MONITORING RED LIGHT RUNNING USING
TRIPWIRE VIDEO DETECTION SYSTEMS

By

Andrzej P. Tarko (corresponding author)
Associate Professor
Purdue University
1284 Civil Engineering Building
West Lafayette, IN 47907
Phone: (765) 494-5027
Fax: (765) 496-1105
Email: tarko@ecn.purdue.edu

and

Lakshmikanth R. Naredla
Research Assistant
Purdue University
1284 Civil Engineering Building
West Lafayette, IN 47907
Phone: (765) 494-5027
Fax: (765) 496-1105
Email: naredla@ecn.purdue.edu
ABSTRACT

Red light running is the major cause of crashes at intersections. This project checks the feasibility of using an Autoscope-based low-cost solution to monitor red light running that uses already installed video detection systems for signals actuation. The monitoring results can be utilized by transportation agencies to detect locations with high rate of red light running to improve local safety proactively through redesigning signals or stepping up enforcement. This paper describes a test facility used in our project, presents details of a prototype Autoscope-based red light monitoring system, and evaluates the prototype effectiveness. Out of one hundred and seven violations observed during five days, fifty-five were detected. Thirty-four false detections were also reported. No significant difference in performance was observed between daytime and nighttime periods. Monitoring of through lanes was considerably more effective than of left-turn lanes.
INTRODUCTION

Red light running (RLR) is a serious but preventable public health problem. The number of violations has been on a rise for the past few years. The public perception of the consequences of red light running seems to be deteriorating. According to the Insurance Institute for Highway Safety, red light runners cause about 750 deaths and more than 260,000 injuries every year (1). According to IIHS (1), the increasing violations that are responsible for majority of the intersection crashes are due to reckless driving behavior. Some experts in the field feel that this behavior is closely associated with other aggressive driving behaviors and that these drivers tend to have more driving violations on their records (2).

Photo technology to enforce traffic regulations has been in use for the past 30 years worldwide. Its use was found reducing the number and severity of traffic collisions in Europe, Australia, and South Africa. The people there supported the use of cameras to discourage red light running. In the U.S., cameras are used for photo-enforcement in several states (for example in New York and California). Cameras are connected to traffic signal controllers, and to inductive loops to detect vehicle presence and speeds (3,4). If a vehicle crosses the stop bar during a red signal, the detectors activate the camera. There is also available a system that uses vehicle-tracking capabilities to detected vehicles on video images to eliminate inductive loops.

These systems designed for RLR enforcement are expensive and require special installations. With the proliferation of the video detection installations at signalized intersections, a question arises whether the existing installations can be utilized to monitor red light running. Such systems, not meant for direct RLR enforcement, would be useful in identifying approaches and periods with frequent RLR behavior. Highway agencies responsible for the operation of the traffic signals would gain a low-cost and proactive method of pinpointing intersections with safety related signal deficiencies to remedy these deficiencies before crashes occur. In addition, the intersections with properly timed signals but with high frequency of RLR could be proposed for photo or police enforcement.

This paper explores the possibility of using a tripwire video detection system to detect vehicles that enter an intersection during a red signal. Tripwire systems are quite well known and often used since they have been available for long time, longer than video detection that utilizes vehicle tracking. A tripwire system detects vehicle presence in spots marked on the image. These spots, called virtual detectors, are pre-specified by the user. Autoscope is the most frequently used tripwire system nowadays. A prototype method evaluated in the presented research includes Autoscope 2004 unit and several surveillance cameras installed at one of the intersections in the Lafayette area, Indiana. To evaluate the method, the missed and false detection rates were estimated for five days of the system operation. This paper provides a detailed description of the installation, the developed method, and the evaluation results.

TEST FACILITY

The Traffic Engineering Laboratory and the Video for the Transportation Applications Laboratory at Purdue University provided a well-instrumented environment for developing and evaluating a prototype method of Autoscope-based monitoring of red light running. The joint laboratory equipment used in this project included four components:

1. Instrumented signalized intersection,
2. Intersection-laboratory communication,
The primary units of the joint laboratories used in this project are presented in Figure 1. The real-time video and signal data were being sent from the instrumented intersection via the fiber optic cable to the Traffic Engineering Laboratory and from there via coaxial cables to the Video for Transportation Applications Laboratory. The signals were analyzed in real time with Autoscope 2004 system and the resulted files further processed to detect red light violations. The true violations were then extracted from time-stamped video images. Details of the method are further explained in this section.

