DEVELOPMENT OF AUTOMATIC NUMBER PLATE RECOGNITION SOFTWARE AND JOURNEY TIME MEASUREMENT

AMRI BIN MOHD YASIN

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

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AMRI BIN MOHD YASIN

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Name of Candidate: AMRI BIN MOHD YASIN (I.C/Passport No: 840109-10-5343)

Registration/Matric No: KGA070028

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DEVELOPMENT OF AUTOMATIC NUMBER PLATE RECOGNITION SOFTWARE AND JOURNEY TIME MEASUREMENT

Field of Study: Intelligent Transportation System (ITS)

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ABSTRACT

There are many useful applications for automatic number plate recognition (ANPR) system such as traffic law enforcement, car toll collection, parking system management and journey time measurement. Among many other advanced techniques to measure journey time, ANPR system has gained lots of intentions because it is a non-intrusive approach and this system does not require any additional vehicle identification to be installed in the vehicle. The aim of this research is to develop offline ANPR software, which can locate and read the number plate with an average rates of more than 80% and to extend the measurement capability of the developed ANPR software for measuring the vehicles journey time. The proposed ANPR software has been developed to suit with the traffic environment in Malaysia. The development of the ANPR software consists of several processing steps: vehicle detection, number plate localization, number plate extraction, character segmentation and character recognition. Several tests were done in order to measure the performance and capability of the developed ANPR software. Based on the results, the system is reliable and robust and its capability to measure journey time indicated that it has a huge potential to be used in traffic and transportation studies.

ABSTRAK

Terdapat pelbagai kebaikan penggunaan sistem pengesan nombor pendaftaran automatic (ANPR) seperti penguatkuasaan undang-undang, sistem kutipan tol, sistem pengurusan parkir dan pengiraan masa perjalanan. Di antara teknik terkini untuk pengiraan masa perjalanan, sistem pengesahan nombor pendaftaran autimatik (ANPR) telah mendapat banyak sambutan kerana sistem ini tidak memerlukan penambahan alat pengenalan kenderaan di dalam kenderaan. Sasaran bagi penyelidikan ini adalah untuk membangunkan perisian pengesan nombor pendaftaran automatik (ANPR) secara di luar talian yang boleh mengesan dan membaca nombor pendaftaran dengan kadar purata melebihi 80% dan memperluaskan keupayaan perisian tersebut untuk mengira masa perjalanan. Perisian yang telah di cadangkan ini telah di bangunkan berdasarkan keadaan trafik di Malaysia. Pembangunan perisian tersebut terdiri daripada beberapa langkah pemprosesan; mengesan kenderaan, mengenalpasti kawasan nombor pendaftaran, mengekstrak nombor pendaftaran, mengasingkan huruf dan mengenalpasti huruf. Beberapa ujian telah di jalankan untuk menilai prestasi dan keupayaan perisian yang telah di bangunkan. Berdasarkan keputusan yang telah diperolehi, sistem ini boleh dipercayai dan keupayaannya untuk mengira masa perjalanan telah menunjukkan bahawa sistem ini mempunyai potensi yang sangat besar untuk di gunakan dalam bidang trafik dan pengankutan.

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AMRI BIN MOHD YASIN

Civil Engineering Department

Faculty of Engineering

University of Malaya

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CHAPTER 1: INTRODUCTION

1.1 Background and Motivation

Traffic engineering is a branch of civil engineering that uses engineering techniques to achieve the safe and efficient movement of people and goods (http://en.wikipedia.org/wiki/Traffic_engineering_(transportation), 30/06/2009). Besides that, the Institute of Transportation Engineers (ITE) defines traffic engineering as "phase of engineering which deals with the planning, geometric design and traffic operations of roads, streets, and highways, their networks, terminals, abutting lands and relationships with other modes of transportation for the achievement of safe, efficient, and convenient movement of persons and goods" (www.ite.org, 17/06/2009). Traffic engineering always concerns with the mobility efficiency condition of people and goods while maintaining the safety and minimizing all the dangerous impacts on the environment. There are several of engineering skills including design, construction, operation, maintenance and optimization of transportation systems that might be included in traffic engineering. However, in practice, it can be seen that traffic engineering actually focuses more on system operation rather than on construction and maintenance activities.

