Development of an

Automated Stop Sign Recognition System (ASRS)

FINAL REPORT

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September 2013

Report Number
CT-2221-F-05-7

Connecticut Department of Transportation
Bureau of Engineering and Construction
Division of Design Services
Architecture, Engineering and Construction (AEC) Applications
Research Unit

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A Project in Cooperation with the U.S. Department of Transportation
Federal Highway Administration

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. CT-2221-F-05-7	**2. Government Accession No.**	**3. Recipients Catalog No.**
4. Title and Subtitle Development of an Automated Stop-Sign Recognition System (ASRS)		**5. Report Date** September 2013
		6. Performing Organization Code SPR-2221
7. Author(s) Richard C. Hanley, P.E		**8. Performing Organization Report No.** SPR-2221
9. Performing Organization Name and Address Connecticut Department of Transportation Division of Design Services Research Unit 2800 Berlin Turnpike Newington, CT 06131-7546		**10. Work Unit No. (TRIS)**
		11. Contract or Grant No. CT Study No. SPR-2221
		13. Type of Report and Period Covered Final Report September 2000 – September 2013
12. Sponsoring Agency Name and Address Connecticut Department of Transportation Division of Design Services Research Unit – Room 4414 2800 Berlin Turnpike Newington, CT 06131-7546		**14. Sponsoring Agency Code** SPR-2221

15. Supplementary Notes

A research project conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration (FHWA).

16. Abstract

The objective of this project was to develop a system to recognize the presence of stop-signs occurring in Connecticut Department of Transportation photolog images of the state highway system.

17. Key Words	**18. Distribution Statement**
Photolog, videolog, image processing, parallel processing, image recognition, sign recognition, stop sign	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA.

19. Security Classif. (Of this report)	**20. Security Classif.(Of this page)**	**21. No. of Pages**	**20. Price**
	Unclassified	26	

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ACKNOWLEDGEMENTS

The author wishes to acknowledge the support of both the Federal Highway Administration and the Connecticut Department of Transportation. The author wishes to acknowledge Mr. Michael Griffith and Mr. James Wentworth of the Federal Highway Administration and Mr. Nicolas Gagarin of Starodub, Inc.

METRIC CONVERSION

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

LIST OF ABBREVIATIONS AND ACRONYMS

ASRS	Automated Stop Sign Recognition System
ConnDOT	Connecticut Department of Transportation
Department	Connecticut Department of Transportation
FHWA	Federal Highway Administration
IT	Information Technology
PC	Personal Computer

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INTRODUCTION

The installation and maintenance of stop signs on the state-maintained highway system and intersecting roadways is the responsibility of the Connecticut Department of Transportation (ConnDOT). As a regulatory sign, stop signs affect the traffic flow of millions of motorists every day. As with all regulatory signs, stop signs also present potential tort liability exposure (defined below) for the State if they are not adequately monitored and maintained. The concept of tort claims as defined by the FHWA Guide to Tort Liability and Risk Management states:

> **Tort.** ***Definition: A wrongful act, not including breach of contract or trust, that results in injury to another person's property or the like and for which the injured party is entitled to compensation.*** When an individual is harmed by another party without criminal intent, he or she may be able file a tort claim. The tort claim must be based on establishing that the party had a duty to perform relative to the injured individual and that this duty was not performed with ordinary care, in a reasonable and prudent manner.

The State of Connecticut, unlike its citizens and business entities, has sovereign immunity from liability. The State of Connecticut’s Office of Claims Commissioner website states the following on this matter:

> Without its consent, the State cannot be held liable in a legal action for any damage or injury it may cause or for the cost of any good, service or benefit it may have received. However, Article Eleven, Sec. 4 of the Connecticut Constitution provides that: "Claims against the state shall be resolved in such manner as may be provided by law." For certain actions, the Connecticut General Assembly has waived the sovereign immunity of the state by statute. Connecticut General Statute § 13a-144 permits persons alleging injuries or losses caused by a defective highway or bridge to file suit against the Commissioner of Transportation in Superior Court.

The ongoing threat of litigation, combined with diminishing personnel resources, were the impetus for a process to automatically detect, identify and classify stop signs in an automated environment.

BACKGROUND AND SIGNIFICANCE

Maintenance of stop signs presented a constant challenge for maintenance personnel within ConnDOT, which had no centralized inventory for tracking installation, maintenance, movement and removal of signs. Installation or maintenance of signs occurred from many disparate and untracked sources, such as construction projects or maintenance activities. The current status of stop signs was monitored via several methods, including:

- Periodic review of installed signage
- Employee field surveys
- Notification from public safety, government or the general public
- Annual photolog vehicle passes over the state-maintained network.