**Instrumented Intersection**

The Northwestern-Stadium intersection equipped with surveillance cameras was a vital component of this research. The Northwestern-Stadium intersection is skewed with high vehicular and pedestrian traffic. Traffic volumes strongly vary during vacations and athletic events. Considerable pedestrian traffic poses a challenge to video-based monitoring of red light running.

The major components of the instrumented intersection, as shown on the left-hand side of Figure 1, include five surveillance cameras, Purdue University traffic cabinet, and the INDOT traffic cabinet. Figure 2 shows a map of the intersection. Four fixed-base cameras (one for each approach) and one pan-tilt-zoom (PTZ) camera are currently installed at the intersection (see Figures 3A and 3B).

The video input from these cameras and the signal and detector status from the INDOT traffic cabinet are transmitted via the Purdue University traffic cabinet and the fiber optic cable to the traffic laboratory. The video images and the control signals received in the traffic laboratory are of excellent quality.

**Intersection-Laboratory Communication**

The fiber optic cable is used to carry video input, traffic signal data, and the PTZ control signals between the instrumented intersection and the Purdue University traffic laboratories. Coaxial cables are used to transmit data within the intersection and within the traffic laboratories. The video and signals data are directly fed to the Autoscope using the coaxial cables. The coaxial cables and the Internet are used to transmit the PTZ camera control signals from the supervising computer in the traffic laboratory to the instrumented intersection.

**Autoscope System**

Autoscope is an image processor, a technology that combines video imaging with pattern recognition (5). It contains microprocessor-based CPU, specialized image processing boards, and software to analyze these video images. Figure 4 shows the picture of Autoscope 2004 unit used in this project. The Autoscope processor is fed with the video and traffic signal input coming from the intersection. The information from the various detectors is combined with logical operations.

The Autoscope system is connected to a supervising computer (see Figure 1) which has software required to control the Autoscope operations. It facilitates placing virtual detectors on
video images. The detectors' operation can be watched on the screen and the detectors can be easily reconfigured if needed. The supervising computer is also used to run the post-processing software for extracting red signal violations from the event files generated by the Autoscope unit.

**Video Acquisition System**

The video signal received in the traffic laboratory is split between the Autoscope and the Video Acquisition system (Figure 1). The Video Acquisition system includes the OPTO 22 server, which produces time stamps, and signal status overlay on video images from the four fixed-base cameras. The video images are then sent to the multiplexing unit, where they are combined into one image and arranged in quadrants. The multiplexed image is recorded and stored digitally on the supervising computer with the Real Producer software. The quality of these images has been compromised to save the storage demand. It should be noted that the video signals sent to the Autoscope for real-time processing are of non-compromised quality.

**METHOD CONCEPT**

This research checks whether video detection can be used to detect vehicles that violate a red signal. The vehicle identification task is not included in the research scope. Two components of the prototype method have been developed for the instrumented intersection: set of detectors with Autoscope standard detector functions saved in a detector file, and a Visual Basic code for detecting red signal violations through processing the event files generated by the Autoscope detectors. The developed method is a hybrid solution where vehicles are detected and the data stored in real time but the detection of red signal violations are done off-line. The proposed method can be used by highway agencies for measuring the frequency of red signal violations. The event files can be stored in a temporary storage facility at the intersection and then sent periodically to the central processing and storage location to be processed off-line.

**Detector Configuration**

Developing a suitable and efficient detector layout turned out to be a long and iterative process of improvements and tests. The presented final detectors' layout is supplemented with comments – the lessons learnt during the development. In a typical installation, one camera per approach should suffice. It is important that the field of view includes several meters of intersection downstream of the stop bar. If this requirement cannot be met, an additional camera is needed at the intersection corner to view the entire intersection area. The combination of the cameras has been used in our test. Since each lane is monitored separately, it is convenient to discuss a detector layout for a single lane. A through lane is discussed first followed by an exclusive turning lane.