Traffic engineering is also closely associated with transportation engineering. Generally, any application which is related to the principles of engineering, planning, analysis and design can be categorized under transportation engineering. In the other definition, transportation engineering is the science of safe and efficient movement of people and goods (http://en.wikipedia.org/wiki/Transport_engineering, 30/06/2009). Besides that, it is important to improve the condition of transportation safety, mobility and enhances the productivity. Actually, this kind of improvement and enhancement can be done through the use of advanced information and communication technologies. In easy words, it can be done through the use of intelligent transportation systems (ITS). ITS is discussed in details in chapter 3. However, this chapter explains a brief description or information on ITS. Nowadays, ITS consists of a wide range of wireless and wire line communication information and electronics technologies. These technologies bring lots of positive impact especially in the traffic and transportation engineering. By integrating the ITS into the infrastructure of transportation system and in the vehicle, these technologies are able to reduce traffic congestion, improve the safety and it is able to enhance the productivity. To date, ITS comprises of several types of systems and it can be categorized into intelligent infrastructure and vehicle systems. (http://www.its.dot.gov/its_overview.htm, 15/06/2009). In this research, automatic number plate recognition (ANPR) software is developed and the developed ANPR software can be used to measure the vehicle journey time. Moreover, it is important to perform this research because nowadays, the traffic congestion especially in Malaysia had become more critical. There is a need to take action in order to solve this problem and to prevent this situation to become worse.

These days, it should be believed that there are more than half a billion vehicles on the roadways worldwide. All those vehicles that travel on the roadways should have their own vehicle identification number and these identification numbers act as the primary identifier. In most of the cases, the identification number mentioned previously is normally a number plate which states a legal license as permission for the vehicle. This permission is used to allow the vehicle to be on the roadway and to enable the vehicle to participate in the public traffic. In other words, all vehicles worldwide should have their own number plate which normally written on a plate (either plastic plate or metal plate). This number plate is mounted onto the vehicle body at both sides which are on the front side and the rear or back side. The vehicle without properly mounted the well visible and readable number plate are not allowed and not permit to be on the roadways.

Theoretically, it is easy to process, sort or analyse data using computers. Most of the tasks will become easier to be carried out especially if the data is already saved in the computer. It cannot be denied that when dealing with the vehicles, number plates are the most important identification data that should be treated by a computer system. Taking advantage of the information provided by the number plate as identification data to be stored in the computer system automatically, the registration of vehicles' movement can be done automatically by a system called ANPR system. This system is able to reduce the use of manpower to monitor the movement of vehicles or to track the vehicles' activities. Actually, the use of ANPR system does not mean that the use of manpower should be terminated permanently. However, ANPR system can be used to replace or redeem the task of manually typing the number plate of the vehicle that travels some location point into the computer system. There are many useful applications for ANPR system. The existing ANPR systems are used for traffic law enforcement (Davies *et al.*, 1990), car toll collection (Lotufo *et al.*, 1990), parking system management (Sirithinaphong and Chamnongthai, 1998), journey time measurement (Bertini *et al.*, 2005; Kanayama *et al.*, 1991) and many more. However, in this research, the ANPR software is developed and the developed ANPR software is used for measuring vehicle journey time. It is discussed in detail through this thesis report.

1.2 Problem Statement

Nowadays, traffic congestion is everywhere. Even in Malaysia, traffic congestion has become more critical especially during the peak period and it increases in all types of human activities. Usually, traffic congestion is happening due to the increase of motorization, urbanization, population growth and changes in population activities. Even though traffic congestions are not always desirable, but most of them are undesirable. The undesirable form of traffic congestion is the congestion that obstructs the movement of journey time between two points and it brings effect to a desired destination. Apparently, this form of traffic congestion caused the journey to become not enjoyable and it is also able to slow down the services. In fact, when the journey is slowing down, it will create delays problem. Delay can easily be understood as the difference between actual journey time and journey time under uncongested condition. In general, traffic congestion is the presence of delays along a roadway or route due to the presence of other users.

