A License Plate Recognition and Speed Detection System

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Contents

I. Abstract

Since the 1980's law enforcement has deployed traffic enforcement camera systems to monitor roadways for traffic violations. There are a variety of commercially available systems today that can capture images of vehicles running red lights, passing toll booths without paying, speeding, or traveling on restricted lanes. "In many cases the LPR unit is added as retrofit in addition to existing solutions, such as a magnetic card reader or ticket dispenser/reader, in order to add more functionality to the existing facility (Ref 32)". Basic systems capture images of passing vehicles and require human intervention to decipher license plate numbers. A person will have to analyze the picture containing the traffic violation, decipher the license plate number of the violating vehicle, and generate the fine for the violation. More advanced systems use image processing techniques to extract license plate numbers from camera images. This allows traffic fines to be automatically generated and sent to the appropriate violator without the need for human intervention. These types of systems are called license plate recognition (LPR) systems or automatic number plate recognition (ANPR) systems.

The technology for these systems has advanced over the generations. Now whole networks of traffic cameras are being deployed across cities to continually monitor vehicles on city roads. Several cities in the United Kingdom including Northampton, Bradford, Stoke and the City of London have deployed ANPR systems. A push is being made to have all roadways in the United Kingdom be monitored by ANPR cameras. Currently, information from all traffic cameras in the United Kingdom is stored in one central repository called the National ANPR Data Centre. The data stored at this central repository is used in a multitude of ways. Data can be accessed in real time by police providing a way to locate suspected vehicles in real time. Data mining techniques are also applied against the central repository providing an endless flow of

information. Questions such as "What traveling patterns did a certain criminal have 3 years ago" can be answered. In the United States, the push for traffic monitoring cameras has not been as great. Many citizens have criticized the effectiveness, accuracy, and legality of traffic monitoring cameras. Traffic cameras, however, have made their way in to the U.S. mostly at toll booth and ez-pass locations. Also, a new network of traffic monitoring cameras is being implemented in New York City called the "Lower Manhattan Security Initiative". It will contain hundreds of license plate readers (along with thousands of other cameras for human surveillance) to flag any suspect vehicles.

The purpose of this capstone project is to build a functional license plate recognition system capable of retrieving and recording a vehicle's license plate number, the speed it was traveling and the date and time the vehicle was detected. System implementation is to be done at the prototype level in which desired functionality is limited by the amount of resources available. Documentation coinciding with this project will describe the project solution. A description of all system hardware and software components and their specifications will be given. The documentation will also include a description of the limitations of our system, a description of a more optimum solution if more resources were available, the test results of our system, a description of currently available commercial systems, the legality of traffic monitoring cameras, and a description of other types of applications our system could be extended to. Our project application will help make our roads safer. It will provide a tool for law enforcement to monitor speeding vehicle activity and assist in tracking down violators. License plate recognition is now a viable mature technology and is being used in a variety of applications today.

II. Introduction

The purpose of this project was to build a system capable of automatically recording the speed and license plate numbers of passing vehicles traveling down a roadway. The speed and license plate number for each passing vehicle is recorded in a computer file. We researched available technology and currently available systems and components to build our system with. We found commercial systems available for license plate recognition but for the most part did not include the calculation of the speed of the vehicle. We researched how feasible it would be to convert a currently available LPR system to also include the speed of the vehicle. We found that commercial systems were well beyond our budget limits costing over $8,000. We also found most systems to be closed systems. They did not provide the open interfaces needed to configure them for our project's application. Instead of using a commercial system, the LPR component of our system was built from scratch. We also found commercially available radar guns capable of detecting a vehicle's speed and able to connect directly to a computer. Again, we found that these radar guns were well beyond our budget limits costing $1,000 or more. If we had more resources, our project would have been much simpler. We could have simply used a "Stalker Radar Speed Sensor" (www.stalkerradar.com) along with "HI-TECH Solutions SeeRoad" LPR system (www.htsol.com).

Since most commercially available products were out of our reach, we had to build our system mostly from scratch. We used available components to build our own LPR system and used two electronics kits to build the radar gun. We designed a system that could be built significantly cheaper and created several original software algorithms. These algorithms are described in section V.C.3 Application Layer Algorithms. Another benefit of developing our system from scratch was the depth of detail we learned about every component in our system.

These details were necessary to learn in order to customize and configure each component to be optimized for our project's application. A good base foundation in the physics behind lighting and optics, image processing, object recognition, radar technology, computer programming, camera terminology, and electronics was required to perform the tasks at hand. The disadvantage of not using commercially available systems is the low quality of the components we used in our system. There are inherent limitations in our system that prevents it from being a practical solution.

There was much work done to implement our project's system. A list of tasks that were performed is given below:

1. Define our project application requirements.
2. Learn techniques used in license plate recognition systems from other papers.
3. Research currently available commercial systems.
4. Determine the components needed for a limited system. Find and purchase components.
5. Build a radar gun from scratch.
6. Build and program a circuit board used to connect the radar gun to the computer.
7. Research image processing techniques.
8. Find available free software libraries to perform the necessary image processing, object character recognition, video camera communication, and serial port communication. Learn how to use those libraries.
9. Create customized software code to call those libraries and perform the necessary functions required by the application.
10. Perform tests to measure the quality of the system.

This document coincides with the system we have built for our capstone project. It first describes license plate recognition (LPR) and radar technologies in general. It then outlines the system we designed and implemented for our application along with its limitations and the test cases we ran against the system. This document then goes on to describe how our application could be extended for other types of applications. It also discusses available commercial systems that detect traffic violations and their legality.

III. License Plate Recognition Concepts

License plate recognition (LPR) is becoming an established technology. Its development over the past two decades has given rise to highly accurate systems. Whole systems can now be purchased for specific applications ranging from private parking access to traffic light violation detection. Different applications require different systems. An LPR system can be located on the side of or above a roadway, at a toll booth, or at another type of entrance way. All LPR systems follow a basic high level process. The process starts when a sensor detects the presence of a vehicle and signals the system camera to record an image of the passing vehicle. The image is passed on to a computer where software running on the computer extracts the license plate number from the image. License plate numbers can then be recorded in a database with other information such as time vehicle past and speed of vehicle. License plate numbers can also be further processed and be used to control other systems such as raising a gate. License plate recognition (LPR) systems are generally composed of four main components; a light source to illuminate the license plate, a video camera to capture images of passing vehicles, a computer with image processing software, and a trigger that signals when a vehicle is passing.

Light Source

Video Camera

Laser Trigger

Computer
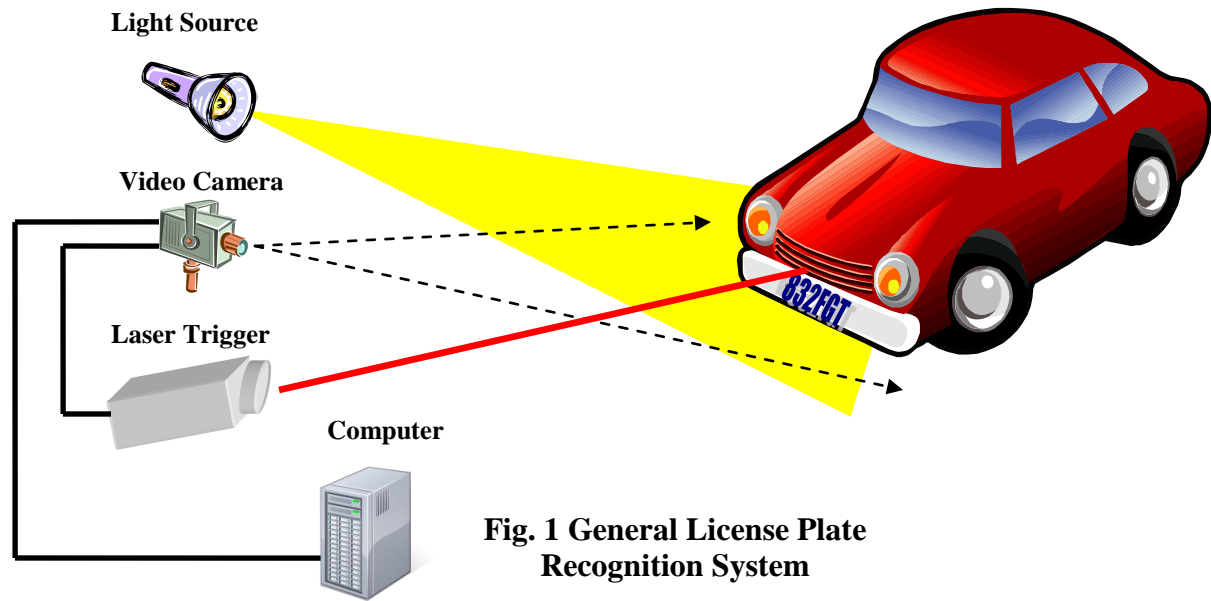
**Fig. 1 General License Plate
Recognition System**

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III.A. LPR Light Source

There are several commercially available light sources on the market today that provide the characteristics required by license plate recognition systems. A good example is the Extreme UF500 infrared illuminator (specs are given in Appendix B). Some commercially available products include both the light source and video camera in one single unit. A good example is EagleVision's Reg-L1 License Plate capture camera (specs are given in Appendix B). Light source characteristics that are desirable for license plate recognition (LPR) are described in the following paragraphs.

The light source should be physically located near the video camera. License plates are coated with reflective paint. When a light source shines on an object coated with reflective paint, the light rays are reflected back to the light source origin. This effect causes the license plate to be significantly illuminated compared to other objects in the picture. An example of this effect is shown in the figures below.

Fig. 2 Camera located near light source   **Fig. 3 Camera located away from light source**
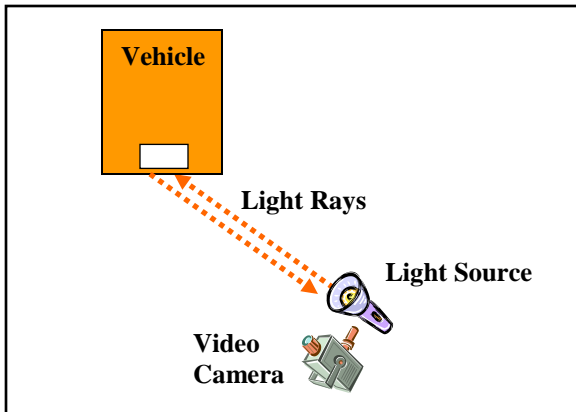
Fig. 4 Camera located near light source   **Fig. 5 Camera located away from light source**
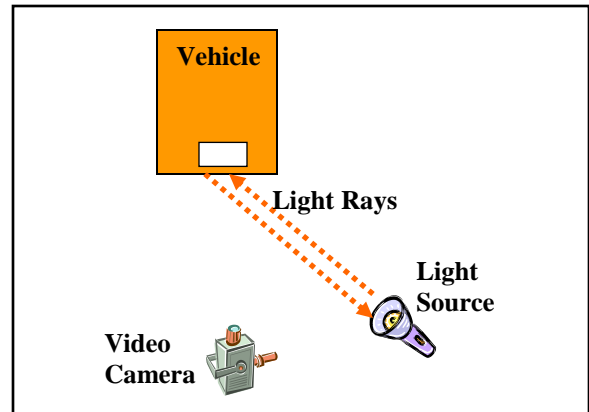
The picture in figure 2 was taken with a light source and camera located near each other. The

light rays striking the license plate in figure 2 are depicted in figure 4. In figure 2, light rays

striking the license plate are mostly reflected back to the light source where the camera is also

located. This is what causes the license plate to be more illuminated than the rest of the objects in

the picture. The picture in figure 3 was taken with a light source and camera that were separated

by an angle of 45 degrees. Light rays striking the license plate in figure 3 are depicted in figure

5. Again, most light rays reflecting off of the vehicle license plate are reflected back to the light

source. However, in this case, since the video camera is no longer near the light source, the

license plate no longer appears more illuminated than the rest of the objects in the image. The

10

reflective paint effect greatly increases the luminescence of the license plate compared to other

objects in the picture when the angle between light source and camera aperture is reduced. A

highly luminescent license plate makes license plate detection based on contrast thresholds much

more accurate. (Contrast thresholding will be discussed later). The reflective paint effect is so

pronounced that it can cancel out the negative effects caused by unclean license plates.

Another desirable LPR characteristic is to project near infrared light (between 720nm-

1100nm). Near infrared light will not blind the vehicle driver because its wavelength is outside

the visible range. Also, light from other sources will not interfere with the light from the LPR

light source. As depicted in the diagram below, a filter placed in front of the video camera will

block all visible light and allow only near infrared light to pass through.
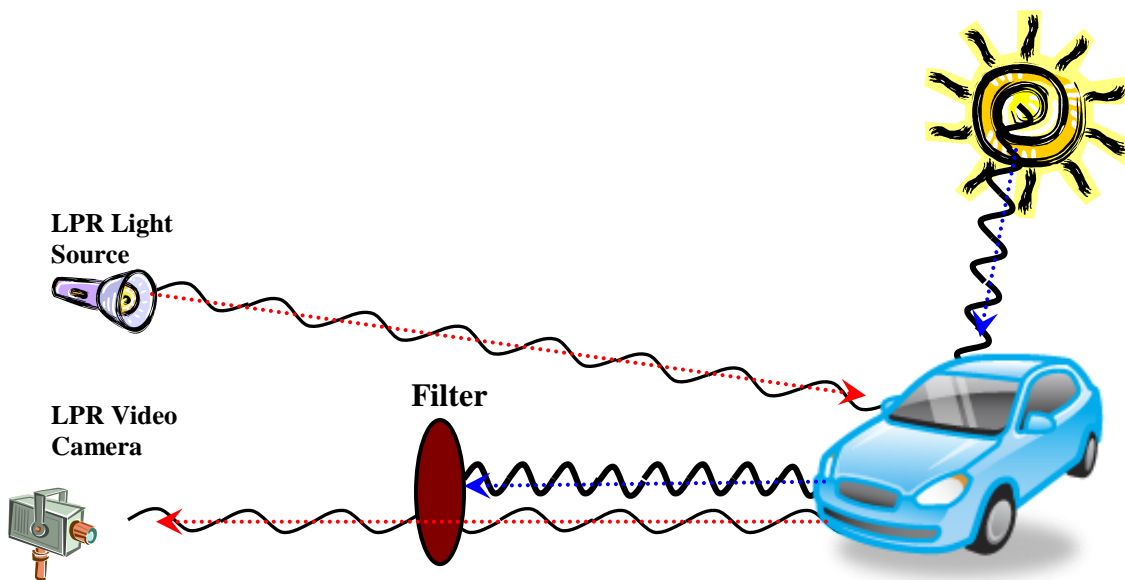
Fig. 6 Visible light is blocked from the camera

Visible light is blocked because sources of visible light such as the sun, do not project

light in a uniform, constant manner. Character recognition software is less accurate when images

received from the camera contain lighting that is non-constant or non-uniform. Trees could block

light from the sun causing regions of the image to appear darker. Sun light intensity changes

according to the time of day or weather. Therefore, only the uniform, constant light provided by an LPR light source should be allowed to enter the camera

Another desired LPR light source characteristic is to output light with high intensity. This is due to several factors. For one, the license plate will be distant from the camera. More distant objects reflect less light back to the camera. Two, the camera will use a fast exposure setting in order to reduce image blur caused by the motion of the high speed vehicle. Three, the telephoto lens used by the camera to magnify the image as well as the filter placed in front of the camera will limit the amount of light received. And four, most CCD chips are not as sensitive to light in the near infrared range requiring more light be received for the same image contrast. All of these factors will cause the license plate image to appear dark and lessen its level of detail. However, an LPR light source with very high intensity can offset these negative effects. The more light that is emitted by a light source, the more light will be received by the camera. With more light, the camera image will contain more detail, making image processing routines more accurate.

Another desirable LPR characteristic is to project a beam of light that illuminates the entire width of the street lane. This will ensure that as long as a vehicle stays within its lane, its license plate will be illuminated when it passes.

A summary of desirable LPR light source characteristics is given in the table below. When a light source contains these characteristics, the intended license plate will be properly illuminated.

Table 1 LPR Light Source Characteristics

Characteristic	Desired Value
Physical Location	As close as possible to camera aperture.
Wavelength of light	Near infrared

Uniform and Constant Intensity	To be as uniform and constant as possible.
Power of intensity	To provide enough lighting so that image detail meets image processing requirements.
Projection Beam Angle	To cover entire width of street lane.

III.B. LPR Camera

The second component of a license plate recognition system is the video camera. The video camera captures images of passing vehicles and transfers those images to the computer. An industrial or computer vision grade video camera provides the characteristics required by LPR systems. A good example is the LXR CX800 (specifications are given in Appendix B). A video camera for license plate recognition has three components; a long pass filter, a telephoto lens, and a CCD chip. A description of these components and their characteristics is provided in the following paragraphs.
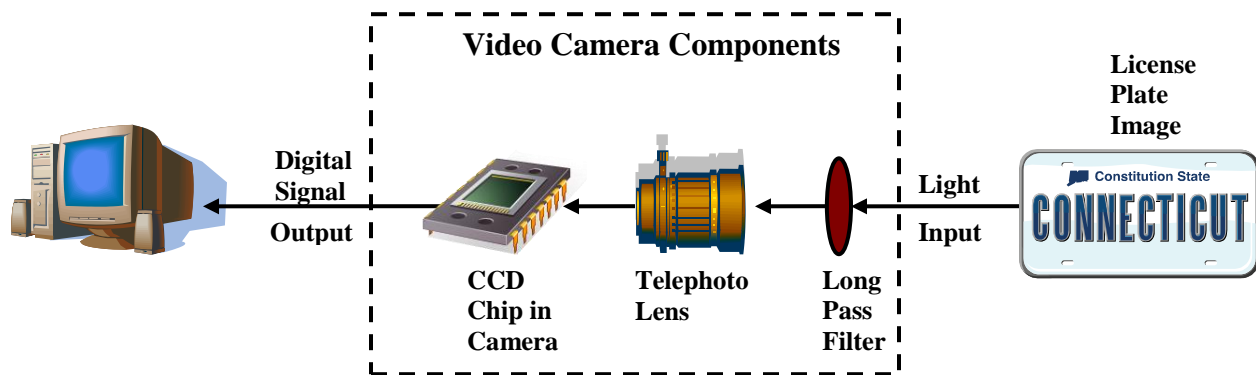
Fig. 7 Video Camera System

As depicted in figure above, light first passes through a long pass. This filter blocks light in the short wavelength region (less than 720nm) and allows light with longer wavelengths (the infrared region) to pass through. A graph of this effect is given below.

13
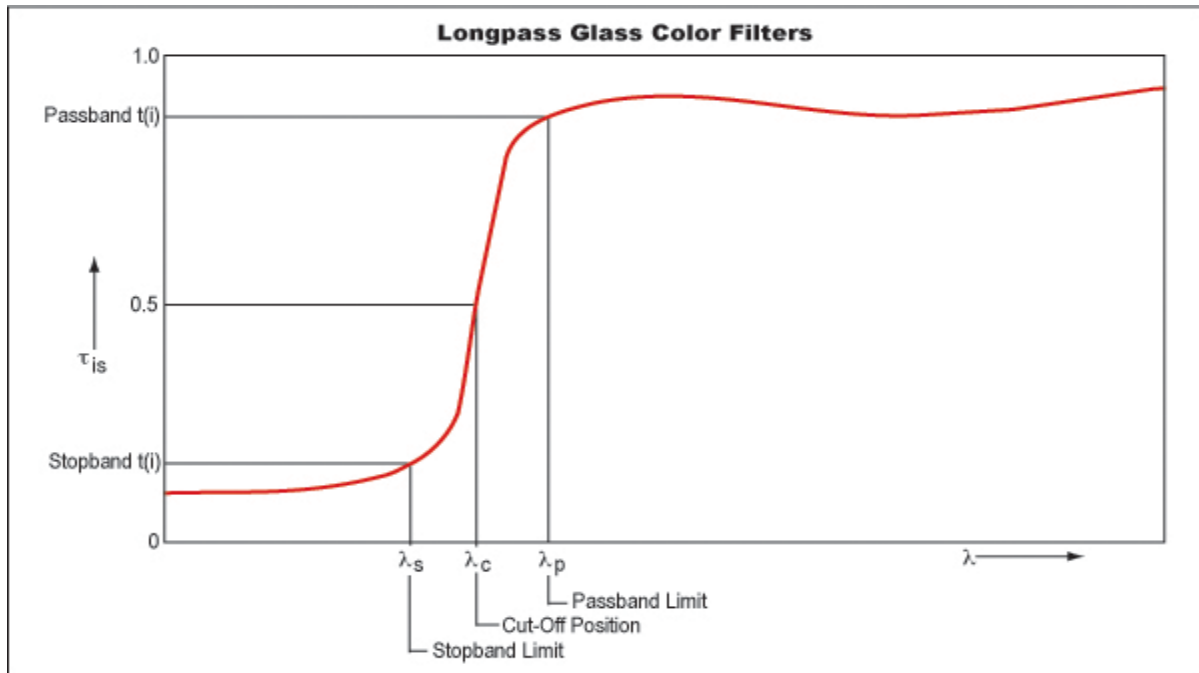
Fig. 8 Longpass filter properties (Ref 42)

All wavelengths of light smaller than the stopband filter are prevented from reaching the CCD chip. All wavelengths of light larger than the passband limit are permitted to reach the CCD chip. An optimal long pass filter would have a passband limit whose value is less than the wavelength of light projected by the LPR system light source. For example, if an LPR system light source projects 850nm wavelength light, the long pass filter should have a passband limit less than this value. By blocking visible light, a long pass filter eliminates the negative effects of visible light.