ConnDOT wanted to improve its overall ability to detect missing signs by focusing on new technologies to supplement diminishing staffing resources. Three of these technologies, highway photolog images, pattern recognition and distributed computing, were considered for this task.

- The highway photolog program had been in existence at ConnDOT since the 1970’s, with the primary function to collect both images and data for the state-highway system using vehicles equipped with automated sensing devices. These include, but are not limited to, GPS, cameras, gyroscopes, roughness meters, and other data acquisition equipment. In addition, photolog image distribution via laser videodisc provided a dense yet inexpensive media for image distribution and retrieval.
- Pattern recognition technology had been rapidly developing with the advent of faster computing equipment. Previous research in other

areas had shown promise in the image processing of pavement images for surface distress, and it was believed that signage would provide a much more defined, consistent target for pattern recognition.

- Distributed computing technologies, until recently, had been utilized for high-end technical applications and academic users. Using many networked computers running during non-work hours appeared to be viable source of the massive amount of computing power required to perform CPU-intensive applications.

Because stop signs are part of the highway and installed at critical control points in the highway network, anything less than adequate performance by the sign may undermine highway safety. The state intended to improve its ongoing efforts to monitor the highway condition and correct any issues in a timely manner in an effort to decrease potential liability exposure. Although ultimately unsuccessful in a final product, the project did provide conceptual and real-world insight which may be useful for other individuals, corporations or government agencies interested in similar techniques.

PROBLEM STATEMENT

Stop signs, as regulatory signs, demand constant and immediate attention to condition and maintenance. With tight budgets and staffing levels, it is difficult for ConnDOT to monitor all state-maintained stop signs.

OBJECTIVES

The primary objective was to develop an automated process to detect stop signs installed on the highway system and determine if they were in place and visible. If successful, it would allow an automated process to augment other traditional reporting methods.

METHODOLOGY

The constant surveillance of stop signs to assure they were performing adequately would be an essential element for the safe and efficient operation of the state-maintained highway network. To address that need an Automated Stop Sign Recognition System (ASRS) would determine the visibility and placement of a sign from a library of photolog images. ASRS would then log the “presence” and “absence” of an adequate sign condition into a database for reporting and further investigation.

The project was divided into several phases as listed below:

1. A discussion with both management and users regarding the overall research and implementation strategy for the project’s deliverables was undertaken.
2. The evaluation criteria to assess performance of the final product were defined.
3. A review of prior literature and technology was conducted, including the areas of image processing, distributed computer processing and transportation sign inventory and safety issues.
4. A task was initiated, in cooperation with the Federal Highway Administration (FHWA), to develop a computer imaging model to detect the stop signs in a photolog image.
5. Computer programming personnel would perform project-related programming duties, including:
    a. Establish a baseline inventory of stop signs on a sample of state roads.
    b. Develop a distributed computing topology and software system for processing images and recording findings.

c. Write status and reporting tools to analyze results.

6. The recognition software and support systems would be used to test the prototype, and the results compared with a manual evaluation.
7. The system would be field-tested and modified per user requirements.
8. Implementation of the final version would be rolled out into full production, including the development of standard operating procedures; transitional support by Research personnel until appropriate technical, personnel and financial resources were obtained.
9. A final report on the research would be published.

Figure 1. Typical Photolog Image

PHASE 1 – REVIEW OF USER NEEDS AND DEFINING EVALUATION CRITERIA

From discussions with management, supervisory and line personnel, the following items were identified for project inclusion:

- Image processing simplicity and speed – an efficient and simple process was needed to analyze photolog images for stop signs.
- Process scheduling and data management - how to schedule, process and track results.
- Automation when and wherever possible – due to a personnel shortage, there could be little if any additional manpower required to operate the system for a long-term implementation.

Given the high demand for an automated system, it was decided to address automation as a primary evaluation criterion, based on the accuracy, repeatability and ease of use. It was determined the ability to know the locations of stop signs and confirm their location and condition was the top priority. Also, newly installed signs should be detected and recorded.

PHASE 2 – PERFORMANCE CRITERIA

Due to the limitations of pattern recognition algorithms, however, it was decided that the system, no matter how accurate, would not be able to recognize all stop signs given the number of angles, lighting conditions, and resolution available using the videodiscs. Therefore, the objective would be for the software to eliminate as many photolog images as possible without sign images, leaving a small subset to be reviewed manually by ConnDOT personnel. In this scenario, the existence of a sign was cross-referenced with the ability of the pattern recognition algorithm to detect the existence of a sign (see Table 1). The best cases would be either a True Positive or a False Negative, in which case the algorithm had performed as intended. A False Positive, while not the best result, was acceptable because in the review of images, the image would be seen as having no stop sign and eliminated from consideration. The condition that was to be avoided at all costs was the True Negative, where the image did have a stop sign but it went undetected by the algorithm.