Since the test included the NB, SB, and EB approaches of the instrumented intersection, four cameras were used: one camera per each approach and an additional PTZ camera for the intersection area enclosed by the stop bars and the crosswalk external edges. To eliminate PTZ camera, the field of view of each approach cameras should include part of the intersection area sufficient to place detectors downstream of the stop bar. Using the fields of view of the cameras, virtual detectors were placed on the images.
As said before, the detector layout for a through lane is explained first. A schematic
drawing in Figure 5 presents the detector components. A stop-bar detector is placed close to the
stop bar with a speed detector stretching upstream of the stop bar. Strong winds can cause false
detections if the count detector is too close to the stop bar.

An additional detector, called a signal detector, is used to input the status of the red
signal. It generates an ON signal as long as a red signal is displayed for the lane. The stop-bar
and the signal detectors are connected together with a logical operation AND. The
corresponding, so called, AND detector, generates ON signal when a vehicle is being detected by
the stop-bar detector and at the same time the signal detector shows a red signal.

The AND detector was used to detect the vehicles that violate a red signal. Unfortunately,
it was found that the configuration of the count and red-signal detectors generate too many false
detection instances. Pedestrians crossing the lane caused frequent false detections. Further, the
shadows of the vehicles in adjacent lanes and sunlight glare on the vehicles were responsible for
additional false detections. To eliminate these false detections, a sequence of directional presence
detectors has been placed downstream of the stop-bar (in the PTZ camera view). These detectors
are called sequential detectors. The call from each sequential detector except the last one was
extended by the time equal to the expected travel time between this and the last detectors. The
sequential detectors with extended calls and the signal detector were connected together with a
logical function AND. This set of detectors generates an ON signal only when a vehicle passes
all the sequential detectors fast enough and during a red signal.

The sequence of detectors may not work well for left turning vehicles because these
vehicles do not follow the same path across the intersection. Hence, some vehicles may not
trigger all the sequential detectors. Some violations would be missed. A different type of
configuration was used for the left turning lanes to eliminate the problem of false detections
caused by pedestrians (Figure 6). Two directional pedestrian detectors were placed on both sides
of the stop-bar detector. A pedestrian were supposed to activate simultaneously one of the two
directional detectors and the stop-bar detector while a vehicle were supposed to activate only the
stop-bar detector. This difference was used in the detection logic to avoid some false detections
of red signal violation. This principle was used for two left-turn lanes on the NB and SB
approaches. The EB left turning movement had the sequential detectors to study the efficiency of
such a configuration for left turns.

Screen captures from the supervising computer (Figure 7) shows the detector
configurations. The upper picture shows an image from the NB fixed-base camera, while the
bottom picture shows an image from the PTZ camera.

Detection Algorithm

Raw output from the Autoscope detectors is collected and stored in the text format. This data is
processed to extract the violations and other relevant information regarding each violation. This
additional information includes:

1. The clock time of violation occurrence,
2. The time of violation occurrence related to the red signal start,
3. The speed and length of the vehicle.

The text files imported to MS-Access are processed with a Visual Basic program. In brief,
the program record by record searches for signal detectors. Once it finds a signal detector, it
reads the starting time of the red signal and its duration. Then, it searches backward for an AND
detector connected to the stop-bar detector in the approach. Then, it moves backward one more record and reads the corresponding vehicle information (speed, length, and time when the vehicle’s front bumper hit the stop-bar detector). This sequence of steps utilizes a certain and fixed sequence of detectors reported in the Autoscope event file. For example, an AND detector connected to the stop-bar detector always follows the stop-bar detector. The algorithm continues the search, this time for a pedestrian or AND detector connected to the sequential detectors in order to confirm the violation. If the violation is confirmed, it is reported in the output file. All the resulted violation information is stored in MS-Excel.

**EVALUATION OF METHOD EFFECTIVENESS**

The quality of any detection system can be characterized by the following measures of effectiveness (6):

1. **Detection rate**, which is the fraction of events that are detected,
2. **False detection rate**, which is the fraction of detections that are false.

These measures are used to evaluate the performance of the developed method. The event to be detected, red light running, has been defined as an act of crossing the stop bar with the vehicle’s front bumper when a red signal is displayed.

Data was collected from April 23rd to April 27th. April 23rd was a rainy day while the other four days were bright and sunny. Approximately eleven hours of data was collected each day, eight hours during the daytime and three during the nighttime.