After light is filtered by the filter it next passes through the telephoto lens. The telephoto lens magnifies the image. Magnification is needed because vehicles will be imaged at a distance and license plate characters will need to be magnified in order for object character recognition software to function accurately. Vehicles are imaged at a distance for three reasons. One, the camera angle, as depicted in figure 9, should be kept at a minimum. The larger the angle, the more distorted the license plate characters will be due to 3D to 2D translation effects.

"Horizontal angle must not exceed 40 degrees (Ref 33)". Two, the camera angle should also be kept at a minimum to prevent motion blur. The larger the camera angle, the quicker a vehicle will move across the camera's field of view, causing a higher chance of motion blur. And three, a larger time frame window will be given for capturing an image of a passing car if it is imaged at a distance. This will prevent vehicles from passing the camera without having their image taken. It should be noted that the distance between vehicle and camera not be so great that minimal light from the license plate reaches the camera. A balance must be achieved to obtain optimum picture quality.
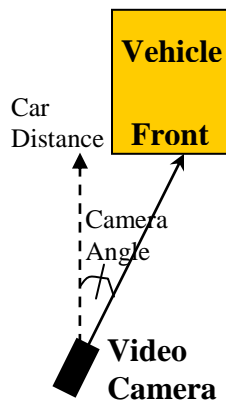
Fig. 9 Video camera orientation

Telephoto lenses have three relevant specifications; focal length, horizontal field of view, and aperture. The focal length determines how much an image will be magnified. The higher the value, the higher the magnification. A license plate under higher magnification will spread across more pixels in an image which in turn increases character recognition accuracy. However, this will decrease the horizontal field of view. The horizontal field of view (HFOV) specification defines how much of a view is captured in a picture. The HFOV specification is given as an angle and is depicted in the diagram below. The HFOV should be wide enough to capture an image of a license plate of a passing vehicle that is traveling within its lane. For example, if a

lane is 9 feet wide, the HFOV should be at least 5 feet wide in order to capture the license plate of a passing vehicle even when the vehicle is traveling within its lane.
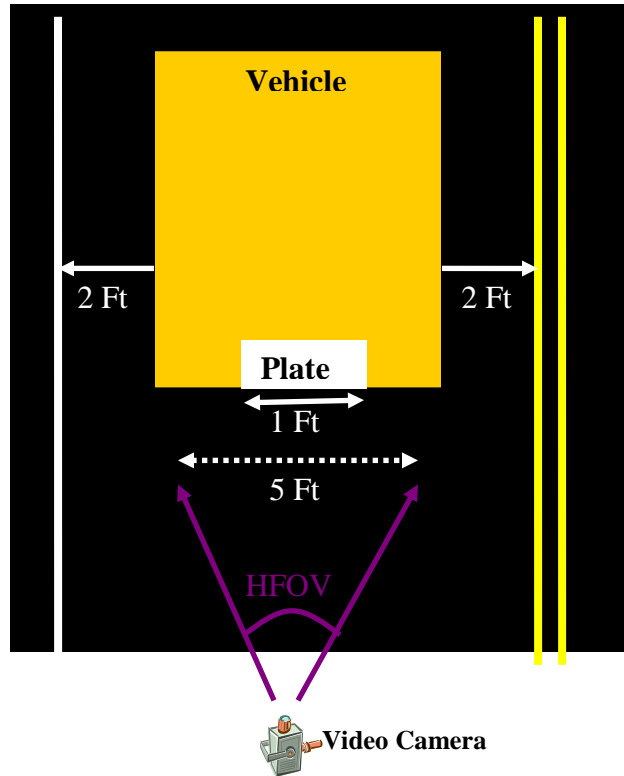
Fig. 10 Camera horizontal field of view

Another telephoto lens specification is the aperture. The telephoto lens aperture defines the size of the hole that allows light to pass through. The larger the value, the more light enters the camera providing faster exposure times. However, too large a value will provide a smaller depth of field and the image will be in focus for only a small range. "The depth of field (DOF) of a lens is its ability to maintain a desired amount of image quality as the object is positioned closer to and further from best focus (Ref 41)." A telephoto lens that meets LPR requirements will have a depth of field capable of imaging cars at varying distances and also allow enough light to enter for fast exposure times.

The video camera has another component called the charge-coupled device (CCD) chip. Light passes through the telephoto lens and lands on the video camera's CCD. The CCD converts electromagnetic energy received from the light into electrical energy. The CCD chip sensors must be extremely sensitive to near infrared light. This is to offset the minimum amount of light energy that will fall on the CCD as previously discussed. Sensitivity is usually defined in a camera specification called the minimum illumination. It is measured in LUX. The lower the LUX value the more sensitive the camera is to light. A very low LUX value is desirable for license plate recognition. Consumer cameras are built to be sensitive to mostly visible light. An LPR camera needs to be sensitive to near infrared light. The graphs below show the difference in sensitivity between a standard consumer CCD chip and one specialized for infrared imaging.
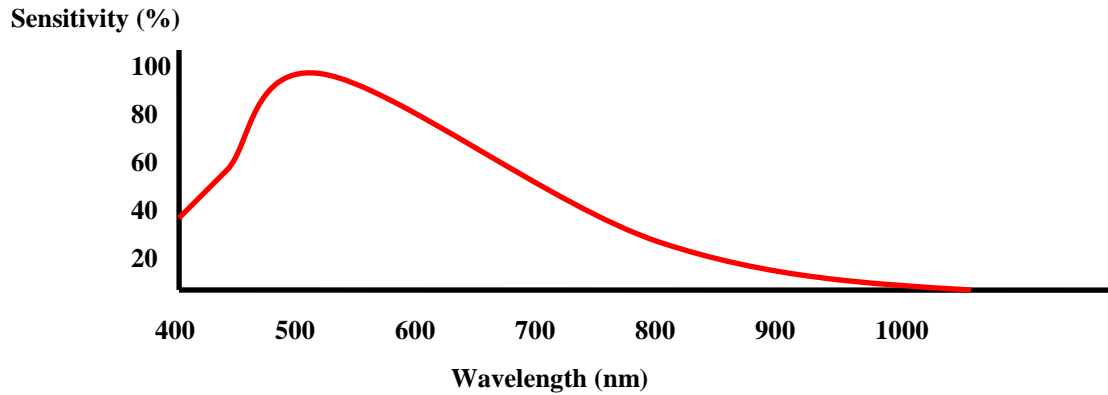
Sensitivity (%)

Fig. 11 Sensitivity for standard consumer CCD (Ref 43)
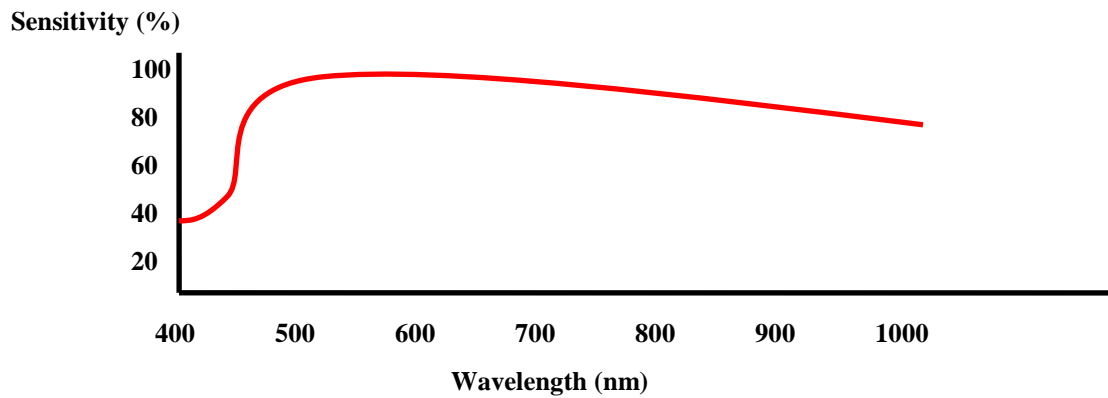
Sensitivity (%)

Fig. 12 Sensitivity for LPR CCD

An LPR CCD is much more sensitive than a standard consumer CCD chip at the near infrared wavelengths of light (>700nm). Such sensitivity is necessary to capture detailed images of high speed moving objects at a distance with near infrared illumination.

Another CCD specification is the large number of image pixels needed to accurately recognize license plate characters. If the camera's field of view covers most of the lane's width, the license plate will extend only a small portion across the image minimizing the number of pixels each license plate character spreads across. It is desirable for a license plate character to cover a certain number of pixels in order to be accurately recognized. For example, if a camera's HFOV is 5 feet across and its horizontal image size is 640 pixels, then the character "1" whose

width is only 5/16" will be 3 pixels wide ((5/16)/(5*12)*640 pixels). This may or may not be enough pixels depending on the object character recognition algorithms being used. On the other hand, having too many pixels can cause a negative effect. The more pixels an image contains, the longer it will take image processing routines to process the image. A balance must be met.

It should also be noted that camera images should be clear and sharp with little noise. Cameras that output digital signals such as DTV or computer protocol signals such as IEEE 1394 generally have better image quality than cameras that output analog signals such NTSC or PAL. It is desirable for an LPR customized camera to output a clear, sharp image to increase the accuracy of software image processing and character recognition routines.

Also, depending on how the video camera is implemented, it should either have a trigger port or a very high frame rate. The trigger port is used to signal the camera when to take a picture. The camera trigger port is connected to the trigger component of the LPR system that senses when a car is present. If the same video camera is also being used as the trigger component then it should have a very fast frame rate. This will ensure an image of the vehicle is captured before passing the camera.

A summary of desirable LPR video camera characteristics is given in the table below. When a video camera contains these characteristics, a high quality image of the intended license plate will be captured.

Table 2 LPR Video Camera Characteristics

Characteristic	Desired Value
Long pass filter	All visible wavelengths of light are blocked.
Telephoto Lens Magnification	Powerful enough to image license plate characters at a distance
Telephoto Lens Field of View	Wide enough to capture license plate when vehicle travels within its lane

Telephoto Lens Aperture	Small enough to provide required depth of field, but large enough for fast exposure time
CCD Sensitivity / Minimum Illumination	High sensitivity. Low LUX value for infrared lighting
Signal Output	Digital or computer protocol for clean high resolution image
Frame Rate (optional)	If camera is also being used as a trigger it must have a high frame rate
Trigger Port (optional)	Most cameras have a trigger port that is used to signal the camera when to take a picture
CCD Resolution	High enough to provide acceptable level of license plate detail when capturing an entire lane width

III.C. LPR Computer

A computer specialized for license plate recognition is similar to a standard PC running a Windows or Linux operating system. An example of a good candidate computer would consist of an MSI Industrial GM965 Mini-ITX motherboard running an Intel Core 2 Duo Mobile processor (see appendix B). There are several characteristics an LPR customized computer should have. A powerful microprocessor and much memory are needed to perform the demanding calculations needed by the image processing and object character recognition algorithms. Having multiple processors is a plus due to the parallel nature of these algorithms. For example, one processor can run low level image processing functions while another processor performs object character recognition functions. For roadside LPR systems, it is desirable to have computers that are compact, weather proof, and consume minimum electricity. They may need to have wireless communication if wired technology is unavailable. The LPR computer may also need to have an image acquisition capture card in order to connect to a camera. The type of card is dependent on the camera interface. If camera output is an analog

signal, such as NTSC, a capture card with composite input is needed. If the camera output is a computer standard, such as the IEEE1394 protocol, a FireWire card may be necessary. It is important to note that different types of cards require different software drivers and the license plate recognition software must be able to communicate with the appropriate driver. Other than these specifications an LPR customized computer is much like any other desktop PC.

Table 3 LPR Computer Specifications

Characteristic	Desired Value
Camera Interface	Must match camera output or have PC card that can connect to camera
Computer Case	Weather proof
Power Consumption	Minimum power input
Processing Power	Comparable to high end desktop machine. The more processors the better.
Wireless capability	Needed if wired technology is unavailable
Capture Card Driver	Must be compatible with image processing software

III.D. LPR Trigger

The fourth component of an LPR system is a trigger. License plate recognition systems need triggers to detect the presence of a vehicle and to signal the system to start capturing images of passing vehicles. There are many different types of triggers. An example of a trigger is MDL's LaserAce® IM OEM Laser Modules (specifications given in Appendix B). MDL's LaserAce modules are laser range finders that detect the presence of a car using laser technology. A trigger is composed of some type of sensor that senses the presence of a passing vehicle and outputs an electrical signal when a vehicle is detected. This signal is sent to a camera's "external trigger" port. The camera starts to capture images when this signal is received. Most triggers are not

specifically sold fold for license plate recognition and must be customized to be incorporated in to the LPR system.

Other types of triggers include pressure sensors, infrared sensors, magnetic field detector sensors, and video cameras. Pressure sensors consist of tubes or wires that are laid across the roadway. When a vehicle rolls over the tube or wire, the pressure in the tube rises or the resistance in the wire changes, causing the sensor to output an electrical pulse. Infrared sensors use infrared light to detect the presence of a vehicle. It is similar to the sensors located on an automatic garage door opener that prevent the door from closing when an object is located under the door. The infrared sensor consists of an emitter and receiver. The emitter sends infrared light to the receiver. If the receiver does not receive the infrared light it sends an electrical pulse, signaling an object is in its path. A magnetic field detector sensor detects the presence of vehicle by the vehicle's magnetic field. All vehicles have a magnetic field due to the large amount of metal used by them. Video cameras can also act as triggers. They can continually monitor the street and use image processing techniques to detect the presence of a moving object. For traffic violation type applications, laser range finders are mostly used to trigger the camera.

There are certain specifications that are desirable for an LPR customized trigger. It is desirable to have a sensor that is unobtrusive as possible. If tubes or wires cannot be laid across the road, then pressure sensors cannot be used. It is also desirable to have a sensor with a very quick response time. Magnetic sensors may not have a quick enough response time for fast moving traffic, triggering the camera at wrong intervals. It is desirable to have a trigger that can be located near the camera. This will eliminate the need for costly extra support structures and long cable runs between camera and trigger. Some laser range finders require they be placed directly over roadways, requiring extra structures to support the system. It is also desirable to

choose a trigger that will require the least amount of work to be incorporated into an LPR

system. Video cameras will require a computer and special software. Care must be taken to

choose the appropriate trigger for the application at hand.

Table 4 LPR Trigger Specifications

Characteristic	Desired Value
Location	Near camera
Response time	Extremely quick for fast moving traffic
Obtrusiveness	As unobtrusive as possible
Work required to incorporate trigger in to system	Minimal

IV. Speed Detection Radar Concepts

At the start of this project we discussed various methods for determining the speed of a motor vehicle, including speed trailers (fig. 13), hand held radar units (fig. 14), laser rangefinders, traffic classifiers, traffic counters with road tubes, ultrasonic detectors, Passive Infra-red (PIR) detectors, and microwave radar units.

Fig. 13 Speed Trailer   **Fig. 14 Hand-held Radar**

The purpose was to have these units act as a sensor to start the camera operation and trigger the license plate recognition software. From our initial research, we concluded that commercially available speed trailers and professional quality police radar units were far too expensive for this project. Speed trailers cost around $5,000 and police radar units' cost around $800. Since the ultimate goal of this pilot project was to combine speed detection, license plate recognition, and wireless mesh networks into a viable system, we felt that the financial support we had could be better utilized in other areas.

We briefly considered laser rangefinders, but decided they were too dangerous and costly, even if we could obtain ones that were used by law enforcement. A special class of laser is required for police laser radar detectors, which adds to their cost. The laser rangefinders used for measuring distance on a golf course, for example, are not manufactured in a way that allows them to be pointed at people. Thus, they would be extremely dangerous if used to measure vehicle speeds. We would also have the problem of measuring the speed of an object since these units are for distance only.

The traffic classifier units and traffic counters with road tubes, while less expensive than the speed trailers and police radar units, have the major drawback of needing to place a portion of the unit in the roadway. We felt that this would require special permission from the various regulatory agencies (State Department of Transportation, State Traffic Commission, City of New Britain, etc.) which may have taken a long time to be granted, if at all.

Both the PIR motion detectors and the ultrasonic rangefinder, while inexpensive, have problems with the wide detection field and short effective distance. The camera system we decided to use provides a quality image at distances from 50 to 500 feet, depending on which camera lens is installed. Although the PIR detector could cover the shorter end of this range, it would respond to any motion within a 60-degree field of view. The ultrasonic detector suffered from an extremely short usable range, which did not exceed 10 feet.

This leaves us with the microwave radar units, of which we found two very inexpensive types. Mattel Toys makes one for their Hot Wheels 1/64 in. scale cars (fig. 15), and the other one is a kit made by Ramsey Electronics (fig. 16).

Fig. 15 Hot Wheels Radar Gun

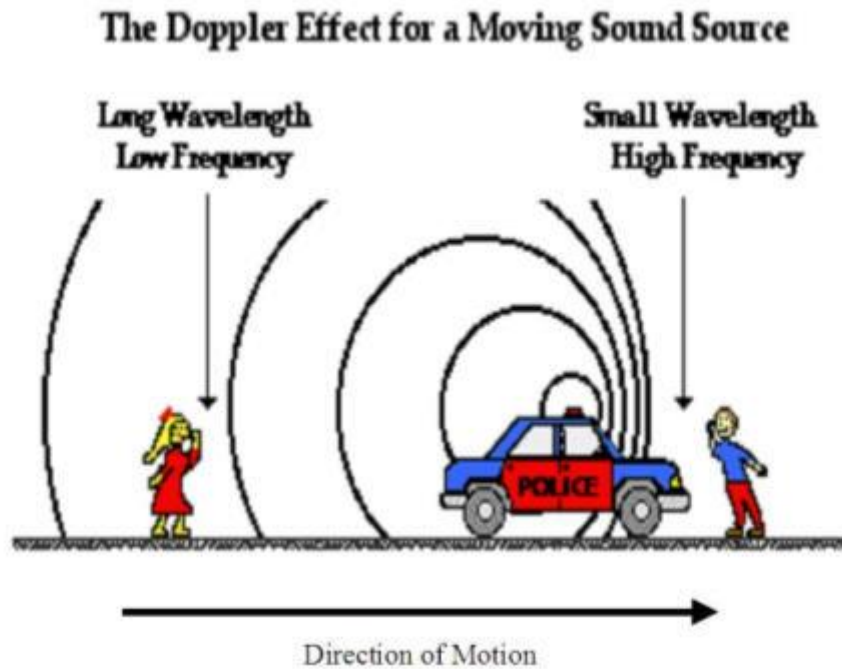
Fig. 16 Ramsey Electronics Radar Kit

Since the Mattel Radar Gun was the least expensive, we purchased that one first. Both of these units operate in the microwave range of frequencies. The Mattel unit at 10.525 Gigahertz (GHz) is an X-band radar unit; the Ramsey kit at 2.6 GHz is in the now obsolete S-band (Ref. 10). Both units determine the speed of an object based on the Doppler Effect.

The Doppler Effect for a Moving Sound Source

Long Wavelength
Low Frequency

Small Wavelength
High Frequency

Direction of Motion

Fig. 17 Doppler Effect (Ref. 14)

The Austrian physicist Christian Andreas Doppler first described the Doppler Effect[*] in 1842. He noticed how the frequency of a sound wave changed as the emitting object moved toward or away from a stationary listener. When the emitting object was coming toward the listener, the pitch or frequency of the sound increased. But as the object moved away from the listener, the pitch decreased. The largest Doppler Effect is heard when the source is moving directly toward or away from the listener. The frequency heard by the listener can be calculated from the following equation:

$$fL = [(v + vL)/(v + vS)] \, fS \qquad \text{(Eq. 1)}$$

where: fL is the frequency heard by the listener

fS is the frequency emitted by the source

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[*] Different sources have differing names for Dr. Doppler. On a NASA website, he is Johann Christian Doppler. Webster's Dictionary has him simply as C.J. Doppler. Wikipedia gives his name as Christian Andreas Doppler

v is the speed of sound (In dry air with a temperature of 21 °C (70 °F) the speed

of sound is 344 m/s (1230 km/h, or 770 mph, or 1130 ft/s).

vL is the velocity of the listener

vS is the velocity of the source

If both the listener and the source are stationary, then vL and vS =0 and fL = fS. The sound heard

by the listener is the same as that emitted by the source. If the source is moving toward the

listener, then vS is negative (by convention, in an inertial reference frame) and the quotient in

Eq. 1 becomes larger; the pitch heard by the listener increases. However, if the source is moving

away from the listener, then vS is positive (by convention) and the quotient of Eq. 1 gets smaller;

the pitch heard by the listener decreases. Conversely, if the listener is moving toward the source

of the sound, vL is positive (by convention); the quotient in Eq. 1 becomes larger and the pitch

increases. If the listener is moving away from the sound then vL is negative; the quotient in Eq.1

becomes smaller, and the pitch decreases.