Traffic congestion usually brings negative subsequences of negative impacts. There are a large number of the negative impacts caused by traffic congestion such as reduce the efficiency of transportation infrastructure, increase air pollution, increase the fuel consumption of vehicles, increase the price of goods and services, elevate crash rates and the clearest negative impact of the traffic congestion is delay or lost time that caused the increase in journey time. Traffic congestion tends to be unpredictable even when it is frequently occurring. As a result, the travelers or drivers including passenger cars, trucks and buses frequently arrive late at their destinations especially during the peak periods and this situation created frustration. Actually, these late arrival times carry a cost such as missing meetings and deliveries, children or students will wait around for the classes to begin (if the drivers are teacher or lecturers), the supervisors will lose their tolerance because arrive late or missed work and etc.

In the intelligent transportation system (ITS), it is divided into two main category systems and one of the categories is an advanced traffic management and traveller information system (ATMIS). This category system provides a wide range of traffic surveillance and assessment of the frequent congestion. It also focuses on smoothing out the traffic flow in the network by providing information on the current traffic condition in order to help the drivers make the best route choice decisions. Besides that, it helps the drivers to decide the best departure time or estimate their expected arrival time based on the information given. One of the important information provided by ATMIS is journey time data. This ITS subsystem is discussed in details in chapter 3 under topic ITS. Back to the discussion, it can be clearly understood that journey time data are very useful to drivers in order to make a decision and schedule plan. There are various techniques which can be used to measure journey time and it is briefly discussed in chapter 2 though literature review and it is discussed in details in chapter 6 which is cover the topic of journey time measurement system. However, one of the techniques used to measure journey time is by using ANPR system. In this research, ANPR software is developed and the ANPR software consists of the following sequence of operation: vehicle detection, number plate localization, number plate extraction, character segmentation and character recognition. Details of the software development are explained in Chapter 5. After that, the developed ANPR software is used to measure journey time. Basically, the ANPR software collects the vehicle number plates and arrival times at different check-points. Then, the number plates between the check-points are matched and journey times from difference in arrival time are computed. This research is performed in order to provide a solution to the traffic congestion problem especially which occurs in Malaysia because as what had been mentioned in earlier discussions, traffic congestion has become more critical in this country. It is a good idea to implement the ANPR based journey time measurement in Malaysia because this research is able to reduce several traffic problems especially related to the traffic congestion problem that also contribute to the delay problems by providing information on current traffic condition and this information can help the drivers make the best route choice based on journey time information and expected delays. Besides that, the journey time data which will be collected using this developed system can be used to obtain traffic data for the transportation planning, design and operation and as well as for performance measures of the developed transportation system especially by the Malaysian government.

1.3 Objectives

Briefly, the objectives of this research can be summarized as follows:

1) To develop offline ANPR software which is able to locate and read the number plate with average rates more that 80%.

2) To extend the measurement capability of the developed ANPR software for measuring the vehicles journey time that can suit with the traffic environment in Malaysia.

1.4 Scope of Work

The Offline ANPR software is developed using a graphical programming language. The developed ANPR software consists of several processing steps which are vehicle detection, number plate localization, number plate extraction, character segmentation and character recognition. Several tests were performed in order to test the accuracy and reliability of the developed ANPR software. The tests were conducted using the recorded mode at five different angles. After that, simple journey time software is developed in order to extend the measurement capability of the developed ANPR software for measuring vehicle journey time. For this purpose, a set of test was performed and the test was performed during the sunny day using the recorded mode at a fixed angle. Two sets of camera systems were located beside the roadway at two different locations. The vehicles were travelled through both cameras. The developed journey time software reads the number plate from each recorded video. The number plates are matched and journey time for each vehicle is calculated by the developed journey time software.

1.5 Thesis Overview

This thesis is divided into eight chapters where each chapter describes the different component of research.

Chapter one is an introductory chapter which consists of background and motivation, problem statement, research objectives, scope of work and thesis overview. This chapter is written in order to provide the basic ideas and fundamental understanding of the research area. It is also explained in general about the traffic congestion problem that currently become more critical especially in Malaysia.

Chapter two discusses the literature review which is covering the previous study about the related subjects. This chapter starts with the ANPR studies and it is focused on the ANPR software which consisting of several processing steps; vehicle detection, number plate localization, number plate extraction, character segmentation and character recognition. Besides that, this chapter also focuses on the journey time studies.

Chapter three describes information and discussion about intelligent transportation systems (ITS) which is cover a little bit about the introduction part of ITS, followed by ITS subsystem and ITS technologies.