Table 1. Decision Table for Stop Sign Existence vs. Detection

Desired Conditions for Sign Existence vs. Detection		*Success Level in Stop Sign Being Detected by Pattern Recognition Algorithm*	
		POSITIVE	**NEGATIVE**
Stop Sign Exists in Photolog Image?	**TRUE**	PASS	**FAIL**
	FALSE	PASS	PASS

PHASE 3 – LITERATURE AND TECHNOLOGY REVIEW

A literature survey and internet searches were conducted on the following relevant areas:

- Image Storage and Digitization – when the project began, Connecticut DOT was storing image for all state-maintained highways on laser videodiscs in an analog format.
- Image Processing & Shape Recognition – several techniques of image processing, such as wavelet theory and shape recognition were examined for applicability to detecting stop signs from photolog images.
- Distributed computing – on one Pentium 3-based machine, it was estimated that searching for stop signs would require over 300 work days. Therefore, a distributed computing environment, where the same recognition software could be operated on otherwise unused machines during off-hours was proposed. The prototype network was proposed to use ten computers for up to thirty days to process the accumulated digitized highway images.

Once these issues had been addressed, the prototype system would be designed and deployed.

PHASE 4 – PHOTOLOG IMAGE STORAGE AND DIGITIZATION

ConnDOT had long been a leader in the photolog technology to be used as source material for the stop sign images. It was concluded that photolog images of the state-maintained highway network that were stored on laser videodiscs would be the source images for the project. An initial concern with image capture and digitization was the large volume of images to be analyzed. Initially, video capture boards were assessed and it was planned that this technology would be used. However, as the project proceeded, the Data Services Section of ConnDOT who operates the photolog project in ConnDOT, moved to a batch-capture process of analog video, whereby images were ultimately stored in a Compressed JPEG Library (.CJL) file digital format. This eliminated the need to digitize analog images for analysis, since any single image could be extracted for submission to the pattern recognition software. This CJL file format has remained the standard used by ConnDOT up through 2008.

PHASE 5 – STOP SIGN PATTERN RECOGNITION SOFTWARE DEVELOPMENT

A review of image processing and shape recognition technology yielded several commercially-available image processing packages for the Windows NT operating system. However, all of these systems required high-level programming expertise using the C++ programming language to customize and operate. Since this skill set was not available among ConnDOT personnel or consultants, the FHWA Advanced Research Projects Office had a contractor who was versed with image processing techniques. Starodub, Inc. was retained as the author for image processing software to be used for the project.

The Starodub software was developed with ConnDOT personnel acting as technical consultants for the system. The algorithm assessed many elements to perform sign detection, including sign position in the image, color classification, shape classification, and angle of incidence to optical axis. The software was also able to be user-configured for both sensitivity and area of highest sign occurrence.

PHASE 6 – DISTRIBUTED COMPUTER PROCESSING

A concern with the image recognition component of the project was the computing power needed to image-process large amounts of photolog images in a timely manner. If the image-processing algorithms were to analyze every possible photolog image where a stop-sign may occur, then the set of images to be analyzed would be approximately 1.2 million (6000 km State-maintained Highway x 2 directions x 100 images/km). When initial testing showed that one computer was able to analyze approximately three images per minute, it was determine one computer would take over 270 days to analyze all images for stop signs. Since the task of image analysis was parallel in nature, a parallel-processing computer workflow topology was proposed that would link six photolog workstations into one central data processing system. Large-scale processing systems were not available for the project, but the personal computers network located at the ConnDOT Division of Research were available and networked, so distributed computing for these images became a viable option.

With distributed computing methodology proposed for the project, each of six computers on the prototype distributed computing network would process a different image using the same stop-sign analysis algorithm, and store results into a centralized database. The results would be compiled into a comprehensive report on the state of the stop signs recognized system-wide, and be compared against a manual inventory for a given sample of highways.

PHASE 7 – SYSTEMS ANALYSIS AND DEVELOPMENT

Systems analysis and development proceeded on parallel tracks with image-processing software development headed by Starodub and distributed processing software development headed by ConnDOT personnel. The two elements were tested and debugged separately, and then finally combined prior to beta testing the system. A small set of images was then tested under varying software parameter settings to “tune” the image processing and shape recognition routines to best identify stop signs in the sample image set.