In general, police Doppler radar systems are set up in the manner shown below:
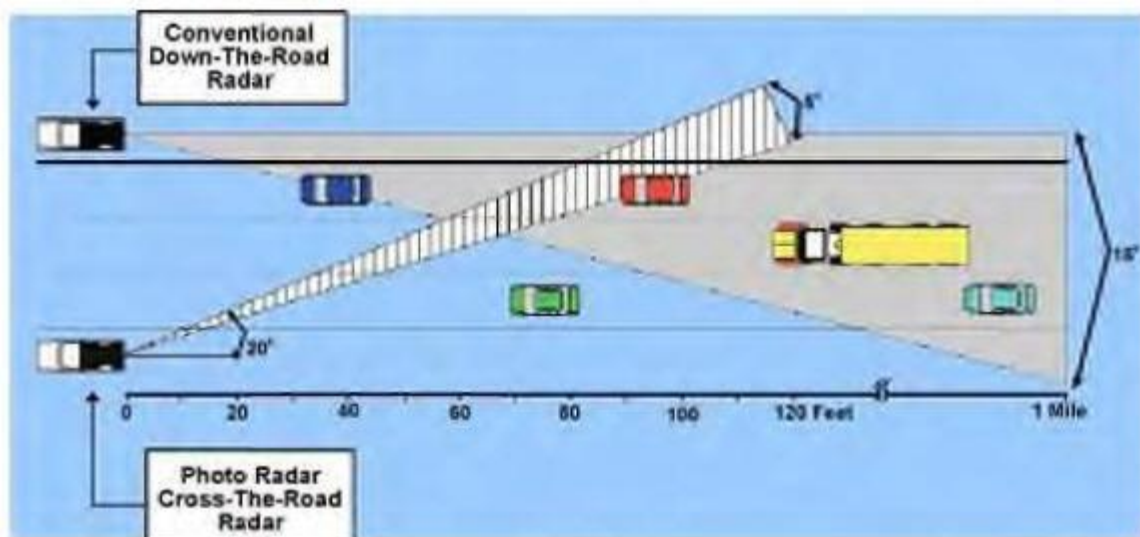
In this project, we will be using the conventional police method of pointing the camera and radar gun down the road. As you can see from the diagram, police radar can detect vehicle speeds when the vehicle is up to a mile away. The radar units we used in this project have a range from 100 ft. to ⅛ mile.

Problems with the Mattel Speed gun

When the Mattel Toy's speed gun was taken out of it's housing (fig. 19, Ref. 5); we discovered the following problems:

Fig. 19 Inside of Mattel Radar Gun

Fig. 20 Radar Gun Circuit Board

1. The circuit board was a double layered board (fig. 20, Ref. 5)

2. The circuit contained an embedded ATmega88 microcomputer

3. The source code on the microprocessor was locked

4. The locks could be removed only by erasing the entire code

5. Even though the ATmega88 has UART pins, we doubted the code was written to address them.

6. A search of the Internet revealed only one partial circuit diagram which was of little help.

7. The source codes and circuit diagrams are proprietary property of Mattel Toys, and they would not release them even for a discontinued toy.

Given these drawbacks, the only part of the Mattel Speed Gun that might prove useful would be the detector tube with it's transmit and receive antennas; all other supporting circuitry would have to be designed from scratch. We felt we had another alternative in the Ramsey Electronics SG7 kit, which will be described later.

V. Our System Design and Implementation

V.A. Overview

The system designed and implemented for this project is called the license plate recognition / speed detection (LPR/SD) system. The system receives two inputs. One input consists of live video taken of passing vehicles traveling down a throughway. The second input is the speed of passing cars obtained from a radar gun. The LPR/SD system processes these inputs, and outputs a computer file. The file contains information on passing cars including their license plate number, the speed they were traveling, and the time and date they passed.
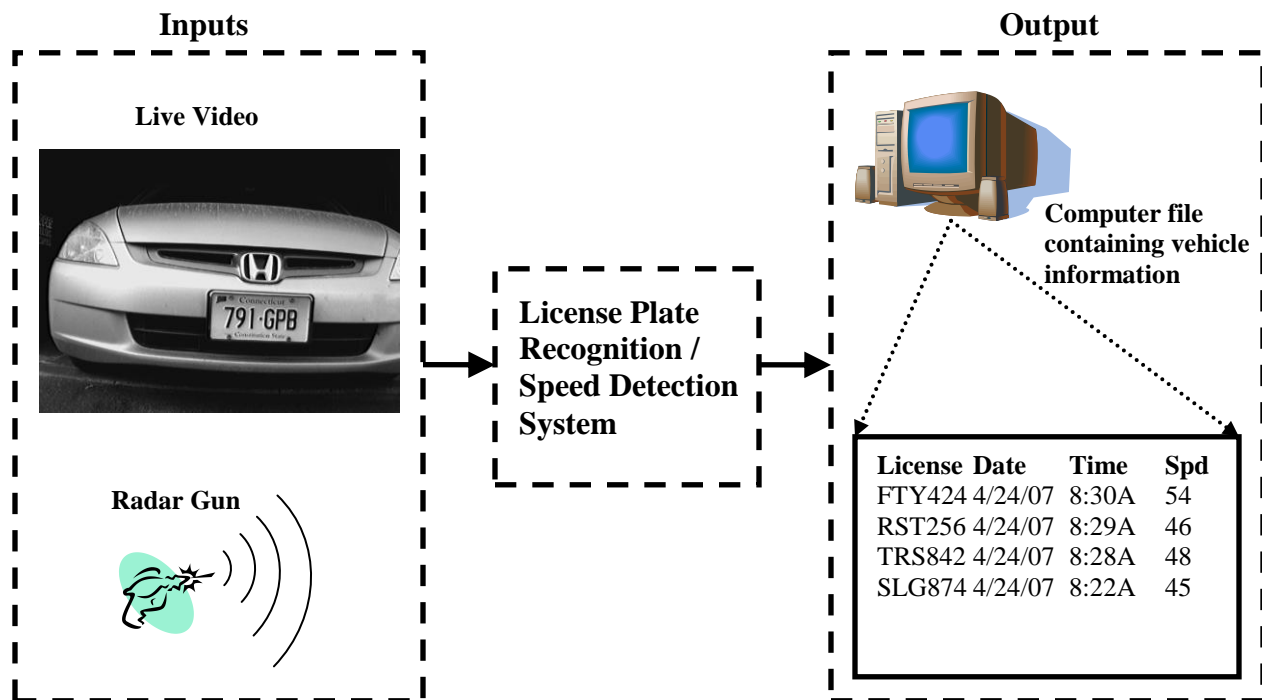
Fig. 21 LPR/SD system inputs and outputs

Our LPR/SD system is physically placed on the side of a throughway. It continuously monitors passing traffic. The system is composed of five main components as depicted in the

figure below; a light source, video camera, computer, serial interface circuit board, and radar gun.
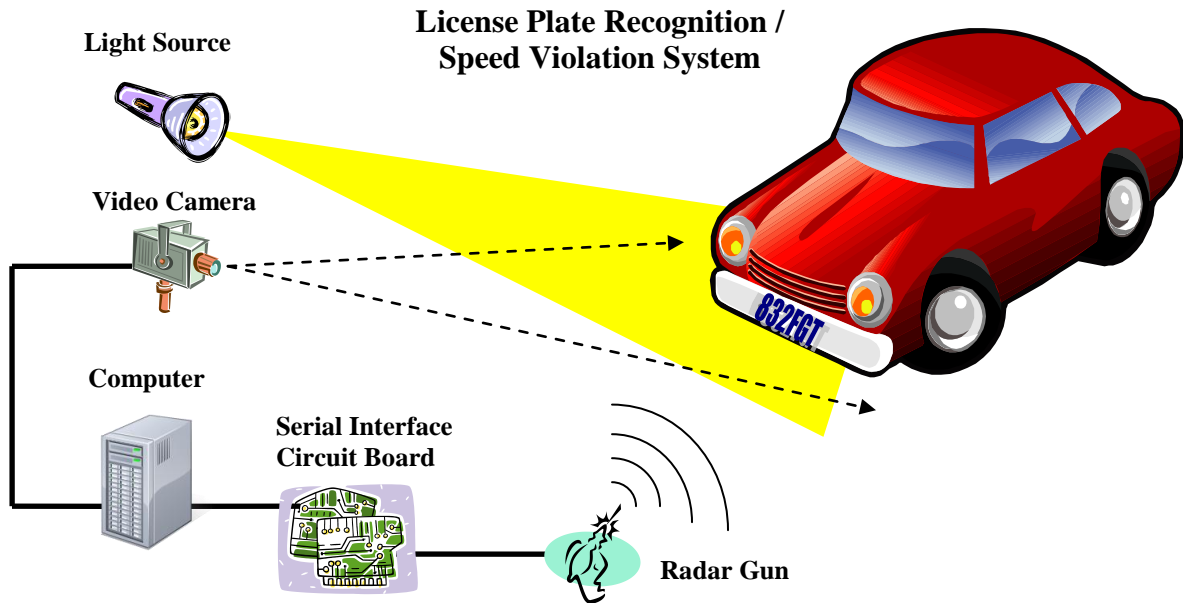
Fig. 22 LPR/SD system components

The light source illuminates the license plate of a passing vehicle. The video camera captures images of the front of the vehicle as the vehicle passes and sends those images to a computer. The radar gun detects the speed of the vehicle and sends speed information to the serial interface circuit board (SICB). The SICB provides a means of passing the speed information to the serial port of the computer. The computer processes images received from the camera and detects the license plate characters from the images. The computer also receives speed information sent by the SICB. The vehicle license plate number and speed are recorded in a file on the computer.

Our LPR/SD system process flow is depicted in the figure below.

LPR/SD System Process Flow
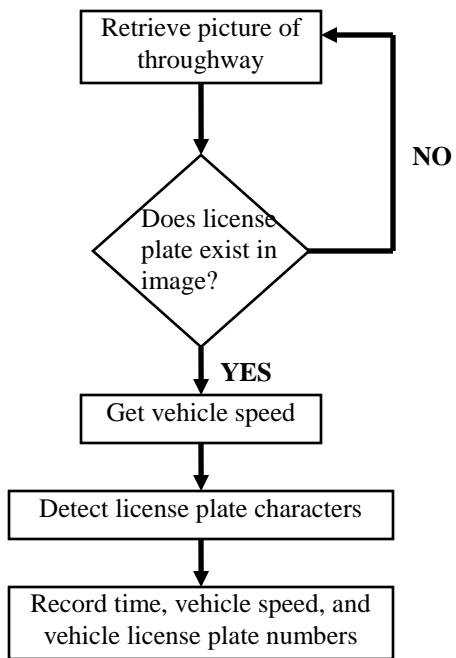
Fig. 23 LPR/SD system process flow

V.B. License Plate Recognition / Speed Detection System Components

V.B.1. LPR Components

The license plate recognition part of our system includes the light source, video camera, and computer components. Our budget limited us to the most basic appliances. We used a vehicle's headlights for a light source, a FireWire webcam for a video camera, and a laptop for a computer. (We also tried using just sun light for a light source). Pictures of our system setup are given below. The system was setup two different ways. One way was to position the system in front of a vehicle and use the vehicle's headlights for a light source. This is shown in figure 24. Another way our system was setup was to position the system on top of a small desk and use only the sun as a light source as shown in figure 25.

Fig. 24 Image of our LPR/SD system in front of a vehicle

Fig. 25 Image of our LPR/SD system positioned on desk using sun as light source

One major difference between our system and a commercial license plate recognition system is our use of visible light to illuminate the license plate. Most LPR systems use near-infrared light. It should be noted that both types of light produce the same effects when shown on reflective paint. The reflective paint on the license plate causes the license plate to be highly lit when illuminated by a light source that is placed near the camera aperture. This holds true whether the light source is emitting visible light or infrared light. It will make it easier for the image processing algorithms to extract the license plate characters from the image. However, using visible light for a light source is impractical. Shining bright visible light at passing vehicles

is dangerous and may temporarily blind the driver of a car. Also, light from external light sources will interfere with the light coming from our light source. Light from the sun or another vehicle's headlights can interfere with our light source light, lowering the accuracy of the image processing algorithms. Using visible light also changes the requirements on our system video camera. As previously discussed, most LPR cameras are sensitive to near infrared light and block all other wavelengths of light. Since our system is using visible light to illuminate the license plate, our camera must also be sensitive to visible light.

For our system video camera, we used a UniBrain FireWire webcam. Complete specifications are given in appendix A. We chose this camera for several reasons. The camera only cost $105 and was within our budget constraints. It was also able to retrieve images at 30 frames per second. We needed the high frame rate in order to capture images of passing vehicles before they drove out of the camera's view. The camera output images in digital format at 640x480 pixels. Therefore pictures were clean with little noise and the high resolution provided the needed detail to recognize license plate characters. A 50 mm focal length lens was mounted on the camera providing the magnification needed to image vehicles at a distance. One major advantage of using this camera was that it used the IIDC DCAM (Instrumentation & Industrial Digital Camera protocol). "Most FireWire webcams available are compliant with the IIDC specification. This means that no device-specific driver is necessary to interface with the camera (Ref 34)". I was able to find a free software library for this protocol and used it to communicate with the webcam. One major disadvantage of using this camera was the long exposure time needed to capture images using a telephoto lens. The long exposure time limited the speed vehicles could travel without causing any blur.

Our video camera served two functions. One, it had to capture high quality images of passing license plates for the recognition software to extract and recognize license plate characters, and two, it was used as a trigger to detect the presence of a license plate in an image. We had to make sure the camera was capable of performing both functions. We also needed to know how to setup the camera to perform both functions. To answer these questions we would have to solve for the three distances shown in green in figure 26.
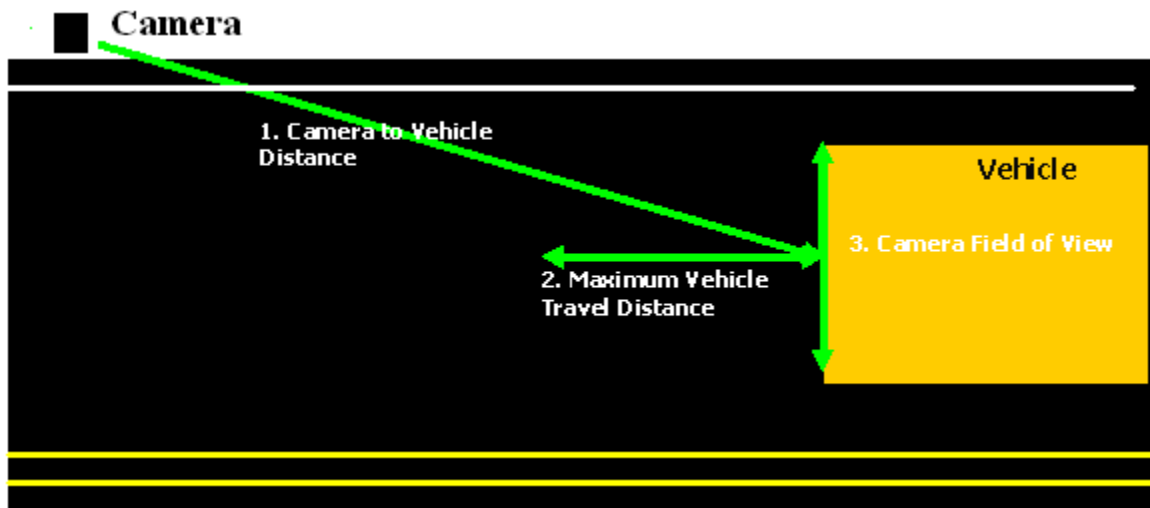
Fig. 26 Three distances to calculate for camera setup

Distance 1, the "Camera to Vehicle Distance" would tell us where to focus the camera on the street lane. This distance was found to be 40.88 feet. Distance 2, the "Maximum Vehicle Travel Distance" is the maximum distance a vehicle could travel within our camera's field of view. This distance was found to be 6.69 feet. From this distance we deduced that once a vehicle's speed reached over 136.84 mph, it may be possible for the vehicle to pass the camera undetected. Distance 3, the "Camera Field of View Distance", is the amount of distance covered by the camera's field of view. This distance was found to be 51.42 inches. From the "Camera Field of View Distance" we deduced that a vehicle could veer up to 19.71" inches from the center of its lane and still be sensed by the camera. From these calculations we predicted that our

camera would be capable of performing both functions. It would be possible to both, capture high quality images of license plates for character recognition, and also, be used as a trigger to signal when an image should be passed to the character recognition routines. Calculations for the distances shown in figure 26 are given in appendix C.

Our LPR system used a standard laptop (Compaq nc6220) to run the image processing and object character recognition software. The processing power of the laptop was fast enough to detect the presence of a vehicle in an image within the 30 frames per second time limit. It was also fast enough to perform the character recognition before a second vehicle would pass. We also purchased a FireWire PCMCIA card for the laptop to be able to connect the video camera to the laptop since it did not have a FireWire port. Using a laptop is impractical for an LPR system. Most systems need to be weatherproofed.

.

V.B.2. Radar Gun

The Ramsey Kit

Ramsey Electronics of Victor, New York (Ref. 3) has been selling hobby electronic kits since the early 1970's. The advantages of using the Ramsey kit over hacking the Mattel toy is that the kit has a full schematic diagram and all parts are labeled. Thus it is easier to locate the point in the Ramsey circuit where we could tap into the circuit for an RS232 fed line. We purchased and assembled a kit similar to the one shown below.

Fig. 29 Ramsey Radar Gun Kit

The Microwave Oscillator Circuitry

The kit contains two printed circuit boards that require assembly, the microwave oscillator board and the speed readout board. . We will discuss each in turn. Figure 30 is the circuit diagram for the microwave oscillator. Figure 31 shows the completed circuit board.

Please note, for reader convenience, we have included data sheets for all transistors, diodes, and integrated circuits (IC) on the CD-ROM attached to this report.