Chapter four is about the hardware configuration and it covers the hardware part in ANPR system and journey time measurement system. This chapter consists of the details explanation of the hardware devices such as camera, lens, infrared illuminator and personal computer and their configuration toward the successful development of a complete system.

Chapter five deals with software development processes where all the development process of each processing step is described. A new localization method is introduced in this research and it is explained in details in this chapter.

Chapter six explains about the journey time measurement system where the discussion is focused on the ANPR based journey time measurement system. In other words, the capability of the developed ANPR software is extended to be used for measuring vehicle journey time.

Chapter seven contains the results which are obtained through the experiments performed in this research. Every result is followed by the discussion and it is discussed everything about the obtained results.

In chapter eight, conclusions have been made based on the obtained results. Some recommendations for the future studies are also presented in this chapter.

CHAPTER 2: LITERATURE REVIEW

2.1 Automatic Number Plate Recognition Studies

Automatic number plate recognition (ANPR) is a system designed to automatically recognize and store number plate data on vehicles passing through a certain point (http://www.tech-faq.com/automatic-number-plate-recognition.shtml, 30/06/2009). It was first invented in 1976 by Police Scientific Development Branch in the UK and the prototype systems were working by 1979. This prototype system was focused on the law enforcement such as detection of the stolen car. Nowadays, the ANPR system uses the latest and advanced technologies such as the use of high speed camera which is able to detect and capture the vehicle number plate at high speed and the development of ANPR software which is abled to process the captured number plate in a very short time.

In most cases, vehicles are identified by their number plates. These number plates are easily readable for humans, but not for machines. For machine, number plate is only an image which can be defined as two-dimensional function $f(x, y)$, where x and y represent the spatial coordinates of a picture element or pixel, and f is a light intensity at that point (National Instruments, 2003). Because of this condition, it is important to develop ANPR software which is able to transform the data between the real world environment and information system. From the previous study, typically ANPR system has a recognition rate of 50-90% of all vehicles at each camera location. The vehicle that has its number plate successfully read at an upstream point will most probably be successfully detected at a downstream point because the probability of a successful reading of a number plate depends primarily on the vehicle characteristics such as the system used, quality of installation, and weather condition (Wiggins, 1999). However, the recognition rate is likely to be lower in an urban environment since the separation between vehicles is lower, and the number plate of vehicles may be obscured by larger vehicles such as double-decker busses (Lie *et al.*, 2005). Further research is needed to verify the recognition rate of ANPR system in the urban environment. The recognition rate will be variable depending on several factors such as the speed of the vehicles being recorded, the varying ambient lighting condition, the weather condition and several other factors. The ANPR system consists of two important components which are hardware and software components. In this research, both hardware and software components are discussed. However, more focus is given to the development of ANPR software rather than hardware components.

2.1.1 Automatic Number Plate Recognition Software

Basically, the ANPR software consists of several processing steps; vehicle detection, number plate localization, number plate extraction, character segmentation and character recognition.

2.1.1.1 Vehicle Detection

Vehicle detection is the first step of ANPR software. The vehicle presence can be software triggered such as analysing changes in the images (Eikvil and Huseby, 2001) or hardware triggered such as inductive loops, magnetic loops (Broumandnia and Fathy, 2005) and infrared sensors (Dai *et al.*, 2001). The software triggered may consume more system resources, but it does not need additional hardware equipment, like the hardware triggered. Both methods have advantages and disadvantages and the use of each method are depending on the applications. However, in this research, the presence of the vehicle is detected using the hardware triggered method. The image of vehicle is captured by using the mechanical device whenever it passes through the detection area and it is discussed in details later on in chapter 5.

2.1.1.2 Localization

Number plate localization is the most important step in the ANPR software. If the software fails to detect the location of number plate, means that the ANPR software will not be able to recognize the character of the number plate. Until now, there have been many methods were used and developed on the number plate localization step. One of the methods which are able to produce a good result is a method based on combinations of edge statistics and mathematical morphology as used by Hongliang and Changping (2004); Leonardo and Colin (2005); Wang and Lee (2003); Zheng *et al.* (2005). Basically, in these methods, the algorithm computes the gradient magnitude and the local variant of the edge in the image. It was performed according to the change of property at the number plate. Then, the possible number plate areas were identified by looking at the areas with high edge magnitude and variance. This method is applicable to the unclear number plate boundary image because it doesn't depend on the number plate boundary edge. However, the used of edge-based method alone is not suitable for the complex image since they are too sensitive to the unwanted edges.

