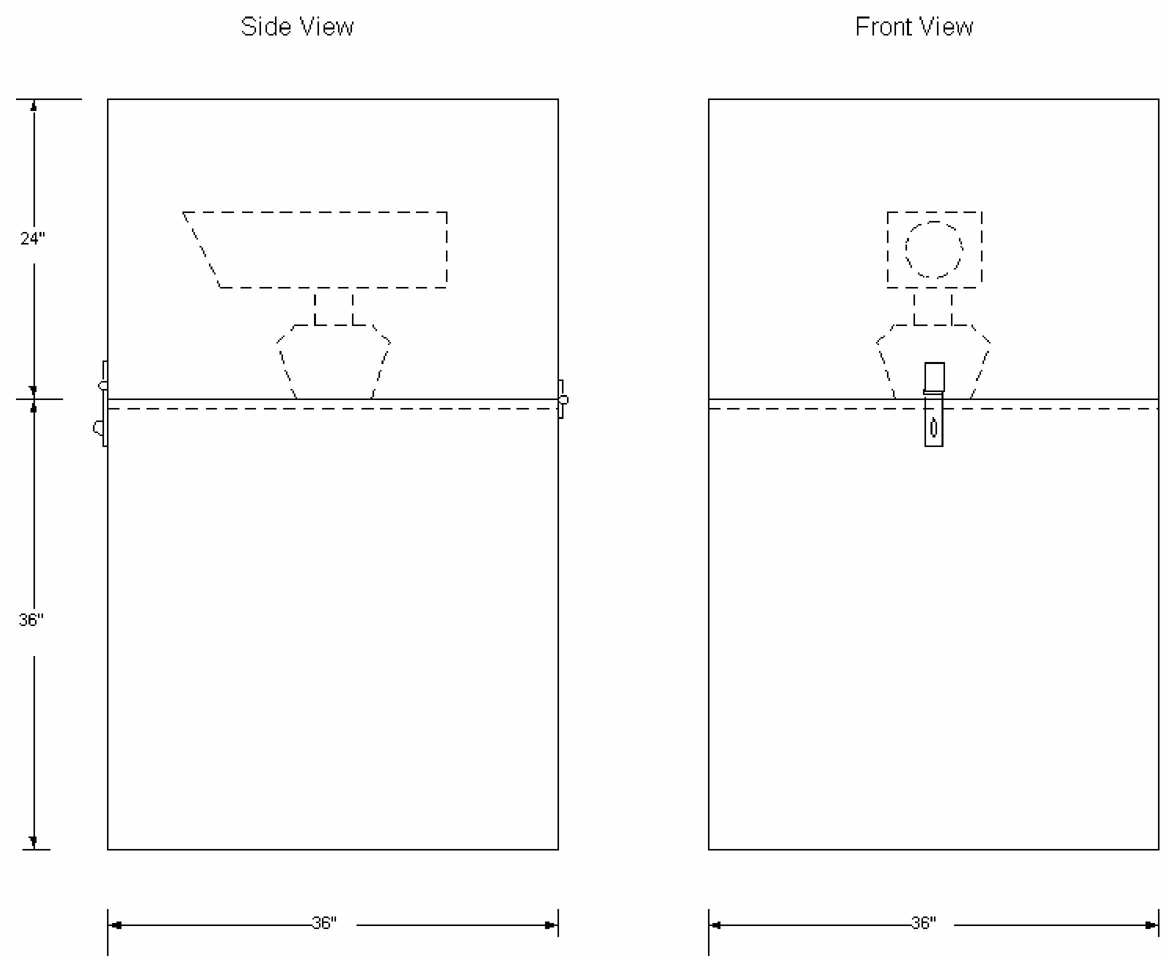

Figure 10. Security Cabinet Dimensions

Two ¾" PVC conduits should be provided for wiring between the security cabinet and the weigh station. One conduit should contain a single RG6 cable terminated with 75 ohm, BNC-male connectors at each end and the other should contain a single twisted-shielded-pair 16 gauge or larger cable such as General Cable Carol Brand no. C2536.