MICROWAVE OSCILLATOR SCHEMATIC DIAGRAM:
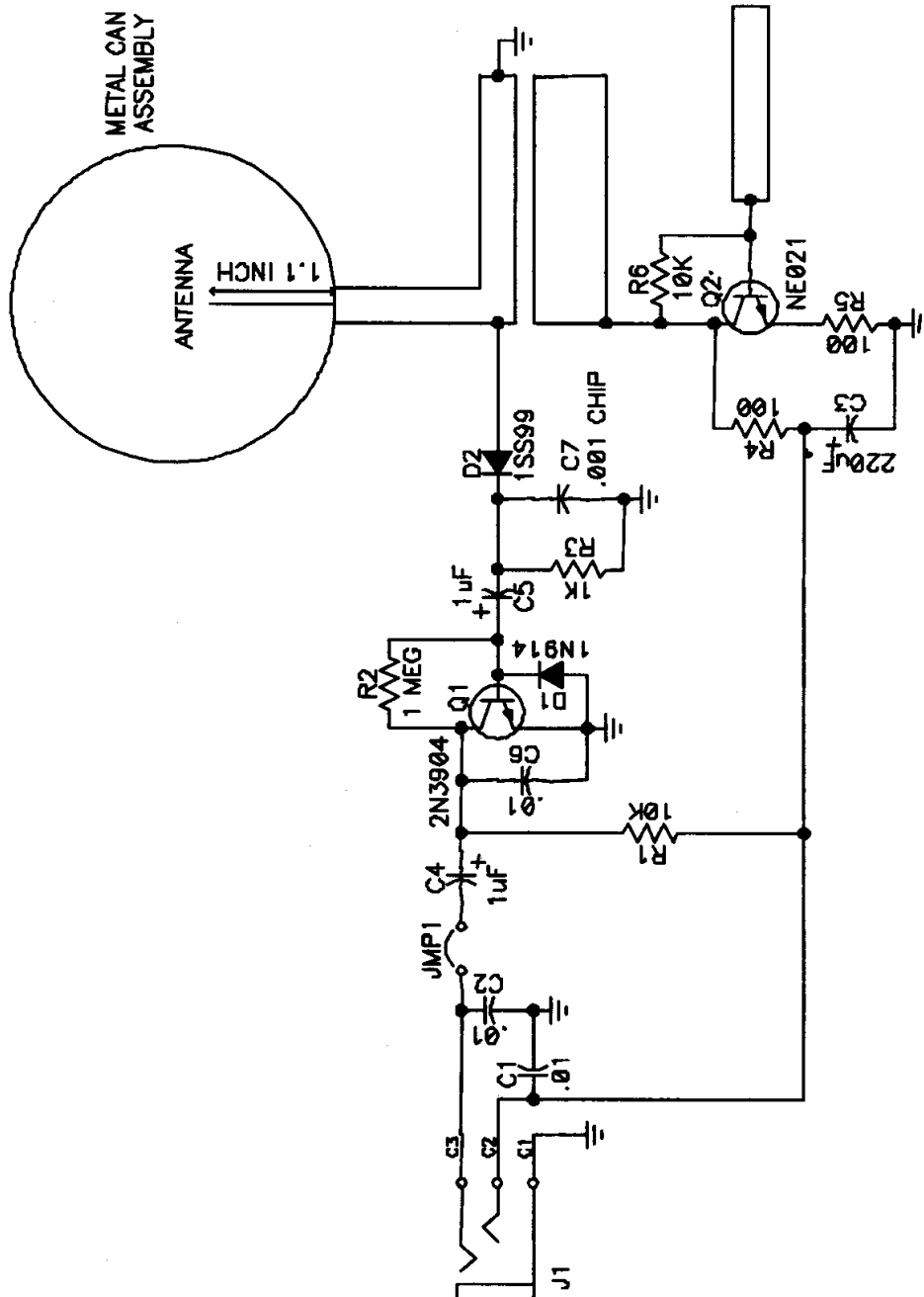
Fig. 30 Microwave Oscillator Circuit Diagram
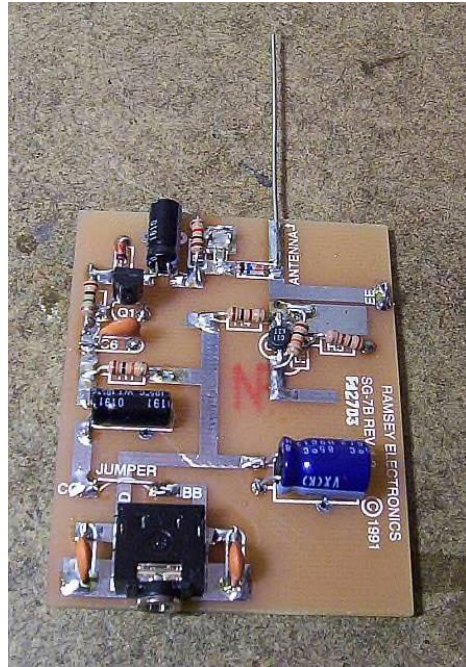
Fig. 31 Assembled Oscillator

The microwave oscillator circuit performs two functions. First, it produces a 2.6 GHz

signal which is broadcast via a quarter-wave dipole patch antenna. Second, it uses a quarter wave

antenna mounted in a resonant cavity to receive the reflected signal from the object whose speed

we want to measure. Two one pound coffee cans (with the ends cut out of one of them) are

soldered together to form the resonant cavity. A stiff piece of wire is cut so that it extends

approximately 1.1 inches into the can. It is mounted $1\tfrac{7}{8}$ inches from the closed end of the can.

This forms a ¼ wave dipole antenna housed in a resonant cavity. The metal walls of the coffee

cans reflect the incoming radiation in a way that allows only those signals with wavelengths that

are multiples of the can diameter to undergo constructive reinforcement. This concentrates and

intensifies the radiation prior to entering the detector circuitry. The resonant cavity also helps

narrow the angle from which the antenna can receive a signal, which improves the pointing

direction. We expect the beam width to be in the range of 15 to 20 degrees, although we haven't measured it.

The oscillating electromagnetic wave induces an alternating current in the antenna wire. This current forms the signal we are trying to detect. The signal is passed to a Schottky diode (a.k.a. hot carrier diode). These diodes have low junction capacitance, low junction voltage, and fast switching speeds; making them ideal for the detection of low voltage high frequency signals. The signal then passes through a low pass filter circuit. This circuit is formed by the R3 1kohm resister and the surface mounted 0.001 micro Farad capacitor C7. A low pass filter is used when we are interested in frequencies below a specified (cutoff) level. The following equation is used to calculate the cutoff frequency:

$$Fc = \frac{1}{2*\pi*R*C}$$

Where: Fc = the cutoff frequency

π = 3.1415

R = resistance in Ohms

C = capacitance in Farads

For this section of the circuit the cutoff frequency is 159.2 kHz. The Ramsey user's manual states "the correct Doppler shift at the operating frequency is 7.76 Hz per mile-an-hour (Ref 1)." Since the readout provides for a two-digit display, we can measure speeds up to 99 mph. This gives a Doppler shift of approximately 770 Hz.

The filtered signal now passes to the base of a NPN 2N3904 transistor that is configured as a common emitter amplifier. The 2N3904 is a general-purpose transistor that can amplify a signal

up to 100MHz. Once the signal has been amplified, it is capacitively coupled to the signal

output jack (J1) and sent to the readout circuit.

The NE021 transistor, the patch antenna and a few passive components form the

remaining part of the circuit. The NE021 transistor is configured as an oscillator and it produces

the 2.6 GHz signal. This signal is passed to the foil patch antenna mounted directly on the

printed circuit board. The signal is coupled to the waveguide and forms the initial radar beam.

The Readout Circuit

Figure 32 shows the completed readout circuit board. Figure 33 shows the speed readout circuit

diagram.
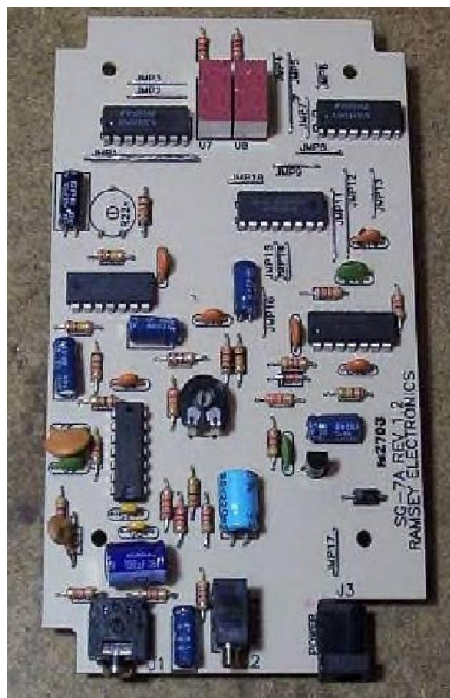
Fig. 32 Assembled Readout Board

LED SCHEMATIC DIAGRAM:
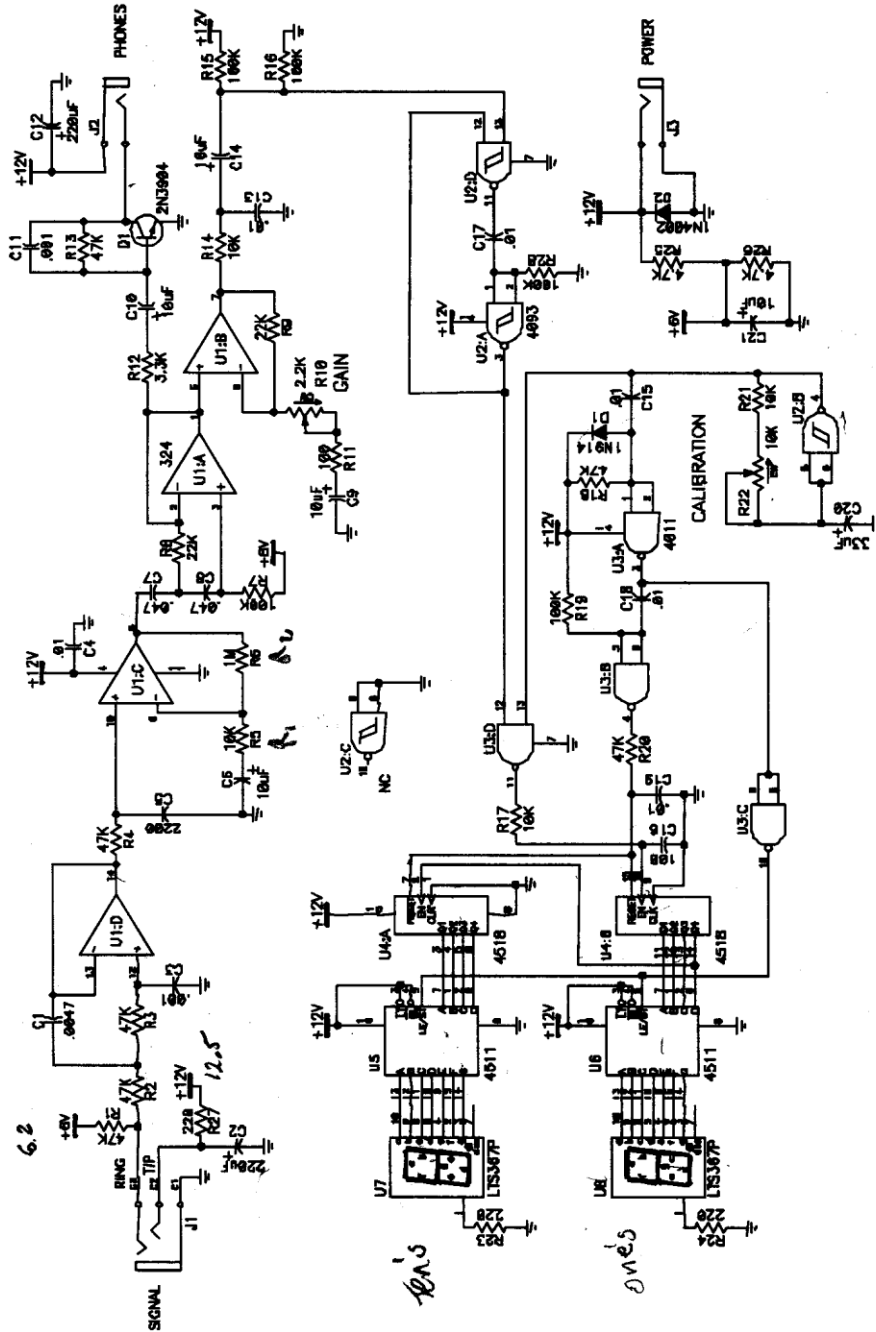
SG7• 12

Fig. 33 Readout Circuit Diagram

I will discuss the pathway the input signal takes through the readout circuit from the input jack to the 7-segment LED display. For brevity, I will ignore the headphone, calibration, and gain control circuitry.

Two six-volt dry cell lantern batteries connected in series powers the readout display. The input power is separated by a voltage divider circuit (formed by resistors R1 and R2), to give a 12 volt supply and a 6 volt supply needed by the integrated circuit (IC) chips.

The signal from the microwave oscillator enters the readout circuit via the signal jack, J1. The signal is amplified by passing through all four stages of an LM324 Quad Op-Amp. The input signal is applied to the non-inverting pin of each amplifier stage and negative feedback loops are used to control the gain and prevent the op-amp from going into saturation. The gain (G) in a negative feedback loop is controlled by the values of the resistors in the voltage divider configuration in the specific loop. The gain (G) = 1 + R2/R1.

The amplified signal leaves the last stage of the LM324 Op-amp at pin 7 and is directed to the input pin of a 4093 Quad Schmitt trigger NAND IC. A Schmitt trigger has the unique ability to convert any type of input waveform into a square wave output and at the same time acting as a noise filter. The graph below (figure 34) shows an arbitrary waveform at the top of the graph and the resulting output after passing through a Schmitt trigger. The Schmitt trigger is a type of comparator IC that uses two independently set thresholds. When the input waveform is below the lower threshold, the Schmitt trigger's output is low. When the input waveform is above an upper threshold, the Schmitt trigger's output goes high. The Schmitt trigger's output changes only at those times when the input waveform's trailing edge crosses the upper threshold

45

limits; or when it's leading edge crosses the lower threshold. The Schmitt trigger IC effectively converts the input signal to a digital signal, i.e. highs = 1, lows = 0.
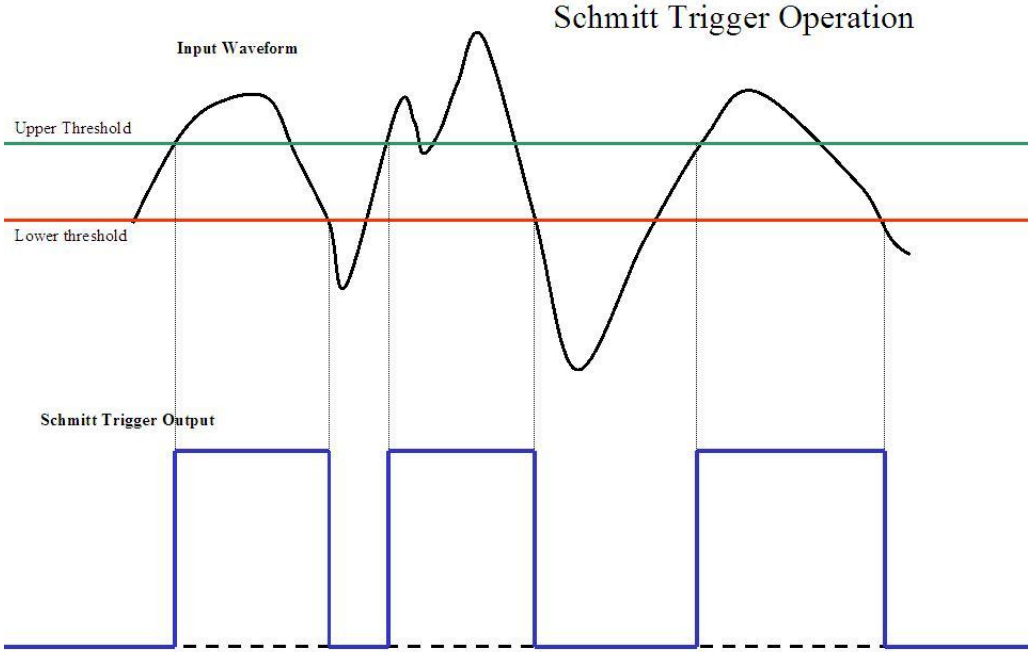
Fig. 34 Schmitt Trigger Operation

A comparator IC uses only one adjustable threshold level. It's output changes each time the input waveform crosses the threshold. See graph below (figure 35). Given the same input waveform, these graphs show the comparator IC to be prone to noise interference. A noisy input signal close to a comparator's threshold level, may cause the comparator to turn on and off unnecessarily.
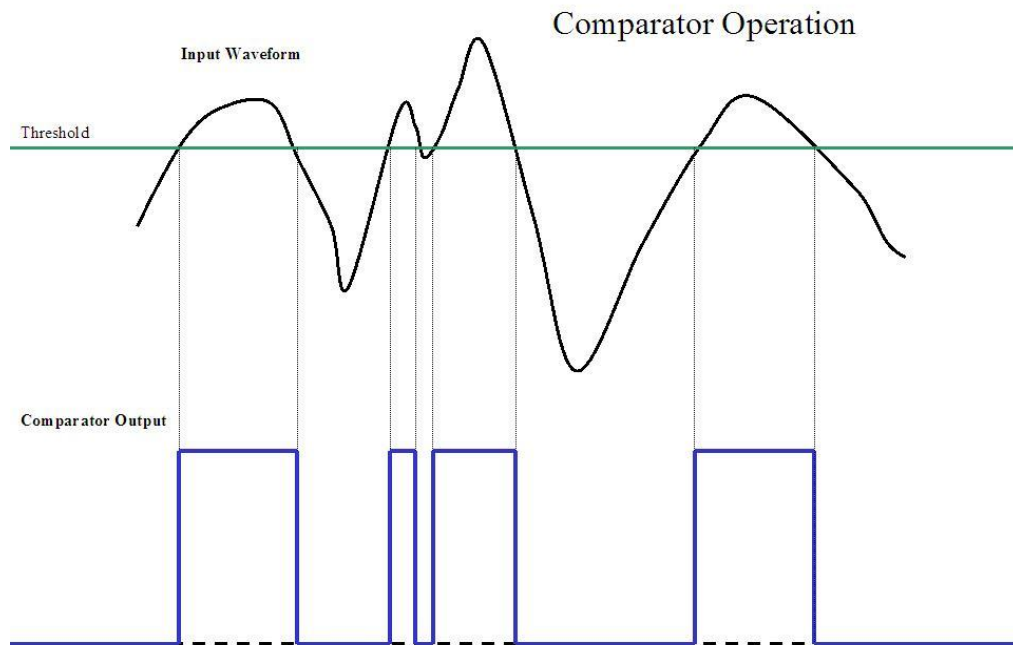
Fig. 35 Comparator Operation

The signal from the Schmitt trigger is fed into a NAND gate, which incorporates the signal from the calibration circuit. The signal then goes to the enable pin of a dual Binary Coded Decimal (BCD) decade counter. The counter drives two separate LED readouts, the tens place and the ones place. When the ones value reaches 9, the counter rolls over and places a high value on the enable pin of the second half of the counter. This half operates the tens place value on the LED display. Combined, these two LEDs form the visual display of the vehicle's speed. This completes the brief description of the circuits in the radar gun.

The unit, according to Ramsey Electronic, is capable of measuring speeds up to and above 99 mph. We <u>did</u> <u>not</u> test the accuracy of this claim. The User's Manual suggests one way of testing the radar gun at higher speeds is to point it at aircraft on landing approach. Since the September 11th 2001, attack on the World Trade Center and the tightened airport security that

resulted, we felt it would be asking for trouble to follow this suggestion. Thus we decided to accept the limitation of a two-digit display.

We came across some Blogs on the web during the course of our investigations concerning the size of an object that can be detected by the radar gun. To detect an object, its physical size must be equal to or greater than the wavelength of the impinging radiation. The Ramsey radar gun operates at a frequency of 2.6 GHz. So an object larger than the corresponding wavelength will be detected, while smaller objects will go unseen.

Use the following formula to calculate the wavelength (λ) corresponding to a frequency of 2.6 GHz:

$$\lambda = c/f$$

where: λ = wavelength

c = speed of light, 186,000 miles per second

f = frequency in Hertz (Hz)

Thus: λ = 186,000 miles/second ÷ 2,600,000,000 cycles/second

= 0. 00007154 miles x 5280 ft/ mile

= 0.3777 ft x 12 in/ ft

= 4.53 in

At a frequency of 2.6 GHz the smallest object that can be detected is 4.53 inches in diameter.

V.B.3. Serial Interface Circuit Board

The optical character recognition system stores the processed images on a laptop computer. We wanted to store the speed data from the Ramsey Radar Gun on the same computer. The Radar Gun kit was not designed to provide a computer interface, so we decided to solder an eight wire ribbon cable to the output pins of the dual BCD decade counter IC chip. The ribbon cable could then be brought to the outside of the Ramsey Readout case. This entailed drilling two one-sixteenth inch holes into the top of the case with the holes spaced far enough apart to allow the ribbon cable to slip smoothly between them. The plastic between the two holes was carefully filed away until the two halves of the case would close without binding or cutting into the ribbon cable. An eight pin breakaway header was soldered to the opposite end of the cable.

The laptop computer has a serial port available for communication with peripheral devices. To convert from the parallel output on the ribbon to a serial input needed by the computer, we used a module from Parallax, Inc (figure 36).
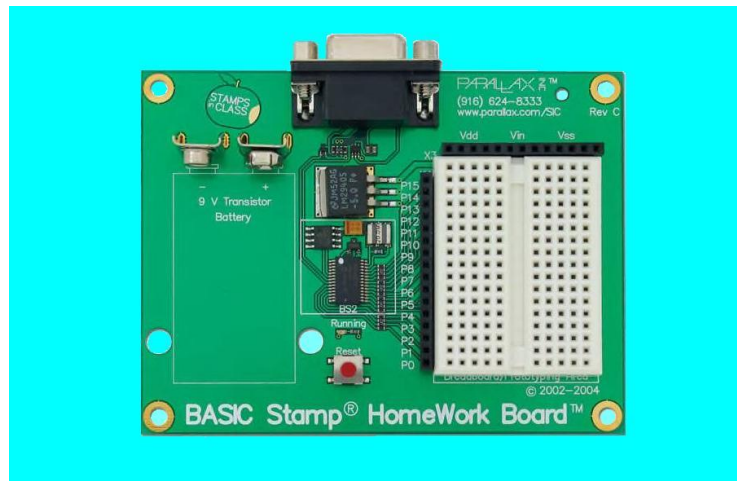
Fig. 36 Parallax HomeWork Board

This unit is from a Parallax training kit for embedded microcontrollers. It contains a programmable PIC microcontroller (µcontroller), a MAX232 chip, and a serial port. The Max232

chip handles the RS232 communication requirements. The ribbon cable from the radar gun plugs

into the black sockets marked P15 to P8 on the left side of the white breadboard.

The PIC µcontroller requires a program in order to function. The BasicStamp2™ modules are

programmed with Pbasic (Parallax Basic) v. 2.5 that is supplied in the HomeWork training kit.