PHASE 8 – BETA TESTING & OPERATIONS

A pilot project was designed to sample a representative set of images and collect results for a sampling of highway images. For the pilot project, approximate 5% (~150 km) of the total state-maintained highway mileage was tested. During this process, the sample set of images was manually analyzed for stop sign occurrences, and the results would be compared to the same set of images as analyzed by the stop-sign image processing algorithms. The final comparison of the manual method vs. automated pattern recognition would then be tallied and reported.

Once the software had been installed on the six test workstations, the process began in earnest.

PHASE 9 – RESULTS AND FEEDBACK

Once the image processing of the sample image set was complete, the results were compared to the manually collected data set.   The results are shown in Table 2, “ASRS Summary Report.” In total, 15,437 photolog images were reviewed for stop signs, and a manual count showed that 25 stop signs were present in this sample. The same sample was then reanalyzed using the recognition software, with the results displayed in Table 2. In this table, the True Negative parameter which was defined earlier in the report corresponds to the shaded box.

Table 2. Observed Values for Stop Sign Existence vs. Detection

Desired Conditions for Sign Existence vs. **Detection**		*Recognition Algorithm Result for Stop Sign Detection*	
		DETECTED	**NOT DETECTED**
Did Stop Sign Exist in Subject Photolog Image?	**YES**	24.0% (6 of 25)	**76.0% (19 of 25)**
	NO	2.2% (317 of 15412)	97.8 % (15095 of 15412)

Many practical observations were gained while performing data collection and analysis. It was quickly evident that while the software was robust and capable of detecting stop signs, the myriad of background information presented in any photolog image proved a challenge to the accuracy of the system. The following issues were identified as being contributing factors attributable to excessive “YES/NOT DETECTED” occurrences:

1) Field Conditions – issues relating to sign location and installation in the field, including:
   a) Lighting and coloration – daytime lighting often varies greatly among photolog images, dependent on cloud cover, seasonal sun angle, time of day, vehicle direction, foliage canopy, and windscreen cleanliness. Since the recognition algorithms looked for consistent fields of red coloration, subtle changes or inconsistencies in coloration were thought to affect results.

b) Scene complexity and visual background – based on the scenery that surrounded and backstopped a sign could affect scene detection. In one case, a red house near an intersection fell behind the stop sign in the photolog image, thus causing an incorrect result. Urban scenarios with advertising signs, buildings, and parked cars all proved to be challenging detection environments.

c) Sign installation and maintenance – as with many signs, stop signs are mounted either on one or two U-channel posts driven into the ground. The sign’s orientation toward and visibility to passing traffic depended on many factors such as initial installation instructions and procedures, as well as life-cycle maintenance to maintain proper orientation and alignment to the traffic flow.

d) Physical obstructions – surrounding trees and foliage, parked vehicles and other physical obstructions can all contribute to reduce the visibility of signage to traffic.

e) Roadway Geometry – because of the fixed distance interval at which photolog images are recorded and the fixed field of view for the camera, in certain cases of sharp curves or grade changes prior to the sign may cause the sign to not be fully visible in at least one photolog image.

f) Impostor shapes – some advertising or private parties may employ similar shapes and colors in advertising or visible media that mimics a similar traffic sign. In addition, some traffic signs have similar problems – the “Stop Ahead” sign contains a small, red octagonal image on the sign to indicate an upcoming stop sign.

2) Photolog Images – issues relating to the photolog images used for data acquisition, including:

a) Camera and video image resolution – at the time the project was conducted, the Photolog Unit was distributing photolog images in NTSC (National Television System Committee) video standard of 525 interlaced scan lines per video image using Sony full-frame format video cameras. Although good for their day, the resulting image did not provide adequate resolution for the task.

b) Photolog image color and brightness – Also contributory was the ability of the camera to color- and light-level balance quickly to the changing roadway scene.

c) Image mastering and retrieval – once acquired, images were mastered to NTSC-format laser videodiscs for storage and subsequent retrieval. Since the original imagery was recorded in analog and not digital form, images suffered a generational loss in video quality when mastering to the videodisc.

In addition, there were other factors that indicated there would be problems during system implementation. These included:

1) Complexity of ASRS software for DOT usage – the software delivered by the consultant, while versatile, did require some continuous adjustment in order to optimize the results. Employees within the Division of Research had been trained on this technique, but the optimization values could change from route to route, rendering the software somewhat complex for the average user.