Besides that, other methods proposed in previous research are color or grey-scale based processing method as used by Comelli *et al.* (1995); Dai *et al.* (2001); Lee *et al.* (1994); Wang *et al.* (2004); Wei and Wang(2001). The successes of these methods were based on color or greyscale segmentation stage. Currently, the available solutions unable to give a high accuracy percentage in normal condition because color becomes unstable when the light changes. Wei and Wang(2001) in their research revealed that the color based processing method is not robust enough for weather conditions, vehicle speed conditions, an extra light or dirty number plate. In the condition where the color values of the image are similar, the car image is difficult to be recognized. This problem also featured in (Lee *et al.*, 1994), where this method failed to localize the images which have very similar color between the body and the number plate of a car and it also fails to localize the images where the size of the number plate region is very small compared with the whole image.

A method was developed to find the location of number plate by searching color point-pairs (Feng *et al.*, 2005). Since the color point-pairs just present in the image edge area, so the edge area of color point-pairs was pre-determined in order to decrease the searching time of color point-pairs as well as to quicken the number plate localization speed. An instructional method was introduced in order to enhance the searching accuracy. Through this method, the probability of many incorrect color points-pairs assemble narrowly in a small area is low. The pre-location of number plate was determined by using morphological open operation and the rotation of vehicle number plate was done before further operations because the number plate’s tilt during the character segmentation and recognition stages caused the serious influence. After the tilt influence of the number plate had been removed through the rotation of the vehicle number plate, the re-locate of number plate was performed. Even though this method produced a good result and able to decrease more than 80% of the workload 80% but there are still problems exist to locate the number plate. The software is unable to recognize the color point-pair if the image is unclear. Therefore, the software becomes invalid.

Research has also been done using a method called Sliding Concentric Window (SCW) to find the number plate area (Anagnostopoulus *et al.*, 2005a). This method was developed to describe the local irregularity in the image using image statistics. In this method, the first image pixel with the pixel size of X1xY1 (window A) and X2xY2 (window B) were created. Then the statistical measurements in A and B were calculated. If the ratio exceeds the fixed threshold value, the central pixel of windows is considered to belong to the region of interest (ROI). However, this method will obtain high percentage accuracy only if the parameters are set to the right value based on trial and error method and it takes too much time (981 ms) to locate the number plate.

Broumandnia and Fathy (2005) in their research introduced the multiple - interlacing method in order to find the location of the number plate. In this method, the image was scanned with N row distance and the existence edges were counted during the scanning process. If the threshold value is less than the number of edges, this indicates the number plate region. However, if the number plate is not found during the first scanning, the algorithm is repeated and the threshold value is reduced. The authors claimed that the developed method produced high speed and performance but they didn't mention the speed and performance rate and the claims made are too general.

Zimic *et al.* (1997) applied fuzzy logic in order to locate the number plate area. In this method, Some intuitive rule was applied in order to describe the number plate and some relationship function for the fuzzy which are 'bright', 'dark', 'bright and dark sequence', 'texture and yellowness' were set in order to get the horizontal and vertical plate position. However, this method is sensitive to the color and brightness of number plates and requires longer processing time compared to the conventional color - based method. This method worked well under the assumption that majority of number plate is white and with black character. Even though it achieved better results, but this method still carries disadvantages of the color-based method. In this research, the use of fuzzy logic method was able to produce a high localization rate which is 97% but required longer processing time which is 5 s to obtain the location of the number plate.

Hough Transform method has also been used to locate the vehicle number plate. It first detects the edges in the input images. Then, the Hough Transform (HT) was applied in order to find the number plate region. It had been acknowledged by the researcher in (Tran *et al.*, 2005) that the processing time of the HT requires too much calculation, when it is applied to binary image with high pixel numbers. Based on this situation, the researchers used the combination of the HT and a contour algorithm. It produced higher accuracy with faster speed and it can be implemented in real time application. HT is too sensitive to the boundary deformation.

Louka (2004) in his research trained a strong classifier for number plate localization by using Adaptive Boosting (AdaBoost) algorithm. This AdaBoost algorithm is suitable for the number plate localization step but it requires some improvement because the algorithm unable to detect the number plate with difference image or size.