The programming is done on a computer running the BasicStamp2 Editor™ software and is then

downloaded to the PIC µcontroller on the HomeWork board. Once the PIC is programmed it will

continue to run its program ad infinitum. To stop the program, just unplug the battery; to start it

again just plug the battery back in. The program we used to acquire data from the Ramsey Radar

Gun is shown below:

```
'Speed Gun Sensor
'Uses a Ramsey Electronics SG7 Personal Radar Speed Gun kit as a speed sensor

' {$STAMP BS2}
'{$PBASIC 2.5}

Main:

 INPUT 15            'Sets pins as input pins
 INPUT 14
 INPUT 13
 INPUT 12
 INPUT 11
 INPUT 10
 INPUT 9
 INPUT 8

 PAUSE 200       'Pauses program for 200 milliseconds

 DEBUG BIN1 IN15, BIN1 IN14, BIN1 IN13, BIN1 IN12, BIN1 IN11, BIN1 IN10,
     BIN1 IN9, BIN1 IN8, CR    'Reads the value on each pin and sends it to the laptop

GOTO Main       'Loops endlessly
END
```

The Speed Gun Sensor program runs a BasicStamp2™ module ({$STAMP BS2}), using the

PBasic v. 2.5 programming language ({$PBASIC 2.5}). In the "Main" section of the program,

we set pins 8 to 15 as input pins and pause the program for 200 milliseconds. This pause time was chosen because it is somewhat longer than the cycling time of the BCD counter, which requires ~143 milliseconds to update itself. After pausing, the DEBUG routine sends the value on each input pin out the serial port to the laptop via an RS232 connection. The value on pin 15 represents the most significant bit and the value on pin 8 represents the least significant bit in the Binary Coded Decimal. The laptop computer takes this binary input and converts it back to the decimal value of the vehicle's speed.

When the Ramsey kit was assembled, we used IC sockets to mount the IC chips instead of soldering them directly to the printed circuit board. This allowed us to solder the ribbon cable to the BCD counter chip without having to worry about damaging the chip (or any other chip during assembly). In testing the Radar Gun – BasicStamp combination, it was noticed that the digital readout on the Radar Gun went blank, which meant we did not have an independent confirmation of the vehicle's speed. The problem appeared to be caused by too large a drain at the BasicStamp connection. To remedy the problem, we first unsoldered the ribbon cable from the Readout's BCD output pins. Then we purchased a second dual BCD decade counter and mounted it on the HomeWork module's breadboard. Next, the input signal was taken from the Readout's Quad NAND gate IC chip at pin 11. The second BCD counter was wired on the breadboard exactly as the one on the Readout's circuit board, except it draws power directly from the lantern batteries and the second BCD's output pins were now connected to the HomeWork board's input pins.

V. B.4 Table of License Plate Recognition / Speed Detection System Hardware Components

Table 5 Our LPR/SD Hardware Components

Component Description	Store Bought From	Purchase Price
Unibrain Fire-I Board Color Video Camera	www.unibrain.com	105$
12V AC adapter	www.unibrain.com	$20
Unibrain FirWire 400 CardBus Card	www.unibrain.com	45$
Unibrain 50mm Telephoto Lens	www.unibrain.com	$70
Ramsey Electronics SG7 kit (Radar Kit)	www.ramseyelectronics.com	$70
Basic Stamp Training Kit (Serial Interface Circuit Board)	www.parallax.com	$80
Compaq nc6220 (Laptop Computer)	www.hp.com	*
TOTAL:		$390

 *Note: We did not include the cost of the laptop computer.

V.C. LPR Software

There are software packages available for license plate recognition. An example is HI-TECH Solutions SeeCar Software Recognition Package (pricelist given in Appendix B). However, these software packages cost over $4,000 per license which was beyond our budget limits. Instead, we wrote our own software to perform the license plate recognition. We researched free available software libraries to minimize the amount of customized code that would need to be written. Customized code was written to glue these libraries together and provide any additional functionality. The libraries and customized code were combined in to one application executable called LPR.exe. The executable runs on Microsoft Windows XP. The following screen shots show the menus and windows of the application.

Application Main Window

Fig. 37 LPR.exe application main window

The picture above shows the main window of the application. There is a main menu on top and live video from the video camera is shown beneath. The main menu contains several items that each open a sub menu. The "Camera" main menu item opens a submenu containing commands to initialize the camera. These include commands to adjust camera settings such as brightness, exposure time, sharpness, white balance, hue, and saturation. The "Mode" main menu item opens a submenu to set the image type. Image types define the image format type, i.e. YUV, RGB, Mono as well as image size, 640x480, 320x240, or 160x120. The "Rate" main menu item

opens a submenu that sets the camera's frame rate, i.e. 30fps, 15fps, 7.5fps, etc. The "LPR" main menu item contains commands to set the intensity threshold and also commands to start and stop recording plate numbers to a file. There are two other application windows in addition to the main window. They are the "Processed Image" window and the "License Plate Detected" window. They are shown below.

Processed Image Window   **License Plate Detected Window**

Fig. 38 Processed image   **Fig. 39 License number detected**
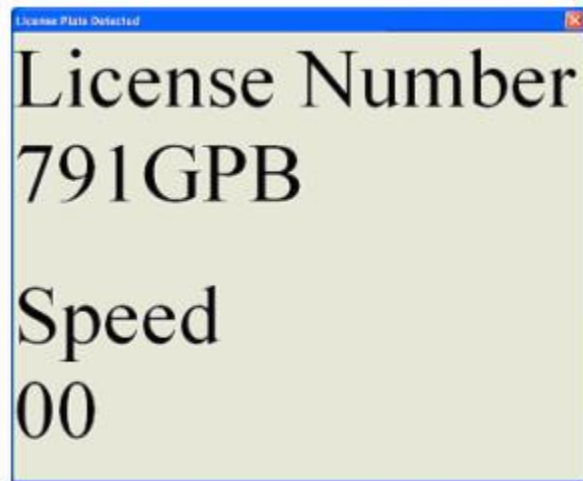
The "Processed Image" window shows live video from the webcam that has gone through image processing. Image processing functions create a black and white image where pixel values are either black (0) or white (1). The "License Plate Detected" shows the last license plate number detected and the speed the vehicle was traveling. The license plate number shown in this window is not an image but text. The three application windows show how the software converts live video to license plate number data.
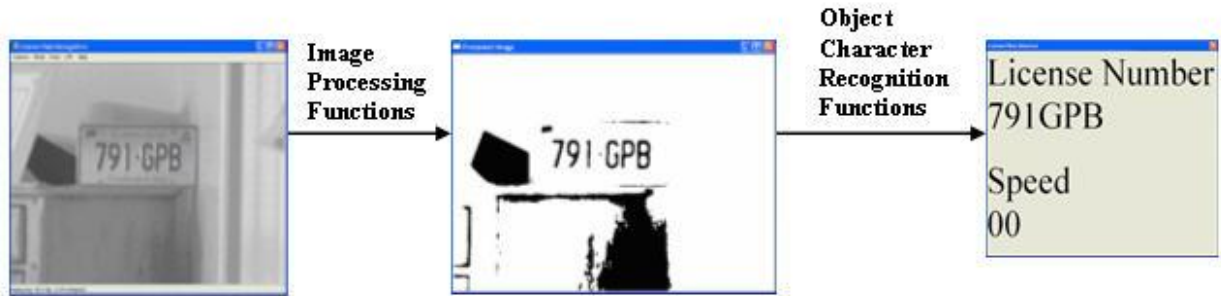
Fig. 40 LPR.exe application windows showing image progression

V.C.1 Instructions for Running the Application

The application is run by double clicking the LPR.exe icon on the desktop. Before the application can successfully record license plate numbers of passing vehicles, the intensity threshold must first be set. The intensity threshold is a value used by the image processing algorithms and will be described in more detail later. To set the intensity threshold, the video camera should be placed in its final position along the roadside. The camera should be focused on a vehicle license plate. The vehicle should be in the center of its lane approximately 38.5' from the camera lens.

1. Click Camera->check link. This will search the laptop for attached cameras.
2. Click Camera->select camera. This will select the desired camera.
3. Click Camera->init camera. This will initialize the camera.
4. Click Mode->640x480 Mono (8 bit). Camera images will be 640x480 pixels, each pixel will have an 8 bit value.
5. Click Camera->Show Camera.
6. Click Camera->Control Dialog (Optional). Set appropriate camera settings for a clear readable image picture or leave on auto settings.
7. Click Rate->30fps. Sets camera to send images at 30 frames per second.
8. Click LPR->Set Threshold plate number. Enter the license plate number of the vehicle in focus.
9. Click LPR->Set Intensity Threshold. This will set the intensity threshold.
10. A popup window will show the chosen intensity threshold. Make sure this number is not 0 and click OK.

Once the threshold is set, the application can start recording license plates of passing vehicles.

Click LPR->Start Recording to record license plate numbers to a file named licensePlates.txt.

V.C.2. Software Architecture

To create the application, we researched available software libraries that were within our budget limits. We then created customized C/C++ code to glue these libraries together as well as add any additional functionality. We used Microsoft Visual C++ to compile and link the application. A diagram of the software layer architecture is given below.

LPR Application				
Microsoft MFC	Intel OpenCV	Serial Library	Tesseract	IIDC DCAM
	Intel IPP			
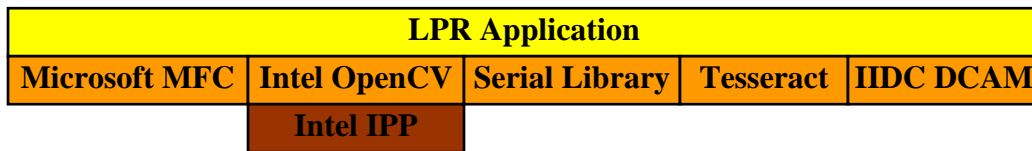
Fig. 41 Application software layer architecture

The LPR application layer contains the customized code we created for the application. It calls functions contained in the lower layer libraries. The Microsoft MFC library was used to help create the user interface. It contains C++ classes for creating application windows and menus. This library is not free and comes with certain versions of the Microsoft Visual Studio package. The Intel OpenCV (Open Computer Vision) library provided computer vision functions to process live video images being received from the webcam. Its functions provided the capability to segment license plate characters in to separate images. This library is free and can be downloaded from www.sourceforge.net. The Intel OpenCV library can be configured to use the Intel IPP (Integrated Performance Primitives) library. This library provides low level image processing functions that are optimized for Intel processors. A student edition of the Intel IPP library can be purchased for $25. The Serial library provides functions for communicating with a computer's serial port. This library was used to retrieve data being sent by the radar gun. The

56

Serial library was written by Ramon de Klein and was downloaded for free from

www.codeguru.com. The Tesseract library provided the functions for object character

recognition. This library converted images of characters in to actual text. This library can be

downloaded for free from http://code.google.com/p/tesseract-ocr/. The IIDC DCAM library

provides communication to the FireWire video camera. The library was developed at the

Robotics Institute of Carnegie Mellon University. It can be downloaded for free from

http://www-2.cs.cmu.edu/~iwan/1394/. The library uses the IIDC DCAM protocol otherwise

known as the Instrumentation & Industrial Digital Camera protocol to communicate with the

camera.

V.C.3 Application Layer Algorithms

Much work was done at the application layer to provide the additional functionality and

customization. At the application layer, the software follows the process flow as defined in figure

23. I would like to expand upon the diamond shape in Figure 23 that states "Does license plate

exist in image?". The algorithm for this decision block is provided in the steps outlined below.

1. First convert the grey scale image received from the camera in to a 1 bit pixel map using an optimal intensity threshold value. An example of this process is shown in the figure below. The input image has pixels in the top two rows whose values are all greater than 50, and has pixels in the bottom two rows whose values are less than 50. The image processing routines receive the input image and output another image. The pixels of the output image are set to 1 if the input pixel value is greater than the threshold value; else they are set to 0.

Input Image			
54	67	94	76
67	87	69	89
45	34	42	29
67	25	48	32

Image Processing
Intensity Threshold = 50

Output Image			
1	1	1	1
1	1	1	1
0	0	0	0
0	0	0	0
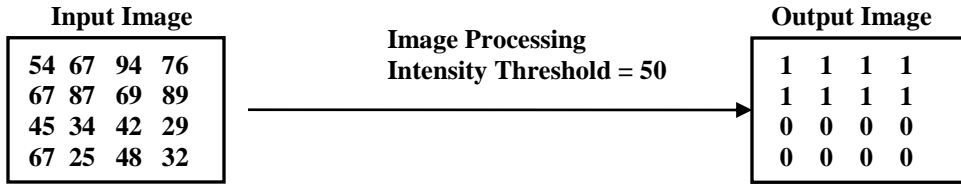
Fig. 42 Image processing using intensity threshold

If the intensity threshold is set properly, then all pixels of the license plate numbers will have a "0" value, and the surrounding pixels will have a value of "1" as depicted in the image below and to the right.
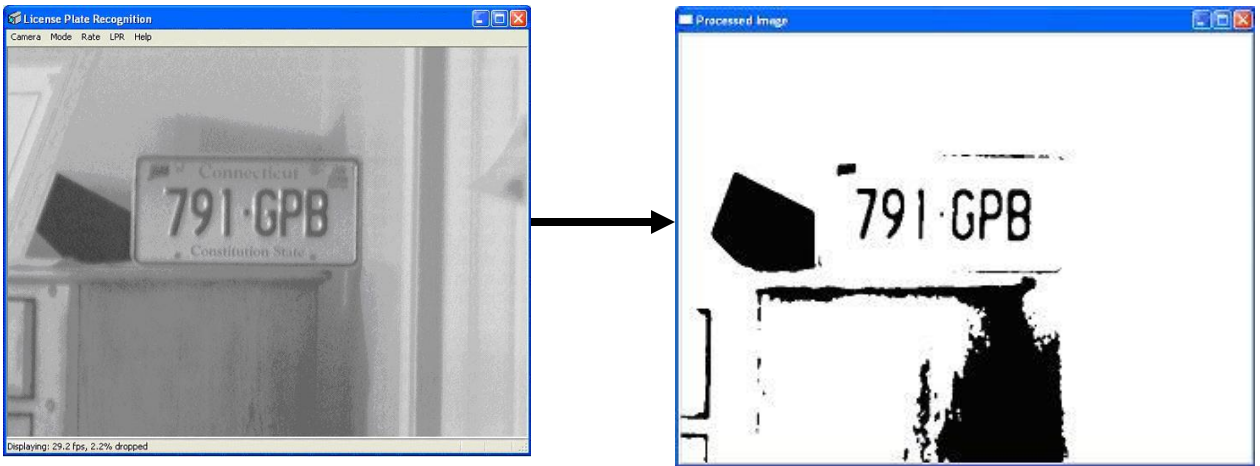
Fig. 43 Image processing using intensity threshold

2. Retrieve contours from the 1 bit pixel map and place them into a hierarchical tree.
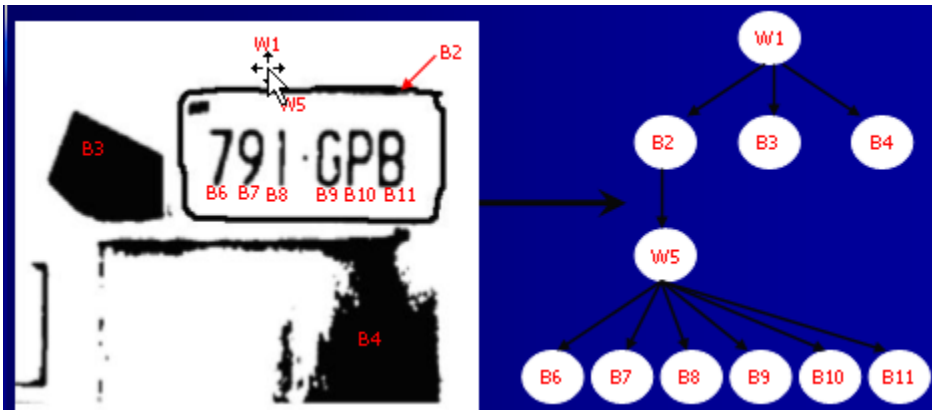
Fig. 44 Mapping image contours in to a tree structure

W1, B2, B3, B4, W5, B6, B7, B8, B9, B10, and B11 are all contours. W1 is the top node in the tree. It contains all other contours. B2 contains contour W5. W5 contain all the license plate character contours.

3. Traverse down the tree, and locate any nodes that have 3 to 6 children that are all of a certain size and are positioned at the same height. These contours are most likely license plate characters. Therefore, a license plate has been detected.

Once a license plate is detected, the contours are passed on to the character recognition functions. These functions convert the images to text.

Another algorithm coded at the application layer automatically calculates the most optimal threshold value. The intensity threshold value is used by image processing functions to determine which pixels are changed to white and which are changed to black. . The algorithm to set this intensity threshold value is simple. The user enters a license plate number that is currently being viewed by the camera. The software then tries a range of threshold values to determine which threshold value provides the closest match to the license plate entered by the user. This threshold value is then used for all subsequent license plate detections. The algorithm steps are given below.

1. Receive the correct license plate characters input by the user.
2. Set threshold value to 0
3. Compare license plate characters detected in image to those input by the user
4. Record how many characters match
5. Increment threshold value
6. Go to step 3 until threshold reaches 255.
7. When the previous steps are complete an array will be created such as the one shown below.

Threshold	147	148	149	150	151	152	153	154	155
Matches	5	6	5	6	5	6	6	6	5

Fig. 45 Array of correct character matches made for a particular threshold value

8. The array contains how many character matches were made for each threshold.

9. The algorithm then finds the longest run of maxes and finds their median. This median is the optimal intensity threshold. I.E. intensity threshold = (152 + 154) / 2 = 153 (intensity threshold is an integer).

This completes the description of the application developed for this project. By using existing free (or relatively free) software libraries and creating our own customized code we were able to build an executable that could recognize and record the license plate numbers of passing vehicles.

V.D. Testing

Testing was done throughout the build of the system. Tests were run against each individual component to ensure its functionality. Three separate components; the radar gun, the serial interface circuit board, and the license plate recognition software were each tested separately. A full system test was never accomplished due to a malfunctioning radar gun. Descriptions of the tests performed for each component are provided in the following paragraphs.

The license plate recognition software component underwent much testing through its development. Several revisions to the source code were made as a result of this testing. In the beginning, tests were made against a stationary license plate. The first version of the source code had several bugs. For one, it was not recognizing license plate characters in certain test cases. It was found that if the background behind the plate was of a certain color or intensity, the recognition software would fail. This was fixed by changing the license plate recognition algorithms. Instead of trying to extract the license plate region from the image, the license plate

characters were first extracted. This was made possible as defined in the algorithm given in Section V.C.3. This algorithm works much better than the first algorithm because the intensity contrast between license plate characters and the license plate itself remains constant across all vehicle images whereas intensity contrast between the license plate and the surrounding region changes from vehicle to vehicle. Test case results improved after this was fixed, but there were still some test cases that failed. It was found that when the registration sticker was placed closely to one of the license plate characters, that character would be misrecognized. This was a result of not having an optimal intensity threshold. The sticker was being seen as part of the license plate character. To fix this, the intensity threshold algorithm as described in V.C.3 was written, so that the optimal threshold intensity was calculated by the software, and the registration sticker was no longer being seen as part of a license plate character.

Once this had been fixed the software worked well against stationary objects. However, further testing showed that if the license plate was visible to the camera for only a very short period of time, the recognition software had trouble recognizing the characters. This test case was done by moving a piece of cardboard quickly in front of and away from the license plate. This was puzzling, because at 30 frames a second, the camera should be able to capture the license plate image no matter how fast I move the cardboard. I discovered where the problem was by watching the application "Processed Image" window. When I moved the cardboard away from the plate, the license plate characters did not suddenly appear in the "Processed Image" window. Instead, the license plate characters faded in slowly even though images were being received at 30 frames per second. This wasn't due to a bug in the code, but is an inherent trait in CCD chips used by common video cameras. It takes time for sensors in the CCD chip to react to changes in color. Data may be pulled from the CCD chip at 30 frames per second; however,

changes in the CCD's pixels may take longer. I discovered that by shining more light on the license plate, the CCD was quicker to react, and the software was able to recognize the license plate in a shorter amount of time. The question remained of whether or not it would be quick enough to capture a speeding vehicle.

It should also be mentioned that the initial source code written had a memory leak. After running the executable for more than five minutes, all system memory was consumed and the computer would crash. It was found that calls to the OpenCV library functions were consuming memory. A certain OpenCV function had to be called during processing in order to free up memory and continue on.

After testing the license plate recognition software with a stationary plate, testing was done outside along a roadside against moving traffic. Testing was done on three separate days. The results of these tests are given below. The "recorded results" section shows what the software recorded to a file for each given test.