2) Lack of long-term IT support for project – originally, IT coop students had been brought in to monitor and document the development, as well as design the user interface for this software. Their contract, however, was not renewed. In addition, a mass layoff of IT personnel in 2006 removed much needed computer programming experience from the Department.

3) Photolog image quality – although the state-of-the-art in 2000 for digital image quality, the cameras and image resolution were not able to provide the consistency in lighting and level of resolution.

Upon completion of the system, ConnDOT chose not to implement the project due to many factors, including:

1. Excessive percentage of video frames labeled as "YES/NOT DETECTED" occurrences, since all of these would need manual review to verify no stop sign actually existed.
2. Inability to develop a clear and sustainable implementation path for the acquisition and maintenance of the stop sign data within ConnDOT.
3. Highly specialized subject matter that ConnDOT had neither the personnel, technical or financial resources to continue develop.

From the items delineated above, it was determined that there were too many items that had to be rectified in order to make the system a viable candidate for implementation of the product.

PHASE 10 – IMPLEMENTATION

Based on the problems encountered during analysis of the system results, it was determined that too many problems with the system existed for a successful implementation to be undertaken.

NEXT STEPS

ConnDOT has completed its research effort in this project. It is anticipated that the baseline documentation will be released to the public domain. After this, no future work is planned related to this project. However, since the time of this research, there have been many advances in the following areas and to revisit a similar task at this time may yield better results. Noted areas of improvements exist in more robust and easy-to-use image processing software; more powerful distributed processing software; a vastly improved photolog image quality; vast increases in network bandwidth, computer storage and CPU processing capabilities.

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Appendix A. ASRS Summary Report

ASRS SUMMARY REPORT

Route #	*Length*	*Observed YES*	*Observed YES*	*Observed NO*	*Observed NO*	*# of Stopsigns*		*Overall Detection Rate*		*Detection Rate*			
		Detected YES	*Detected NO*	*Detected YES*	*Detected NO*	*Observed*	*Detected*	*Success*	*Failure*	*Stopsigns*	*Absence*	*False*	*Error*
1 A E	316	1	2	4	306	3	5	98.4%	0.6%	33.3%	98.7%	1.3%	66.7%
2 A E	1591	0	0	15	1576	0	15	100.0%	0.0%	0.0%	99.1%	0.9%	0.0%
3 N	2324	0	0	48	2276	0	48	100.0%	0.0%	0.0%	97.9%	2.1%	0.0%
4 E	7524	0	2	124	7394	2	124	99.9%	0.0%	0.0%	98.4%	1.6%	100.0%
17 A N	489	1	1	10	477	2	11	99.8%	0.2%	50.0%	97.9%	2.1%	50.0%
160 W	1191	1	4	55	1131	5	56	99.7%	0.3%	20.0%	95.4%	4.6%	80.0%
160 E	1193	1	4	32	1156	5	33	99.7%	0.3%	20.0%	97.3%	2.7%	80.0%
411 W	323	0	0	22	301	0	22	100.0%	0.0%	0.0%	93.2%	6.8%	0.0%
411 E	322	0	0	5	317	0	5	100.0%	0.0%	0.0%	98.4%	1.6%	0.0%
426 N	35	0	2	1	33	2	1	97.1%	5.7%	0.0%	97.1%	2.9%	100.0%

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Appendix B. ASRS Stop Sign Detection Rate Report

Asrs Summary Report

Route #	Length	Observed Stopsigns	Observed Stopsign/100 Frames	False Positive	Failure	Failure/100 Frames	Stopsign Detection Rate -Failure
1A E	316	3	0.9494	2	0.6329%	0.2003%	66.7%
2A E	1591	0	0.0000	0	0.0000%	0.0000%	0.0%
3 N	2324	0	0.0000	0	0.0000%	0.0000%	0.0%
4 E	7524	2	0.0266	2	0.0266%	0.0004%	100.0%
17A N	489	2	0.4090	1	0.2045%	0.0418%	50.0%
160 W	1191	5	0.4198	4	0.3359%	0.0282%	80.0%
160 E	1193	5	0.4191	4	0.3353%	0.0281%	80.0%
411 W	323	0	0.0000	0	0.0000%	0.0000%	0.0%
411 E	322	0	0.0000	0	0.0000%	0.0000%	0.0%
426 N	35	2	5.7143	2	5.7143%	16.3265%	100.0%
813 E	106	2	1.8868	1	0.9434%	0.8900%	50.0%
838 E	15	2	13.3333	2	13.3333%	88.8889%	100.0%
914 E	14	2	14.2857	1	7.1429%	51.0204%	50.0%
TOTAL	15443	25	0.1619	19	0.12%	0.1856%	76.0000%

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