Red light violations were detected in two ways: by watching the recorded video images with superimposed signal status and time, and by executing the detection algorithm. Watching the video images is considered a quite reliable method that gives ground-truth results. A sample case of red light violation is shown in Figure 8, which also gives a clear picture of how the video file looks. The snapshot of a vehicle crossing the stop bar is shown. Figure 8 shows the overlaid status of the signal phases, the date and the time. The status of all the eight signal phases is denoted by dots. A dot indicates a red signal while ‘G’ or ‘Y’ indicates a green or yellow signal respectively. Thus, the vehicle was caught crossing the NB approach stop bar during the all-red interval at 4:13:10 PM on March 13, 2001.

The violations extracted with the developed method were checked against the violations collected from the video images. The performance of the system was measured separately for the daytime and the nighttime periods (see Table 1). The percentages are also calculated for the different types of movements (see Table 2). Performance of the two different detector configurations for left turn lanes is also discussed (see Table 3).

From Table 1 can be concluded that the performance of the method is satisfactory, although the authors hoped for better results. A little more than half of the events were detected by the system. The false detection rate was thirty eight percent.

It was initially assumed that violation happens if the stop-bar crossing time related to the beginning of a red signal is higher than zero. A high false detection rate prompted for increasing the time threshold from zero to 0.2 seconds. As expected, there was a trade off between the missed and false detection rates. Reduction of the false detection rate was accompanied with a reduction in the detection rate. It was found, however, that the reduction in the detection rate was considerably smaller than the reduction in the false detection rate. The false detection rate dropped from 68% to 35%, while the detection rate reduced from 53% to 48%. Only part of the sample was used in this exercise, thus these numbers do not match the ones reported in Tables 1
and 2. A minimum vehicle length of five feet was used to eliminate some of the false detections, especially during night when the detectors picked up the headlights instead of the vehicles.

The results in Table 1 indicate the method performed similarly during the daytime and nighttime periods.

From Table 2 can be concluded that the through movement are significantly better than the left turning movements. Not only the detection rate for the through movement is high, but also the false detection rate is low. This makes the monitoring method promising for through movements.

Some of the differences in method performance between the through and the left turning movements can be attributed to the use of pedestrian detectors in lieu of the sequential detectors. This effect was checked by comparing the results for the NB left turn (pedestrian detectors) with the EB left turn (sequential detectors). The SB left turn was excluded since it had only five detections. The comparison shows an obvious superiority of sequential detectors over pedestrian detectors (Table 3). Nearly twice higher was the detection rate for the EB left turn than for the NB left turn. At the same time, the false detection rate for the EB left turn was less than half of the rate for the NB left turn.

It must be stressed here that a quite large portion of the events classified as false detection where in fact caused by vehicles that entered the intersection a small fraction of second before yellow turned red. Such behavior, although legal, may be considered aggressive driving. The reported dependency of the missed detection rate on the time threshold indicates that less severe violations have tendency to be more frequently missed than more severe ones. On the other hand, a considerable number of missed detections resulted from failure to detect the vehicle. These occurrences had no relation to the violation “severity.” For these cases, there is no basis to claim that the detected and undetected violations are statistically different.

The heavy computational load of the Autoscope processor can be partly responsible for missed vehicle detections. This problem can be mitigated by reducing the number if lanes monitored and by eliminating redundant detectors.

**SUMMARY AND CONCLUSIONS**

The total detection rate was fifty one percent, while the false detection rate was thirty-eight percent. The rather low fifty-one percent detection rate is due to the poor method performance for the left turns.

No considerable difference in the method performance was seen between the daytime and the nighttime. This is in spite of the fact that during nighttime, the video sensors detected vehicles’ headlights. Although the system works well during nighttime, it misses more violations than it does during the daytime.

The Autoscope can be used effectively to collect the vehicle data, to configure the detector layouts interactively, and to assess the detectors’ operations by directly observing them on the screen.

The total detection rate is sufficiently high for the through movements, but not for the left turning movements. This may be because of the different configurations used for the through and left turning movements. The false detection rate is also comparatively high for the left turning lanes compared to the through lanes. Overall it was noticed that the configuration used for left
turning lanes produced more unstable results, while the configuration used for the through movements works acceptably well.

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REFERENCES


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<td>51.4</td>
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<th>Total</th>
<th>Through</th>
<th>Left Turn</th>
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<td>Detection Rate (%)</td>
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<td>False Detection Rate (%)</td>
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<td>Number of Violations</td>
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<td>Detection Rate (%)</td>
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<tr>
<td>False Detection Rate (%)</td>
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<tr>
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<td>18</td>
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