Day 1
April 12, 2008, 2:30PM – 4:00PM
Weather – Partly Cloudy
Light Source Used – Sun
Camera to vehicle distance – 52 feet
Speeds Tested (mph) – 5, 10, 20, 30
Plate Number – 08CB10
Test Results – Only the 5 mph test detected a license plate. It detected 5 of the 6 license plate characters correctly.
Recorded Results –
08C810 , Sat Apr 12 15:05:50 2008 , 00
08CB1 , Sat Apr 12 15:05:51 2008 , 00

Day 2
April 20, 2008, 2:44PM-3:30PM
Weather - Sunny
Light Source Used – Sun
Camera to vehicle distance – 38 feet
Speeds Tested (mph) – 5, 10, 30, 40

Plate Number – 791GPB
Test Results – The license plate was detected at all speeds. Most of the tests resulted in 4 to 6 license plate characters being detected correctly.
Recorded Results-
91GPB , Sun Apr 20 14:44:10 2008 , 00 (Actual plate 791GPB)
791GPB , Sun Apr 20 14:44:10 2008 , 00
791GPB , Sun Apr 20 14:44:10 2008 , 00
791GPB , Sun Apr 20 14:44:10 2008 , 00
791GPB , Sun Apr 20 14:44:11 2008 , 00
791GP8 , Sun Apr 20 14:44:11 2008 , 00
791GPB , Sun Apr 20 14:44:11 2008 , 00
791GPB , Sun Apr 20 14:44:11 2008 , 00
791GPB , Sun Apr 20 14:44:11 2008 , 00
791GPB , Sun Apr 20 14:44:11 2008 , 00
791GP , Sun Apr 20 14:44:11 2008 , 00
716PB , Sun Apr 20 14:49:36 2008 , 00
7916P , Sun Apr 20 14:57:53 2008 , 00
7916P1 , Sun Apr 20 15:02:16 2008 , 00

Day 3
May 3, 2008, 1:30PM – 2:15PM
Weather – Overcast
Light Source Used – Artificial lighting from a set of vehicle fog lights.
Camera to vehicle distance – 40 feet
Speeds Tested (mph) – 5, 10, 25, 30
Plate Number – 791GPB
Test Results – The license was detected at all speeds. Most of the tests resulted in 4 to 6 license plate characters being detected correctly.
Recorded Results –
791GPB , Sat May 03 13:50:21 2008 , 00
791GPB , Sat May 03 13:50:21 2008 , 00
791GPB , Sat May 03 13:50:21 2008 , 00
791GPB , Sat May 03 13:50:21 2008 , 00
791GP , Sat May 03 13:50:21 2008 , 00
**I*J , Sat May 03 13:51:40 2008 , 00
**1f8 , Sat May 03 13:51:40 2008 , 00
791FPB , Sat May 03 13:51:40 2008 , 00
791GPB , Sat May 03 13:51:40 2008 , 00
791GP , Sat May 03 13:52:03 2008 , 00
791GPB , Sat May 03 13:52:03 2008 , 00
791IPB , Sat May 03 13:52:03 2008 , 00
I91IPB , Sat May 03 13:52:04 2008 , 00
791*PB , Sat May 03 13:52:04 2008 , 00
791IP8 , Sat May 03 13:52:04 2008 , 00
791UP8 , Sat May 03 13:52:04 2008 , 00
791FPB , Sat May 03 13:52:04 2008 , 00

It should also be noted testing was done to make sure the application could communicate with the serial interface circuit board. Even though the radar gun was malfunctioning, we installed a dummy program on the serial interface board that continuously sent random 2 digit numbers. I tested to make sure that these numbers were received, displayed on the computer screen, and recorded to a file along with the license plate number and time and date.

A picture taken during testing is shown below.
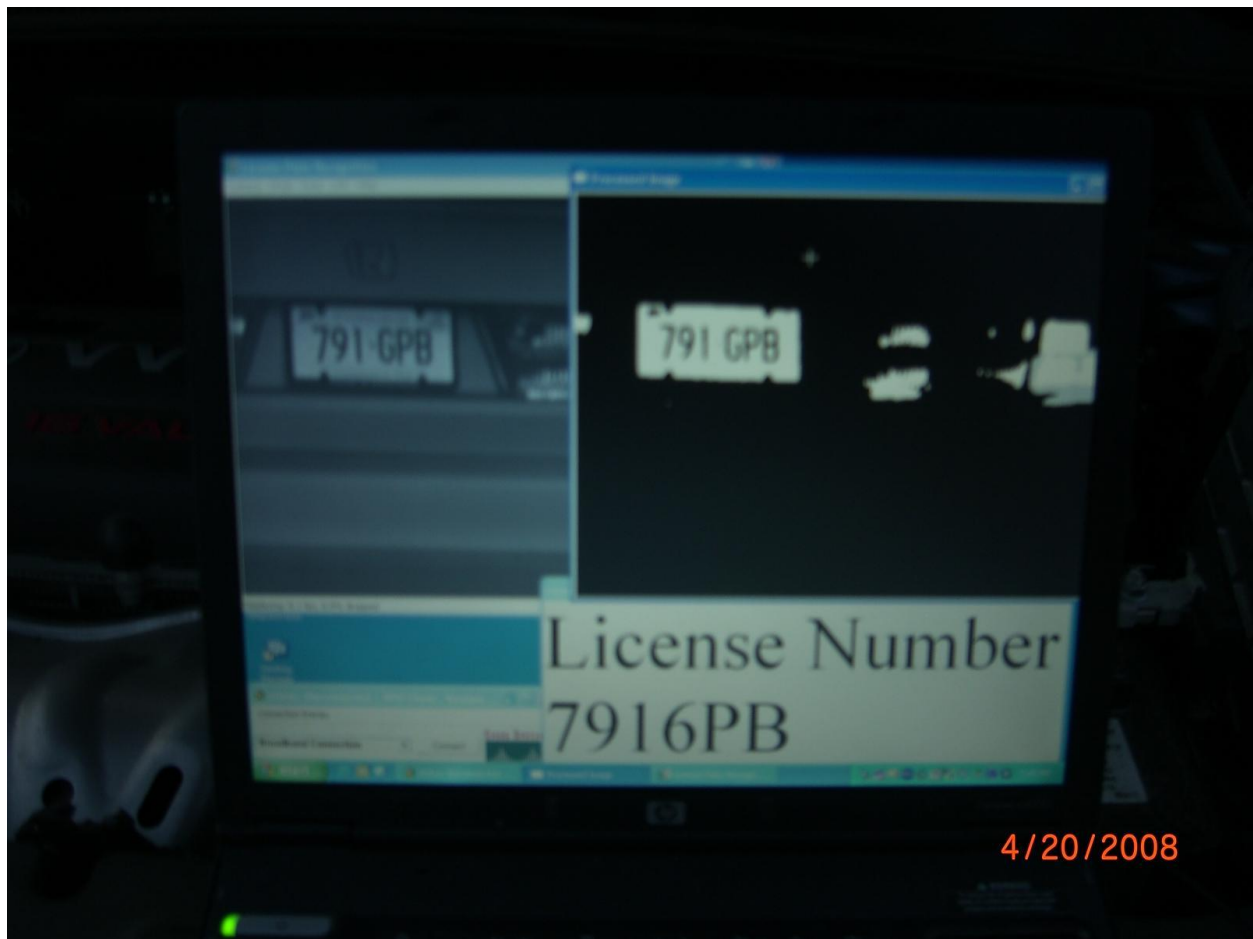
Fig. 46 LPR.exe application in action

VI. Additional Applications

The license plate recognition and speed detection system we have designed and implemented for this project can be further extended to other types of applications. One such application would consist of a traffic display that would flash a driver's license number and warning message if the driver were speeding. Similar systems exist today. These speed display signs flash the driver's speed as well as a customized message according to the driver's speed.

Fig. 47 Example of variable message traffic displays

Our system would flash the driver's speed as well as display the driver's license plate number in the customized message. An example message could read "License Number FDK425 has been recorded for speeding". The effect would create more of a fear factor for the speeding driver. Our speed display sign could be built on top of our current license plate recognition system. The new system design would consist of a commercially available traffic display similar to the one shown above customized to communicate with our system. The new system is depicted in the diagram below.
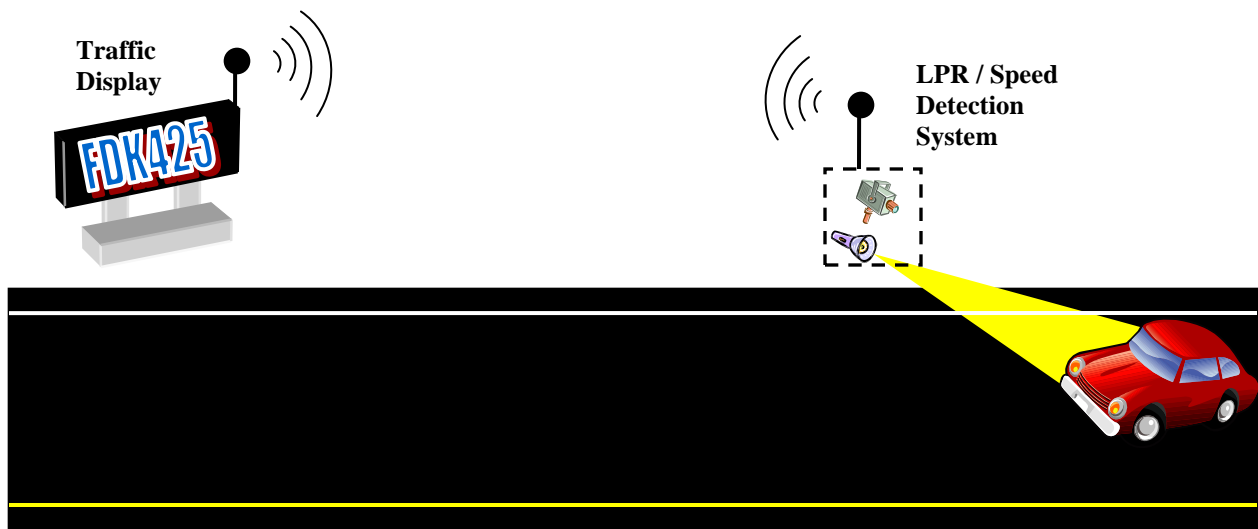
Fig. 48 LPR application with traffic sign

Wireless technology would be needed to communicate between the LPR System and traffic

display due to the physical distance needed between them. Since the LPR system detects license

plates at around 40 feet, it would have to be positioned further in front of the traffic display to

provide the time delay needed to display the message for several seconds for the driver to see.

Over 354 feet separation would be needed to display the message for more than 3 seconds for a

car traveling 80mph. Only a small amount of bandwidth would be needed for the wireless

communication. The LPR system would only be sending speed and license plate information to

the traffic sign. The data size would consist of a few bytes for each car. ZigBee wireless

technology would match the performance and range needed. Digiboard's ZigBee modules such

as the XBee-PRO Znet 2.5 OEM RF Module would work well. These modules connect to the

serial port of a computer and provide 250kpbs bandwidth at up to one mile away.

There are many different traffic display signs available. We would only need one which

could be programmed through a serial or USB port. It would not need speed radar capability

since our LPR system would already be sending speed information. A computer would be

needed to communicate with the traffic display and also to receive the wireless signals being sent by the LPR system. A Via mini-ITX computer would be a good match for the requirements needed. Customized software would also need to be created. Overall the system would be very similar to the system we developed for this project. However, instead of recording license plate and speed information to a file, they would be sent wirelessly to the remote computer connected to the traffic display sign.

Another type of application our system could be extended to is a wireless network of LPR/Speed detection systems connected together in a hierarchical star topology. The network would span across a city or town and be monitored by the local law enforcement. Each LPR/Speed system would record speeds and license plate numbers of passing cars and send the information to a centralized database. The database would be located at a local police station where police officers could watch traffic flow in real time. Each LPR system would be a node in the network that would communicate with other LPR systems using wireless technology. Zigbee technology could be used for this application as well. The diagram below depicts the network topology.
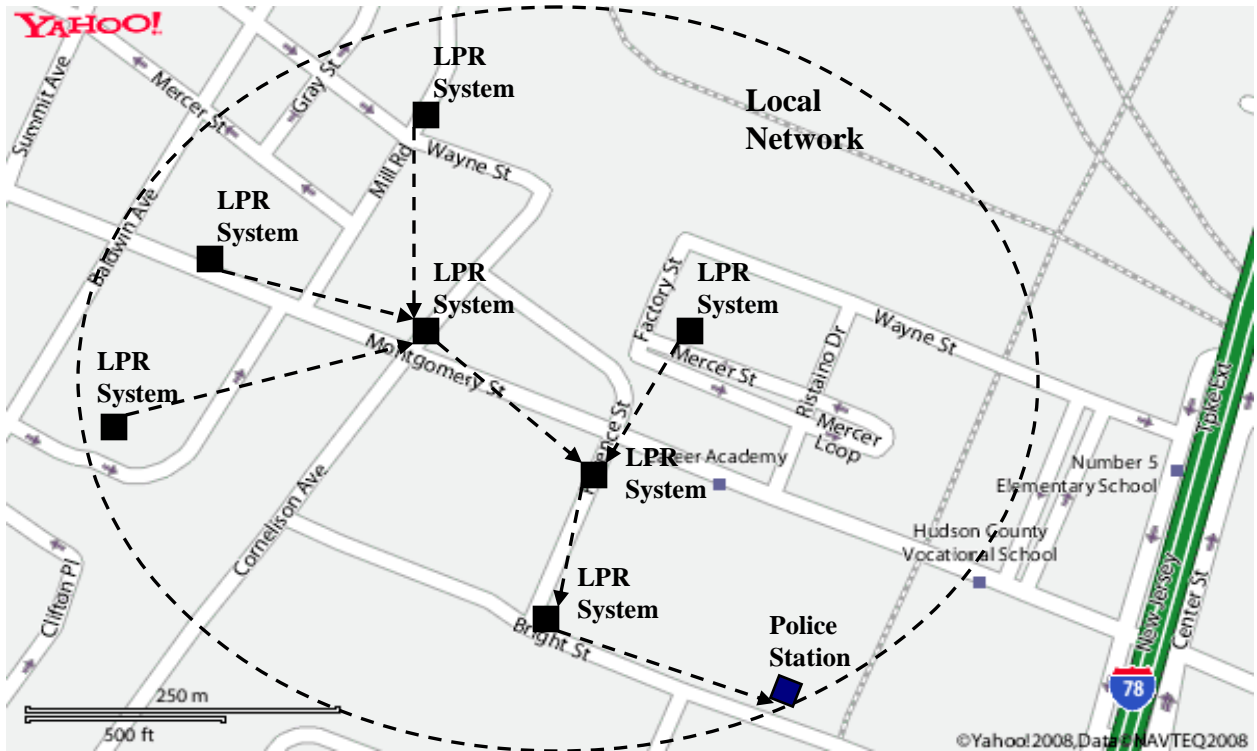
Fig. 49 LPR application of networked LPR/SD systems

LPR systems located furthest from the police station would send license plate and speed information to LPR systems located closer to the police station until the data reached the centralized data base at the police station. Since Zigbee wireless technology offers ranges of up to one mile, the LPR systems could be placed up to 1 mile apart. The 250kbps bandwidth offered by Zigbee would be large enough even to handle the increased bandwidth needs at nodes closer to the police station. This is due to the small data size of the information being transferred across the network. If there were a need to have LPR systems further distant from the police station, such a system could be implemented using cell phone technology such as CDMA or GSM. The network architecture could have a hierarchical star topology such as the one shown below.

Fig. 50 LPR application of networked LPR/SD systems in a hierarchical star shaped network

At the police station the central database would record all traffic information received from the remote LPR/Speed systems. An application would run on top of the database that could display this information on to a dispatcher's computer screen. A map would display where a vehicle had passed as well as at what time the vehicle had passed and the speed they were traveling. An example is shown below.
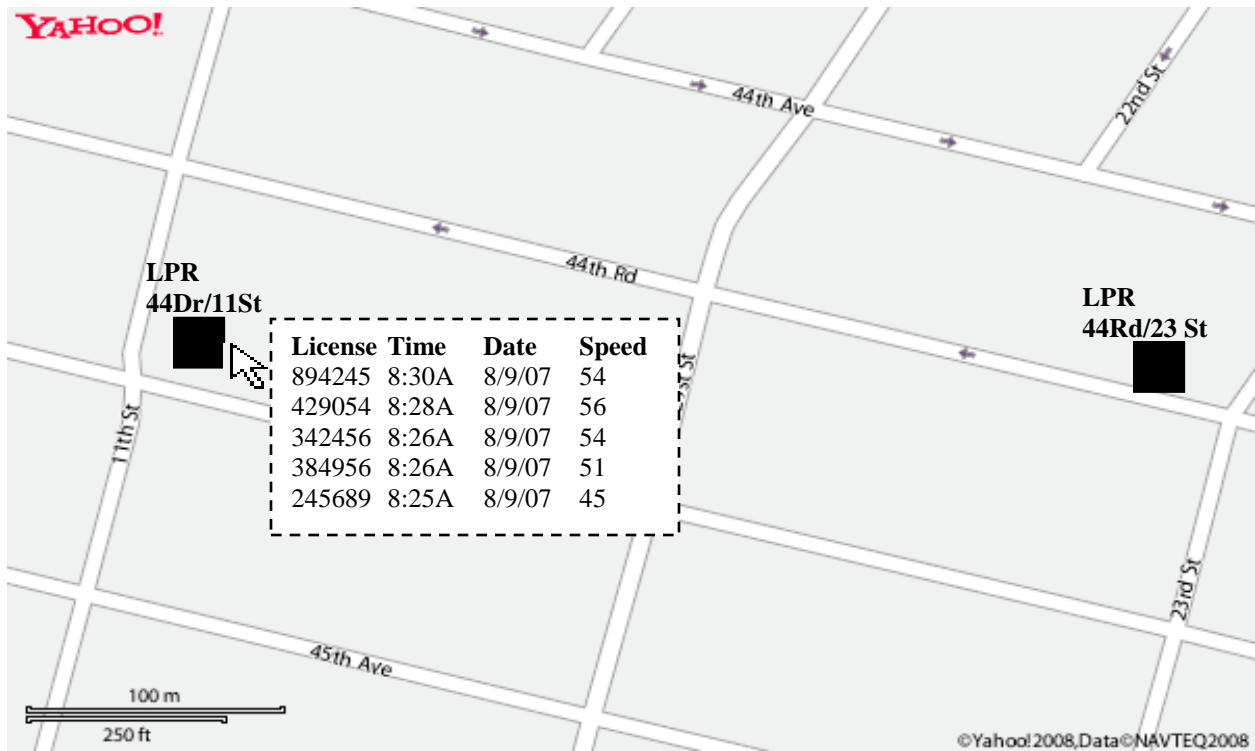
Fig. 51 Example of an LPR application window showing real time traffic flow

The map would be scroll and zoom capable showing the locations of LPR/Speed systems. When an LPR/Speed system is clicked on, a table is displayed listing vehicle information, such as at what time vehicles passed and at what speed they were traveling. Queries could also be run against the database, such as "Show the travel paths taken by a vehicle with license plate number "FDE124" between 8:00 AM and 10:00 AM on December 8, 2006". The map would highlight which LPR/Speed systems the vehicle had passed and at what times. This type of application could be helpful for many different types of scenarios. Law enforcement could easily track a criminal's path in real time and be able to locate and capture them.

VII. State of the Art Commercial Systems

One of the first traffic radar systems was built by Automatic Signal Company for the Connecticut State Police in 1947. These early radar units were based on heavy, bulky vacuum tube technology and consisted of three parts; a 45 lb. box containing the transmitter-receiver, a strip-chart recorder used to produce a permanent record, and a calibrated analog meter to provide a reading in miles per hour. Originally, the transmitter-receiver was mounted on a stand-alone tripod or it was bolted to the hood of the patrol car. It is interesting to compare this description with figure 52, which shows today's technology.

Fig. 52 Modern Radar Gun

The hand-held radar gun was invented by Bryce K. Brown of Decatur Electronics in March 1954, and was first used in Chicago, Illinois by Patrolman Leonard Baldy in April 1954. It is interesting to note, the State of Connecticut has a statute that states "On and after July 1, 1992, no hand-held radar device that emits nonionizing radiation may be used in this state by any state or municipal police officer in the course of his employment for the purpose of preventing or detecting any violation of any law relating to motor vehicles (C.G.S., Title 7, Chapter 104, § 7-294z).

Early radar guns used frequencies in the 2 to 4 GHz S-band range (Ref. 10). Microwave ovens and some low powered communications devices also operate at these frequencies. For this reason and the fact that the gun had a maximum range of only 500 feet, the guns are now obsolete. A vehicle moving at 55 mph would traverse this range in 6.2 seconds; not much time for the old vacuum tube technology to respond to a stimulus.

X-band (10.525 GHz) radars were developed and deployed in the mid 1960's. They had better performance characteristics in bad weather when compared to K and Ka band radars; but they also had wider beamwidths.

K-band (24.15 GHz) was introduced in the mid to late 70's and had been used by the military during WWII. These devices were very susceptible to weather conditions, as a result of water vapor absorption at 22.24 GHz.