Components to be purchased to assemble a system would be:

Qty 1 Infrared Camera with pan/tilt and controller - CATAMOUNT Model no. P3150
Qty 1 PC Computer Pentium III 1Ghz, 40 Gb hard drive, 128 Meg Ram, 17” LCD monitor
Qty 1 HP Inkjet Printer Model 940
Qty 1 ATI All-in-Wonder AGP video card
Qty 1 24 volt - 100 watt AC power supply

5.0 Implementation

The system design for the hard wired version is ready to deploy. Beyond the cost of the purchased parts, additional cost to deploy would include site specific engineering for equipment placement, acquisition costs, system assembly costs, and system testing costs. As of June 2000, the bottom line cost per location should be approximately $40,000 plus the cost of the installation of the conduits required and the concrete pad for the camera system.

Currently, the system requires an operator to evaluate the image and to make a decision of stopping the subject vehicle for more scrutiny. It is possible to automate this process by utilization of machine vision technology and the integration of the system with the weigh station directional sign control circuitry. The goal would than be to screen each vehicle as it passes on the entrance ramp, identify vehicle to receive more scrutiny, and to automatically route the vehicle to the rear of the weigh station.

Appendix A

Thermal Imaging System Technical Specifications
Wired Deployment

General	
Outdoor components (camera, pan/tilt, transmitter/receiver)	Weatherproof Package – NEMA 4
Storage Temp	-40º to +70º C
Operating Temp	-10º to +50º C
Azimuth Range	± 180 deg.
Azimuth Rate	Variable 0 – 40 deg/sec
Azimuth Control	Proportional – Manual Joy Stick
Elevation Range	- 20, +45
Elevation Rate	Variable 0 – 20 deg/sec
Elevation Control	Proportional – Manual Joy Stick
Communications Link	RF – 2.4 Ghz video and 900 Mhz data
Nominal Range	500 ft
Video Output	RS-170, NTSC (no monitor included)
Infrared Image System-	
Spectral Response	7 – 14 µm
Detector Type	Uncooled ferroelectric
Spatial Resolution	320 x 240
Video Update Rate	30 Hz. – real time
Image	Grayscale
Image Polarity	Switchable black-hot/white-hot
Video Format	RS-170, NTSC
Contrast / Brightness	Automatic
Field of View	18 deg
Focal Length	50 mm

Appendix B

Thermal Imaging System Technical Specifications
Wireless Deployment

General	
Outdoor components (camera, pan/tilt, transmitter/receiver)	Weatherproof Package – NEMA 4
Storage Temp	-40º to +70º C
Operating Temp	-10º to +50º C
Azimuth Range	± 180 deg.
Azimuth Rate	Variable 0 – 40 deg/sec
Azimuth Control	Proportional – Manual Joy Stick
Elevation Range	- 20, +45
Elevation Rate	Variable 0 – 20 deg/sec
Elevation Control	Proportional – Manual Joy Stick
Communications Link	RF – 2.4 Ghz video and 900 Mhz data
Nominal Range	500 ft
Video Data Format	RS-170, NTSC
Print Capability	Inkjet Printer
Operator Interface	Pelco pan/tilt control and dual monitor PC
Power Requirement	120v AC, 1 Amp, 60 Hz
Infrared Image System	
Spectral Response	7 – 14 µm
Detector Type	Uncooled ferroelectric
Spatial Resolution	320 x 240
Video Update Rate	30 Hz. – real time
Image	Grayscale
Image Polarity	Switchable black-hot/white-hot
Video Format	RS-170, NTSC
Contrast / Brightness	Automatic
Field of View	12 deg
Focal Length	75 mm
Visible Image System	
Spectral Response	Visible Spectrum
Spatial Resolution	320 x 240
Video Update Rate	30 Hz. – real time
Image	Color
Video Format	RS-170, NTSC
Contrast / Brightness	Automatic
Field of View	24 deg
Focal Length	30 mm