A method based on Vector Quantization to obtain the location of a number plate is presented in (Rodolfo and Stefano, 2000). The higher picture compression is possible to be performed by the Vector Quantization (VQ) method. When compared to the classical approaches, VQ method can provide the hints of image regions contents. This additional information can be used to increase the performance to locate the number plate.

In this research, a new method called pattern matching is developed in order to find the location of the number plate area and this method is able to solve some of the problems mentioned in the previous researches. The detailed explanation of the developed method is discussed in chapter 5.

2.1.1.3 Number Plate Extraction

The vehicle number plate is extracted from the background image after the location of a number plate is found. Based on previous research, this step was included in the number plate localization setup. However, in this research, the number plate localization step and the number plate extraction step are different steps. The number plate extraction step is discussed in details in chapter 5.

2.1.1.4 Character Segmentation

The extracted number plates established in the number plate extraction step are inspected in the number plate optical character recognition (OCR) phase or number plate identification phase. In this OCR phase, two major tasks are involved which are character segmentation and recognition. Several methods are used in order to segment the character of number plates after successfully localizing and extracting the number plate in the captured images. The examples of character segmentation methods are featured vector extraction and mathematical morphology (Shigueo *et al.*, 2005), horizontal and vertical projection (Tran *et al.*, 2005) and fuzzy c-means clustering algorithm (Nijhuis *et al.*, 1995).

The research made by Shigueo *et al.* (2005) proposed a novel adaptive approach for character segmentation and attribute vector extraction from critically degraded images. Based on the histogram, the fragmented characters were segmented by the algorithm. Then, the morphological thinning algorithm locates the reference line. The reference lines used to separate the overlapped character. The baseline for segmenting the connected characters was determined by the algorithm. Basically, this approach is able to detect connected character. The obtained results are good and show potential. This method can be used for character segmentation on the number plate during off-line mode. However, this method is not suitable to be used for real-time number plate recognition since the algorithm is computationally complex.

Tran *et al.* (2005) in their research used horizontal and vertical projection approach for the character segmentation. The horizontal projection approach was used to detect and to segment rows in 2 row number plates. The positions with minimum values of horizontal projection are at the start or at the end of a row of the number plate. The characters were segmented using the vertical projection approach where the minimum values in the vertical projection were searched and only the minimum positions which give cut pieces satisfied all predefined constraints were considered as the points for character segmentation. The researcher noticed that in some cases, this method does not work correctly.

Besides that, fuzzy c-means clustering algorithm is used by Nijhuis *et al.* (1995). In this approach, a global thresholding was applied based on the average grey scale value of the 100 pixels with the largest gradient value. Then, the searching process of a connected component on the resulting binary image was performed. After that, a connected component was marked as a potential character based on the rules concerning the minimal area, width and height of characters. The selected components are only passed on to the recognizer module if it makes up a valid number plate. However, the use of this approach rejects about 24.6% of all images during the segmentation stage and this rejection rate can be considered as high. A thresholding technique was adopted in this ANPR software for character segmentation and is discussed in chapter 5.

2.1.1.5 Character Recognition

Several algorithms used in OCR applications make use of Hidden Markov Models in order to recognize the characters (Tran *et al.*, 2005), Neural Networks (Anagnostopoulus *et al.*, 2005b; Broumandnia and Fathy, 2005; Chang *et al.*, 2004; Leonardo and Colin, 2005; Nijhuis *et al.*, 1995), Support Vector Machine (SVM)-based character recognizer (Kim *et al.*, 2000) and template matching (Comelli *et al.*, 1995; Huang *et al.*, 2004).

Basically, the recognition starts with a pre-processing step. A parameterization of the ROIs was identified in the previous stage when Hidden Markov Models (HMM) were employed. In Tran *et al.* (2005), the ratio of foreground pixels in a window was used in the model. Then the window was scanned in the image from left to right and top to bottom. After that, a character image was classified into one of 36 classes and the training sets which were extracted from the image of vehicle number plates were used to train this model. Finally, some specific rules of Vietnamese vehicle number plates were used in order to improve the accuracy. This research revealed that the necessity to perform high-quality analysis once implementing HMM, which poses a constraint on the efficient distance of the recognition system.