In 1992, the Federal Communications Commission expanded the previously allocated Ka-band (33.4 to 36 GHz) for use with traffic control radars. These units have a narrow beamwidth, but they are also affected by weather conditions which shortens their operating range. Manufacturers of Ka –band radar have engineered their systems to provide channels either

100 MHz wide or 200 MHz wide. Since the allocated operating frequency spans a 2600 MHz range, a radar gun with a 100MHz channel width will have 26 different channels for its operation resulting in less interference with the system.

The last of the "radar" type systems is the LIDAR or LADAR. The acronym stands for LIght Detection And Ranging or Laser Detection And Ranging, and they were developed in the 1990's. They use Class 1 (eye-safe)[*] pulsed Infra-red (IR) laser diodes at frequencies at the upper end of the IR spectrum and produce very narrow beams. This is an important attribute when trying to measure vehicle speeds in congested areas. These units are harder to operate compared to X and K band radar units. They need to be pointed directly at the moving vehicle using a crosshair sight. Thus, the operating officer needs to be stationary when using a LIDAR, whereas X and K band radars can be used in a moving police vehicle. In either case, the officer operating the radar unit must be trained and certified in their operation.

Photo radars (figure 53) and Red Light Cameras (figure 54) are two types of automated traffic enforcement devices that are used in various parts of the United States.

Fig. 53 Photo Radar

Fig. 54 Red Light Camera

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[*] The FDA' Center for Devices and Radiological Health regulates the manufacture and sale of laser devices in the United States. Class1 lasers are defined by the American National Standards Institute.

Early in their development stages these devices used wet-film cameras to record alleged violators' actions. This required a police officer to manually retrieve the film, have it developed, and then it required visual inspection to obtain a license plate number. When Charge Coupled Device (CCD) cameras became available in digital cameras, they replaced the film camera. The pictures could now be recorded on flash drives, saving the time and expense of developing film. However, an officer still had to retrieve the flash drive. With the proliferation of wireless communications devices, it should only be a matter of time before a company like Hi-Tech Solutions replaces the wired connections in the diagram below with wireless connections via Bluetooth or ZigBee technology. For a listing of major radar gun manufacturers, please see Appendix A.
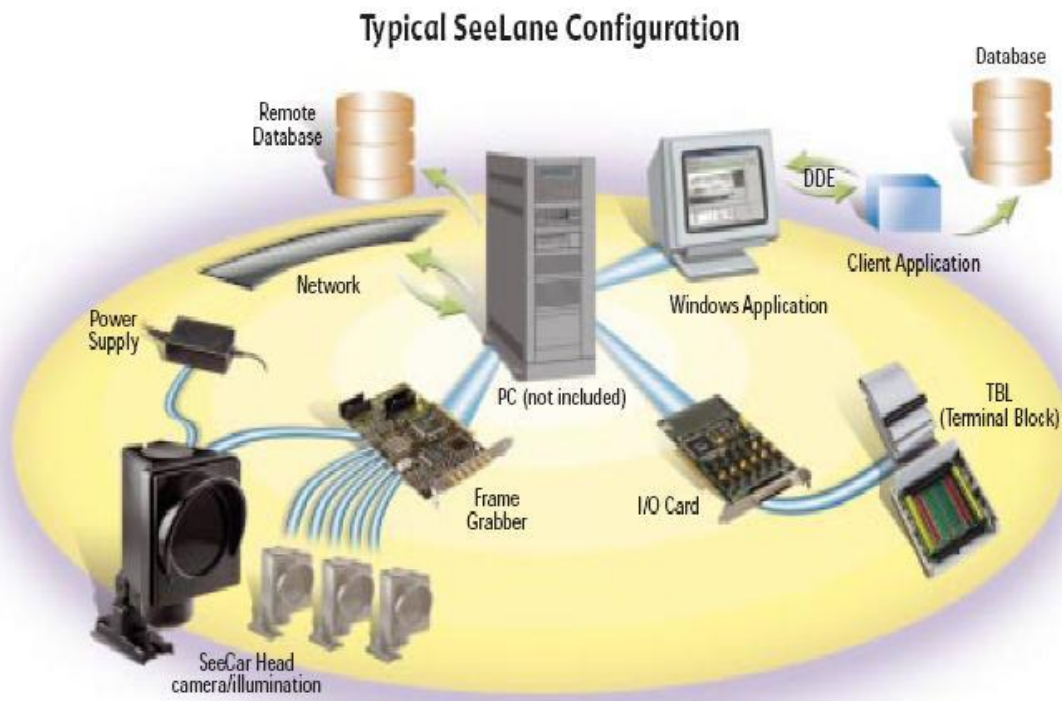
Fig. 55 Possible Traffic Enforcement Network

As with any new technology affecting people's lives, automated traffic enforcement systems have been the object of various legal challenges, which we'll briefly discuss in the next section.

Legality of LPR/traffic violation systems

Disclaimer: In this section we discuss the legality of license plate recognition systems. Since we are not lawyers, the material presented here <u>is not</u> to be construed to be legal advice, nor is it intended to be an exhaustive treatment of the subject matter.

Research has shown that some of the major causes of motor vehicle accidents are speeding and failure to obey traffic signs and signals, i.e. stop signs and red lights. In 2002, over thirteen thousand people were killed in speed related motor vehicle accidents, which resulted in a cost to the American taxpayer of $10 billion. Statistics for 2003 have shown more than 176,000 people were injured by motorists that ran stop lights. This has lead to an additional $14 billion dollar tax burden. This is above and beyond all the pain and suffering resulting from these accidents.

The Insurance Institute of Highway Safety conducted a 9-month study using photo radars in Scottsdale, Arizona. The study was confined to an 8-mile stretch of the 25-mile long highway known as "the Loop". Prior measurements showed fifteen percent of the motorists were driving at speeds < 10 mph above the posted limit. By the end of the study period the percentage had dropped to less than 2%. Similarly, in Montgomery County, MD, the number of speeding motorists dropped by 70%. However, once the program in Scottsdale ended, the average speeds went up to 69 mph in a 65-mph zone and more than 12% of the drivers were traveling at 75 mph or more. As a result of such studies and in order to prevent the violation of traffic laws, the

Federal Highway Administration and the National Highway Traffic Safety Administration have indicated their support for automated enforcement systems. Numerous states (Arizona, California, Colorado, Delaware, Hawaii, Illinois, Maryland, New York and Virginia) have enacted statutes allowing the use of these automated systems to enforce traffic laws (Ref21). Connecticut statute (C.G.S. Title 14, Chapter 248, § 14-219c, Vehicle Highway Use), does not specifically mention photo radar or red light cameras, but the statute's phrase "any other speed monitoring device approved by the Commissioner of Public Safety" could allow for their use. In the 2005 legislative session, House Bill 5744 (Ref. 31) attempted to introduce devices that are "designed to automatically record the image of the license plate of a motor vehicle that is entering an intersection in violation of a traffic control signal". However, the bill was never signed into law. In the January 2007 session, raised bill #1443 was introduced in the State Senate where it has been referred to the Joint Committee on Judiciary; it has not left the Committee. In November 2007, Connecticut Governor Jodi Rell proposed installing automated traffic enforcement devices along a stretch of Interstate-95 in East Lyme where I-95, I-395, and Route 1 intersect. This proposal is being reviewed by the Department of Public Safety.

The National Highway Safety Commission has set 65/55 mph as the speed limit on much of the Federal Interstate Highway system, with lower limits set for densely populated areas. It is the responsibility of the individual states to establish appropriate speed limits for roadways that are not part of the Interstate system. For example, Connecticut General Statute Title 14, Chapter 249, Part 1, Section 14-309, assigns the responsibility for determining safe speed limits to State Highway Traffic Commission.

In most states motor vehicle violations are considered warrant-less misdemeanor violations and in general they fall under common law practice (Ref. 28). According to common

law, a warrant-less crime must be committed in presence of a police officer and the arrest for the crime must be immediate. This has lead to a number of legal challenges to moving violation arrests based on the use of photo radars or red light cameras. The challenges have two components. First, since the photo radar/red light cameras are machines and not human beings, the requirement "in presence of a police officer" was not met. Second, the infraction was recorded by a device that required the retrieval of film or the processing of digital data introducing a time delay, the arrest was not immediate. An on-line review (Lexus-Nexus and Loislaw databases) has shown the courts to be unsympathetic to these arguments provided that the citation is issued "in a reasonable amount of time". Various state laws have defined the meaning of "in a reasonable amount of time". For example, the State of Rhode Island defines it to be within 14 days of the occurrence of the infraction. Other states require the citation to be mailed within 48 hours of the infraction. The U.S. Supreme Court to date has not commented on nor felt obligated to redefine common law practices; thus legal challenges based on a strict interpretation of common law will continue to fail.

Further legal challenges to the use of photo radar and/or red light cameras have contended that these devices violate a person's rights under the 4th, 6th, and 14th Amendments to the U.S. Constitution. The Fourth Amendment states in part "the right of the people to be secure in their persons, houses, papers, and effects, against unreasonable searches and seizures, shall not be violated." For a photo radar/red light camera to be considered constitutional under the 4th Amendment it must provide the government with "probable cause" to assume that a crime has been committed. Probable cause is defined under the 4th Amendment as "a reasonable belief" that a crime has been committed. Reasonable belief is based on the circumstances. Thus, the reasonable belief that establishes the probable cause requirement is present when the police

officer has sufficiently trustworthy facts and circumstances such that a prudent person would conclude that the suspect has or is committing a crime.

The Sixth Amendment to the U.S. Constitution states "In all criminal prosecutions, the accused shall enjoy the right to a speedy and public trial, by an impartial jury of the State and district wherein the crime shall have been committed, which district shall have been previously ascertained by law, and to be informed of the nature and cause of the accusation; to be confronted with the witnesses against him; to have compulsory process for obtaining witnesses in his favor, and to have the Assistance of Counsel for his defense.(emphasis added)". A legal challenge to the use of a red light camera was brought up in the case of Dajani v. Maryland. The court dismissed the case based on the lack of standing to sue based on the plaintiff's failure to show threat of immediate or future injury. Plaintiff Dajani then argued in federal court that the traffic code was unconstitutional based on the Sixth Amendment and the Fourteenth Amendment (All persons born or naturalized in the United States and subject to the jurisdiction thereof, are citizens of the United States and of the State wherein they reside. No State shall make or enforce any law which shall abridge the privileges or immunities of citizens of the United States; nor shall any State deprive any person of life, liberty, or property, without due process of law; nor deny to any person within its jurisdiction the equal protection of the laws. (emphasis added)). The federal court upheld the state courts opinion base on subject and jurisdictional grounds and did not address the constitutional issues.

Opponents to the use of photo radars and /or red light cameras claim that there are alternatives to their use. One alternative is to remove unwarranted traffic lights and replace them with four-way stop signs. However, in general, traffic lights are installed at intersections that

experience high traffic volumes or high speeds where stop signs are not appropriate. A second alternative is to adjust the signal's timing to provide a longer yellow light. Even where the signal's yellow phase had been lengthened, people still ran the red light. A third suggested alternative has been to change the geometry of the intersection to make the traffic signals more visible to drivers.

However speed and distraction are the main culprits resulting in drivers running red lights. Proponents of these traffic control devices claim that the gain in safer roadways is measurable. Indeed, both the Insurance Institute for Traffic Safety and the National Highway Traffic Safety Commission supports their use. The cameras photograph only the vehicle's license plate thereby reducing the privacy issues. Adequate notice is given to the persons receiving the citation to allow them to obtain legal counsel. The public highway does not provide for the same expectation of privacy that is accorded a person's home. All drivers operate their vehicles in plain and open view. Finally, in all states of the Union, speeding and running traffic lights is against the law. Connecticut was the first state to adopt speed laws in 1901; 12 mph in the city and 15 mph in rural areas (Ref. 23).

The preceding was a necessarily brief overview of the legality of these traffic control devices. For those interested in this area, we urge you to follow up with the references and resources provided at the end of this work.

VIII. Conclusion

License plate recognition systems exist today for a wide range of applications. The technology behind LPR systems has advanced over the years and has greatly increased in accuracy. Most commercially available systems sold today are sold by system integrators who must configure and customize systems for the application being implemented. We started our capstone project by first defining a semi original LPR application specification. The specification required a system be built to record the speed and license plate numbers of passing vehicles. We researched currently available systems for commercial use and found their products to be too costly.

The only way to build a system within our budget constraints was to design a limited system from scratch. In so doing, we learned the intricacies of every component of the system. We researched what components we could afford and purchased those components. We defined optimal specifications for those components and provided examples of higher quality products that met those specifications. We learned the physics behind light and radio frequency waves as well as camera terminology. We implemented original algorithms in software to perform image processing and character recognition for an LPR type application. We researched currently available free (or almost free) software libraries that provided the functionality we needed and integrated them in to our application. We also soldered circuit boards and a radar kit to reduce the costs of buying commercial systems. We created software to run on the serial interface circuit board as well.

Our system, although only partially functional and having many limitations, can easily be improved upon. We have formed a good base and with the addition of higher quality products a more practical system could be implemented. The software created can easily be reused. It was

quite a fun experience to build the system and have something real and tangible at the end. It was

a great way to learn about science, mathematics, computer programming, and electronics. I hope

our efforts will be continued by other students who partake on the challenge of building a license

plate recognition system.

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    Kit Ramsey Electronics Model No. SG7

13) Readout Circuit Diagram: "Speedy" Personal Speed Radar
    Kit Ramsey Electronics Model No. SG-7

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Appendix A: Our LPR/SD System Component

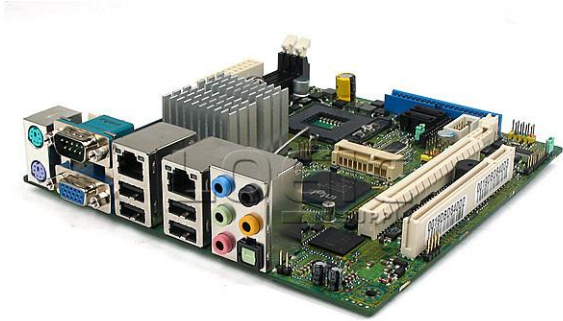# Specifications

The Unibrain Fire-I board color camera was used for our LPR/SD system.

Specification	Fire-i board color	Fire-i board monochrome	Fire-i board color RAW
Device type: IIDC 1394-based Digital Camera			
Compliance	v 1.04	v 1.04	v 1.04
Reported Manufacturer Name	Unibrain	Unibrain	Unibrain
Reported Model Name	Fire-i BCL 1.2 (before Apr 04: Fire-i 1.2)	Fire-i BBW 1.3	Fire-i BCR 1.2
Interface	IEEE-1394a, 2 ports (6 pins), 1 remov.	IEEE-1394a, 2 ports (6 pins), 1 remov.	IEEE-1394a, 2 ports (6 pins), 1 remov.
Speed	400 Mbps	400 Mbps	400 Mbps
Photo			

Sensor: Sony Wfine* 1/4" CCD   * Wfine CCD is a trademark of Sony Corporation

	Fire-i board color	Fire-i board monochrome	Fire-i board color RAW
Sensor name	ICX-098BQ	ICX-098BL	ICX-098BQ
Scanning	progressive	progressive	progressive
Effective pixels (H x V)	659 x 494	659 x 494	659 x 494
Pixel shape (H x V)	square, 5.6 x 5.6 µm	square, 5.6 x 5.6 µm	square, 5.6 x 5.6 µm
Color	yes, RGB filtering, Bayer	no color filtering	yes, RGB filtering, Bayer
Resolution TV-lines (H x V)	400 x 400	480 x 480	480 x 480

Optics: provided separately

	Fire-i board color	Fire-i board monochrome	Fire-i board color RAW
Mounting base standard	M12x0.5	M12x0.5	M12x0.5

Recommended lenses from Unibrain (many models also from other manufacturers)

	Fire-i board color	Fire-i board monochrome	Fire-i board color RAW
IR filter coated 2.1 mm	all lighting conditions	visible light only	all lighting conditions
IR filter coated 4.3 mm	all lighting conditions	visible light only	all lighting conditions
IR filter coated 8.0 mm	all lighting conditions	visible light only	all lighting conditions
not IR filter coated 12 mm	avoid halogen and sunlight	visible light and close IR vision	avoid halogen and sunlight

Picture modes: progressive VGA uncompressed, modes selection by 1394 link

	Fire-i board color				Fire-i board monochrome				Fire-i board color RAW			
Resolutions	640x480, 320x240, 160x120				640x480				640x480			
Codings	YUV, RGB, Monochrome				Monochrome				Monochrome			
Video Modes / Frame rates	30 fps	15 fps	7.5 fps	3.75 fps	30 fps	15 fps	7.5 fps	3.75 fps	30 fps	15 fps	7.5 fps	3.75 fps
640x480 RGB-24 (24 bits)		X	X	X								
640x480 YUV 4:2:2 (16 bits)		X	X	X								
640x480 YUV 4:1:1 (12 bits)	X	X	X	X								
640x480 Y-Mono8 (8 bits)	X	X	X	X	X	X	X	X	X	X	X	X
320x240 YUV 4:2:2 (16bits)	X	X	X	X								
160x120 YUV 4:4:4 (24 bits)	X	X	X									

Picture settings: selection by 1394 link

	Fire-i board color	Fire-i board monochrome	Fire-i board color RAW
Gain	Auto / Manual 0 - 30 dB	Auto / Manual 0 - 30 dB	Auto / Manual 0 - 30 dB
Shutter	Auto / Manual 1/3400s - 1/31s	Auto / Manual 1/3400s - 1/31s	Auto / Manual 1/3400s - 1/31s
Black level	Auto / Manual	Auto / Manual	Auto / Manual
Gamma	OFF(linear) = 1 / ON (visual) = 0.45	OFF(linear) = 1 / ON (visual) = 0.45	OFF(linear) = 1 / ON (visual) = 0.45
Backlight compensation	6 modes + OFF	6 modes + OFF	6 modes + OFF
Sharpness	OFF(linear) = 0 / ON (visual) = manual	OFF(linear) = 0 / ON (visual) = manual	not supported
White Balance	Auto / Manual	not supported	Manual only
Color Saturation	Manual	not supported	not supported
Reference picture generator	Bars and ramps, all modes. ON/OFF	not supported	not supported

Power supply: 8 to 30 VDC, software switched by 1394 link

	Fire-i board color	Fire-i board monochrome	Fire-i board color RAW
Source	by 1394 link / external jack input	by 1394 link / external jack input	by 1394 link / external jack input
Standby power	400 mW typ., 450 mW max.	400 mW typ., 450 mW max.	400 mW typ., 450 mW max.
Operation power	900 mW typ., 1 W max.	900 mW typ., 1 W max.	900 mW typ., 1 W max.

Appendix B: Commercial Components

MSI Industrial GM965 Mini-ITX Motherboard

MS-9803 SPECIFICATIONS

Processor	Core 2 Duo Mobile (Merom & Penryn), Celeron M 5xx (Merom) Socket P (478 pin) 800/533 MHz FSB
Chipset	Intel GM965 northbridge ICH8M southbridge
System Memory	2 DDR2 533/667 SDRAM sockets Up to 3.25GB memory size
VGA	Built-in Intel Graphics with GMA X3100 Technology
Expansion Slots	1 PCI Express (x16) 1 PCI (32-bit) 1 PCI Express Mini Card
Onboard IDE	1 ATA 100 (40-pin)
Onboard Serial ATA	2 SATA (3Gb/sec.) connectors
Onboard USB	8 USB 2.0
Onboard LAN	1 Intel 82566DC 10/100/1000 1 Intel 82573L 10/100/1000
Onboard Audio	ALC888 7.1/5.1 channel HD audio codec
Back Panel I/O	1 PS2 mouse port 1 PS2 keyboard port 1 VGA port 1 RS-232 COM port 2 LAN ports 4 USB 2.0 ports 6 Audio jacks: line-out, line-in, mic-in, rear surround-out, center-/subwoofer-out, S/PDIF-out (optical)
Onboard I/O Connectors	1 IDE slot 1 LVDS connector 1 DIO connector (16 GPIO) 1 RS-232 COM connector 1 Parallel port connector 1 S/PDIF connector 2 SATA connectors 1 TV-out connector 2 USB 2.0 connectors for 4 USB ports 1 Front panel connector 1 Amplifier connector (4-pin) 2 Fan connectors ATX power connector

MDL LaserAce® IM OEM Laser Modules

LaserAce® IM

Product number: 9001

OEM Laser Module

The LaserAce® IM OEM Laser Modules are compact class 1 eye safe, rugged, multipurpose laser distance meters for integration into OEM applications. The laser distance measuring modules have been specifically designed for additional integration each giving a reflectorless range of up to 700m (2300ft), 300m (1000ft), 150m (500ft) and 35m (110ft) for the IM700, IM300, IM150 and IM35 respectively. The sensors can be integrated into a number of suitable system applications requiring, primarily distance measurement.

LaserAce® IM OEM laser modules can be configured to output range, speed and height of vehicles or objects and may also be set to trigger cameras in tollbooth or law enforcement applications. The laser sensors can also be further integrated to produce vehicle profiles and scans, classify and identify them, count axles, over height detection and much more.

Kapsch TrafficCom based in Austria use the LaserAce® IM 300's for triggering cameras in toll booths. DI R Wieden of Kapsch TrafficCom commented, **"LaserAce® IM is easy to integrate and to adopt according to the given surroundings (conditions of the location). The product perfectly fits the requirements for vehicle detection and camera triggering that we have defined."**

"The primary reasons we have used the LaserAce® IM, laser modules are because they can accurately detect vehicles and classify truck versus passenger car without requiring a second mounting structure (e.g. gantry) or installing something in the roadway for multi-lane free flow applications. Most other laser detector devices must be mounted pointing straight down and thus in order to trigger a camera mounted above a lane, requires a second mounting structure (one for the laser and a different one for the camera). The MDL laser eliminates the need for the second gantry and allows us to mount the trigger device right next to the camera housing." Quote from JAI Pulnix, Denmark

Alongside traffic applications the LaserAce® IM OEM laser module is used in military, security, construction and aviation markets. From a target designator, motion detector, surveying tool and altimeter, each market segment has its own special requirement. Here at MDL we are aware that no two applications are exactly the same so we work with our OEM partners to provide unique solutions to their individual applications and are always willing to help. LaserAce® IM OEM laser module is cost effective, accurate, fast and environmentally sealed to IP67 making it the most robust sensor on the market today!

The OEM laser modules use time-of-flight technology, put simply, it measures the time taken for a very short pulse of infrared laser light to travel from one window in the module, to a very low noise detector in a second window. The distance to the target is calculated from the time taken to make the round trip. The reflected light signal levels are very low, so the greater the reflectivity of a target, the longer the range over which this target can be 'seen'. Therefore, reflective targets will increase the range of each of the LaserAce® IM OEM laser modules.

We provide a set of standard systems, which are designed for easy integration in all applications based on commonly required specifications. Other variations are available and customisations can be provided for OEM integrators. Please talk to us about your applications and needs so that we can show you how our LaserAce® OEM Laser modules can help you.

LXR CX800 Video Camera

Extreme CCTV® SURVEILLANCE SYSTEMS

SX800, CX800 & CZ800 Series
Extended Infrared LXR CCD Cameras

Product Description

LXR is short for the **ELIXIR** sensor … or **Enhanced Light Integrity for Extended Infra-Red** spectral response. This new generation CCD marks a quantum advance in photopic response, IR response and dynamic range. The **benefits are clear**: no blooming, no streaking, no smearing. The applications are extremely interesting: night vision, vehicle monitoring, high speed surveillance, license plate reading.

These 1/2" CCDs are high performance, LXR extended-infrared board cameras designed for use in covert, night-time or dark room installations. Their low light capability rivals that of other high-performance cameras with military spec performance.

LXR boards also have low smear characteristics made possible by its wide dynamic range. Excellent bright light performance allows for use without mechanical auto-iris lenses.

Product Image

↑ CX800   ↑ SX800   ↑ CZ800

Lenses shown (from left):

1. VA550   1/3" Varifocal Auto Iris 5 – 50 mm
2. VA358   1/3" Varifocal Auto Iris 3.5 – 8.0 mm
3. VA8551 1/2" Varifocal Auto Iris 8.5 – 51 mm

Specifications

Model	SX800 Series	CX800 Series	CZ800 Series
LXR 1/2" CCD	Standard	Standard	Standard
Mono / Color / IR	Mono / IR	Color only	Dual pass Color / IR
Image Sensor	1/2" Interline	1/2" Interline	1/2" Interline
Video Signal Ouput	1 V p-p, 75 ohm	1 V p-p, 75 ohm	1 V p-p, 75 ohm
CCD Effective Pixels	811 (H) x 508 (V) – EIA 795 (H) x 596 (V) - CCIR	811 (H) x 508 (V) – EIA 795 (H) x 596 (V) - CCIR	811 (H) x 508 (V) – EIA 795 (H) x 596 (V) - CCIR
Sync System	DC: Internal	DC: Internal	DC: Internal
Min. Illumination	0.01 lux @ F1.2 (SAGC on)	0.1 lux @ F1.2 (SAGC on)	0.1 lux @ F1.2 (SAGC on)
IR Sensitivity	Zero (0) lux from 780 nm – 1050 nm	N/A	Zero (0) lux from 780 nm – 1050 nm
Resolution	600 TVL	480 TVL	480 TVL
S/N Ratio	> 48 dB	> 48 dB	> 48 dB
Electronic Shutter	1/60 to 1/100,000 – EIA 1/50 to 1/100,000 – CCIR	1/60 to 1/100,000 – EIA 1/50 to 1/100,000 – CCIR	1/60 to 1/100,000 – EIA 1/50 to 1/100,000 – CCIR
Gamma Correction	0.45 / 1	0.45 / 1	0.45 / 1
Backlight Compensation	Auto Detect On/off; Histogram plus 225 area window weight		
Gain Control	AGC 30 dB; SAGC 36 dB	AGC 30 dB; SAGC 36 dB	AGC 30 dB; SAGC 36 dB
Operational Range	-10°C to + 50°C 14°F to 122°F	-10°C to + 50°C 14°F to 122°F	-10°C to + 50°C 14°F to 122°F
Humidity Range	Up to 80% RH	Up to 80% RH	Up to 80% RH
Power Supply	12 VDC ± 10%	12 VDC ± 10%	12 VDC ± 10%
Power Draw	2.9 W @ 12 VDC	2.9 W @ 12 VDC	2.9 W @ 12 VDC
Lens (standard)	C/CS Mount Type Lenses	C/CS Mount Type Lenses	C/CS Mount Type Lenses
Lens (available)	Video Drive Lenses	Video Drive Lenses	Video Drive Lenses
Dimensions	57mm x 51mm x 38mm 2.2" x 2.0" x 1.5"	57mm x 51mm x 38mm 2.2" x 2.0" x 1.5"	57mm x 51mm x 38mm 2.2" x 2.0" x 1.5"
Weight	4 oz (110 g)	4 oz (110 g)	4 oz (110 g)

UF500 Infrared Illuminator

Extreme CCTV®
SURVEILLANCE SYSTEMS
UF500 Series
Infrared Illuminators

Key Features

- High output to 250 meters (820 ft) illumination distance
- Range of beam patterns from spot to wide angle
- Range of filters from 730 nm to covert 950 nm
- Low operating cost, using less power
- Even-Illumination, US Patent #6158879
- No foreground over-exposure
- No background under-exposure
- Rugged and weatherproof
- Long bulb life at 3,000 hours
- Low operating voltage at 28.6 VAC
- Extends the dynamic range of CCD cameras in night time conditions

Product Image

Product Description

The UF500 series of illuminators for CCTV applications is specially designed for covert or semi-covert operations using special gold optics and high efficiency quartz halogen bulbs for **unsurpassed night viewing up to 820 ft.** The unique $cosec^2$ lens reverses the inverse square law to provide evenly distributed illumination from the foreground to background for the entire scene. The shorter and thicker bulb filaments operating at lower voltages and temperatures are less vulnerable to shock and vibration. The result of these features is a high-performance illuminator with 40% higher efficiency and 50% longer life than traditional illuminators.

The U.S. Patented UF500 by Extreme CCTV, is the favored illuminator in the UK where night-time video monitoring is broadly utilized for proactive policing.

Applications

- Night-time surveillance where normal lighting is too expensive or prohibited
- Covert surveillance in a wide range of outdoor conditions
- Prison properties
- School ground properties
- Airport grounds where visible lighting is prohibited
- Police surveillance to streets and buildings
- Enhancement to motorized pan-tilt-zoom cameras for low-light and backlight conditions

Certifications / Compliance

CSA Std C22.2 (No 0-M1991)	General Requirements
CSA Std C22.2 (No 0.4-M1982)	Bonding & Gmdg of Elec Equip
CSA Std C22.2 (No 66-1988)	Specialty Transformers
CSA Std C22.2 (No 205-M1983)	Signal Equipment
CSA Std C22.2 (No 91-M91)	Special Purpose Enclosure
CSA Std C22.2 (No 250-00)	Luminaires
UL Std No 506	Transformers, Specialty
UL Std No 50	Enclosures for Elec Equip
UL Std No 1598	Luminaires

EagleVision Reg-L1 License Plate capture camera

Extreme CCTV®
SURVEILLANCE SYSTEMS

REG-L1
DHC-Imaging™ License Plate Capture
(Definitive High-Contrast Imaging™)

Key Features

- Extreme's proprietary DHC-Imaging™ technology for definitive high-contrast license plate capture
- Precision engineered optics captures plates from vehicles moving up to 100mph (~160kph) for high speed applications
- Metaphase LEDs deliver powerful infrared illumination for effective license plate capture up to 75ft (23m)
- Advanced ambient rejection technology solves problems related to glare from sunlight, headlights and high-beams
- 600TVL 1/2" LXR CCD for excellent performance under infrared
- 24/7 license plate capture in day or dark conditions
- Energy efficient operation at 12VDC or 24VAC
- Small, compact housing with covert, installer-friendly design
- Suitable for outdoor use in all-weather conditions
- Long-life LEDs save time and money by eliminating bulb changes
- High-contrast DHC-Imaging™ allows optimal DVR integration or Automatic License Plate Recognition (ALPR) performance
- DHC-Imaging™ technology delivers images of both conventional plates and Digital License Plates (DLPs)

Product Description

REG-L1 - featuring DHC-Imaging™ - delivers advanced performance license plate capture for technical surveillance and represents the third generation of license plate capture solutions from Extreme CCTV. Combining Extreme's latest proprietary technology, DHC-Imaging™ integrates advances in optics, infrared illumination and Ambient Rejection technology to produce high-contrast license plate images characterized by unmatched clarity.

Using solid-state Metaphase-LEDs, REG-L1 achieves an operational range from 12ft to 75ft, previously unattainable for any LED-based capture system. Combined with Extreme's Ambient Rejection technology, REG-L1 provides high-contrast license plate capture across the complete spectrum of ambient lighting conditions from total darkness to direct glare from sunlight or high-beams.

Consisting of a 1/2" LXR CCD, the high speed optical engine within DHC-Imaging™ captures plates from vehicles moving up to 100mph (160kph). REG-L1's breakthrough speed capability now enables effective license plate capture for highway and other high speed applications. Additionally, DHC-Imaging™ has capture capability for not only conventional plates, but also Digital License Plates (DLPs).

REG-L1 is housed in a weather-sealed unit compliant to NEMA4, proven for successful application in extreme environments. The high-efficiency Metaphase-LED array eliminates the need for routine bulb changes while consuming an average of only 24 watts, allowing REG-L1 to operate at either 12VDC or 24VAC.

REG-L1 integrates seamlessly with industry standard DVRs, IP video servers and wireless broad equipment. The DHC-Imaging™ technology is precision engineered to deliver high-contrast images for in intelligent software platforms such as REG-ALERT for Automatic License Plate Recognition (ALPR) applications.

Product Images

REG-L1 delivers definitive high contrast images of license plates. Shown here with EXMB.028B and EXMB.015 bracketry. EXMB.028 (not included) must install with EXMB.015 for pole mount applications.

The DHC-Imaging™ technology in REG-L1 captures plates from vehicles moving at up to 100mph under any lighting conditions including highbeam headlight glare.

Applications

- Government buildings
- Traffic monitoring
- Borders
- Parkades
- Toll Booths
- Airports
- Hotels
- Highways
- Private estates
- Law enforcement
- 12VDC or 24VAC environments
- Digital License Plates (DLP)
- Automatic License Plate Recognition (ALPR) applications

SeeCar Product Line

HI-TECH solutions

Ref: PLINT2/104

SeeCar Software Recognition Package
International Price List – Jan 2004

SeeCar Software Recognition Package (SRP)

The SeeCar SRP is intended primarily for OEM applications. The SeeCar SRP provides an output string which includes the license plate number for each image received. This product is available either as a Windows DLL, Linux SLL or as a Windows CE DLL.

One SeeCar SRP license is required for each processor or PC station utilizing this software package. An SDK (software development kit) with sample applications, recognition player and documentation is provided together with the purchase of a SeeCar SRP.

Price: $4,250 per license, discounts apply to volume orders as per table below

Applicable Countries: Worldwide (specific country list available upon request)

Payment Terms: Prepayment upon placement of order.

Quantity Discount Schedule

Min. Qty	Max Qty.	Discount (%)	Price ($)
1	5	0	4,250
6	9	10	3,825
10	19	15	3,613
20	49	20	3,400
50	99	25	3,188
100	199	30	2,975
200	399	35	2,763
400	599	40	2,550
600	999	45	2,338
1000		50	2,125

Commercial Radar Gun Specifications

<u>**Speed Measuring Device Police Radar**</u>

CONSUMER PRODUCT LIST (CPL)
January 2003

UNITS CURRENTLY IN PRODUCTION:

S=Stationary/M=Moving

MANUFACTURER	MODEL	X	K	KA	S	M (3)	HANDHELD	SAME DIRECTION	DUAL (2) ANTENNA	FASTEST TARGET
Applied Concepts	Stalker			•	•	•	Yes	No	N/A	Yes
Applied Concepts	Stalker Basic		♦			♦	Yes	No	No	No
Applied Concepts	Stalker Dual		•	•		•	No	No	Yes	Yes
Applied Concepts	Stalker Dual SL		•	•		•	No	Yes	Yes	Yes
Applied Concepts	Stalker Dual DSR (Direction Sensing) (4)			•	•	•	No	Yes	Yes	Yes
Decatur Electronics	Genesis I	•	•	•		•	No	No	Yes	No
Decatur Electronics	Genesis I Remote Display		•			•	No	No	Yes	No
Decatur Electronics	Genesis GHS		•		•		Yes	N/A	N/A	No
Decatur Electronics	Genesis II		•	• (6)	•	•	No	Yes	Yes	Yes
Decatur Electronics	Genesis-VP		•		•		Yes	N/A	N/A	Yes
Decatur Electronics	Genesis-VP Directional (4)		•		•		Yes	N/A	No	Yes
Decatur Electronics	Harley-Davidson Genesis-VP Directional (4)		•		•		Yes	N/A	No	Yes
Kustom Signals	Eagle	•	•	•		•	No	No	Yes	No
Kustom Signals	Eagle Plus (1)	•	•	•		•	No	No	Yes	Yes
Kustom Signals	Silver Eagle (1)	•	•	•		•	No	No	Yes	Yes
Kustom Signals	Golden Eagle (1)	•	•	•		•	No	Yes	Yes	Yes
Kustom Signals	Directional Golden Eagle			• *		• *	No	Yes	Yes	Yes
Kustom Signals	Falcon		•		•		Yes	N/A	N/A	No
Kustom Signals	HR-12		•			•	Yes	No	N/A	No
Kustom Signals	KR-10SP		•			•	No	No	Yes	No
Kustom Signals	PRO-1000 DS		♦			•	No	No	Yes	No
Kustom Signals	Talon			•	♦	•	Yes	Yes	No	Yes
Kustom Signals	Trooper		•			•	No	No	Yes	No
McCoy's LAW LINE	SpeedTrak Elite Ka (1)			•		•	No	Yes	Yes	Yes
McCoy's LAW	SpeedTrak		•			•	No	Yes	Yes	Yes

94

Manufacturer	Model										
LINE	Elite K (1)										
McCoy's LAW LINE	SpeedTrak Elite KD (Direction Sensing) (1,4)		•			•		No	Yes	Yes	Yes
MPH Industries	BEE III (4)		•	•	•	•		Yes	Yes	Yes	Yes
MPH Industries	K-55	•	•			•		No	No	Yes	No
MPH Industries	Python Series II	•	•	•		•		No	Yes (5)	Yes	Yes (5)
MPH Industries	Speedgun		•			•		Yes	Yes	No	Yes
MPH Industries	Z-15		•		•			Yes	No	No	No
MPH Industries	Z-25		•		•			Yes	No	No	Yes
MPH Industries	Z-35		•		•			Yes	No	No	Yes
MPH Industries	Enforcer		•	•	•	•		Yes	Yes	Yes	Yes
Municipal Electronics	TS3		•		•			Yes	N/A	N/A	No
Progressive Electronics	TOMCAT		•		•			Yes	No	No	No
Tribar Industries	Muni Quip KGP		•		•			Yes	N/A	N/A	No
Tribar Industries	Muni Quip MDR	•	•			•		No	Yes	N/A	No
Vindicator	VH-1		•		•			Yes	N/A	N/A	No

UNITS PREVIOUSLY APPROVED, BUT NO LONGER IN PRODUCTION:

| MANUFACTURER	MODEL	BAND	S/M	MANUFACTURER	MODEL	BAND	S/M
CMI	Speedgun Magnum	X	M	Kustom Signals	KR-11	K	M
Decatur Electronics	Hunter	X	M	Kustom Signals	Road Runner	K	S
Decatur Electronics	Hunter HHM	X	M	Kustom Signals	Trooper	X	M
Decatur Electronics	MVR-715	X	M	Kustom Signals	PRO-1000 (DS)	X	M
Decatur Electronics	MVR-724	K	M	MPH Industries	BEE-36 (A)	X,K	M
Decatur Electronics	RA-GUN GN-1	X	S	MPH Industries	K-15	X,K	S
Decatur Electronics	RA-GUN KN-1	K	S	MPH Industries	K-35	X,K	S
Federal Signals	Enforcer	K	M	MPH Industries	S-80	X,K	M
Kustom Signals	HR-8	K	S	MPH Industries	S-80 MC	X,K	M
Kustom Signals	HAWK	K	M	MPH Industries	Python (Series I)	X,K,KA	M
Kustom Signals	KR-10SP	X	M	MPH Industries	Bee-36 A	X,K,KA	M

NOTES:

(1)   Any time/distance feature has not been tested by the IACP testing program.
(2)   Optional dual antenna capability has not been tested by the IACP testing program.
(3)   All moving mode radars can also be employed in the stationary mode.
(4)   Direction-sensing feature was not evaluated for this model.
(5)   Same direction and fastest target capabilities are not tested in the X and K bands.
(6)   Both "Silver Ring" and "Patch" Ka-band antennas have been tested.

Test results and analysis contained herein do not represent product endorsement by the IACP nor product approval or endorsement by the Nati Highway Traffic Safety Administration (NHTSA), the U.S. Department of Transportation, the National Institute of Standards and Technology the U.S. Department of Commerce.

PLEASE NOTE: CPL certification for any individual radar device will be voided by any third party modifications not specifically approved the original equipment manufacturer and the IACP.

Appendix C: Camera Setup Calculations
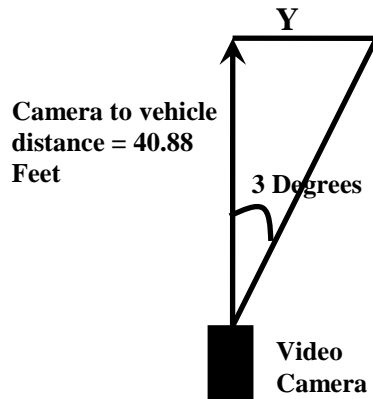
Given: Camera horizontal field of view = 6 degrees
Given: License plate character width = 1.125"
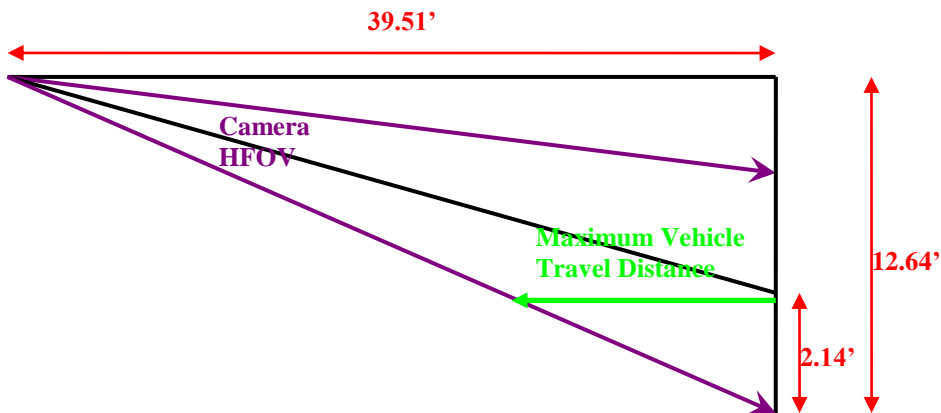Given: Camera horizontal resolution / 2 = (640 / 2) = 320 pixels
Given: Minimum number of pixels a license plate character can span and still be recognized = 14
Y / 320 Pixels = 1.125" / 14 Pixels
Y = 25.71"
Camera to vehicle distance = 25.71" / tan(6 Degrees/2) = 490.58" = 40.88'
Camera Field of View Distance = 2 x Y = 2 x 25.71" = 50.42"

Maximum Vehicle Travel Distance / 39.51' = 2.14' / 12.64'
Maximum Vehicle Travel Distance = 6.69' (When vehicle is in center of lane)