Multi-Layer Perceptron (MLP) Neural Networks were used for character recognition (Broumandnia and Fathy, 2005; Nijhuis *et al.*, 1995). In Broumandnia and Fathy (2005), the learning program learns various fonts of Farsi numeric and letters by back propagation algorithm. It was guided for lots of cycles towards achieving an excellent performance. This p rocess consumes lots of time. The number of hidden layers is 20 which were selected by trial and error method. After that, the city word was recognized by using a holistic paradigm approach which used neural network with back propagation algorithm learning. Nijhuis *et al.* (1995) in their research were used the binary connected components as inputs. In order to recognize the full set of characters, the MLP was trained. Based on result, this method achieved an outstanding result which is 98.5% in 10000 set images.

A Self Organized Neural Network was used by Chang *et al.* (2004). In order to bear noise or broken characters obtained from number plates that were tilted with respect to the camera, the researchers implemented a Self Organized Neural Network based on Kohonen's Self Organized Feature Maps (SOFMs). This technique focuses on accuracy of complexity and execution speed. In this research, the character recognition rate was 95.6% (based on 1061 number plates).

Leonardo and Colin (2005) in their research used Feed Forward Artificial Neural Network for character recognition. In their research, the fixed size greyscale images were used as input for OCR. Over training of the neural network is prevented by using Bayesian regularization. The neural network output value was set to 0.05 when the input is not the desired glyph, and 0.95 for correct input. The researchers claimed that neural networks for OCR provide faster processing speeds and improved flexibility to handle font variations, damage marks and perspective distortion effects compared with template matching.

Additionally, in (Kim *et al.*, 2000), the researchers performed character recognition using Support Vector Machines (SVM). The number plate was segmented vertically into two regions and then, both regions were segmented horizontal. The variance of grey levels was applied to the segmented regions using the linear sum of intensity projection and the intensity varies of projection direction. Four SVMs-based character recognizers were used to recognize the characters. The research was reported remarkable result of 97.2%. However, the style was specially developed for Korean number plates and not suitable for the other countries.

A proper method to recognize the single character is pattern matching method. The method prefers to utilize the binary image. This method also applied in Comelli *et al.* (1995), where a normalized cross-correlation operator was applied between a sub-area of the normalized image and each prototype in order to detect the presence of a prototype into the given image. The recognition procedure was based on the computation of each character template containing the number plate. It was reported that the time spent to run the complete system was about 1.1 seconds per image.

Template matching is also implemented successfully in (Huang *et al.*, 2004). In the research, the characters were resampled according to the estimation of character size. After that, the image was binaries so that the distances have more contrast. Then, an unknown pattern is assigned to the character to which it is closest in term of a predefined metric. Usually, the characters in the acquired image do not exactly match any prototype. Therefore, the Root Mean Squared Error (RMSE) was used to measure the similarity of two images for the characters in the acquired image. In this research, a similar method which is template matching method is used and it is discussed in chapter 5.

2.2 Journey Time Studies

Journey time can be defined as the total time to traverse a given highway segment or road segment (Garber and Hoel, 2003). Joiurney time data are fundamental part of a number of performance measures in many transportation studies. Chun-Hsin *et al.* (2003) stated that journey time can be used in the transportation planning, design and operation, and evaluation. Besides that, it can be used for performance measures by the developed transportation system. The journey time data are very useful to drivers in order to make decisions or plan schedule. The drivers can add the buffer time or extra time to their average journey time when planning trips in order to ensure on-time arrival.

In recent years, there has been increased in traffic congestion especially on the urban freeway. This situation will give impact to the drivers and road users especially travelers because more journeys will be affected by the delay. Kwon *et al.* (2000) mentioned that for the traveler that routinely traverse a given route, they won't be affected by the delay problem because they are able to allocate buffer time or extra time for their journey. In some other country, they have a system called route-guidance system which is used to suggest optimal alternative routes or warn of potential congestion to the drivers or road users. Based on this system, the drivers can decide the best departure time or they can estimate their expected arrival time based on the predicted journey times. Bertini *et al.* (2005) stated that the journey time calculation depends on vehicle speed, traffic flow, and occupancy which are highly sensitive to the weather condition and traffic condition. These elements make a journey time prediction very difficult to reach optimal accuracy.

From the previous study, it has clearly mentioned the importance of the journey time data especially in traffic applications and transportation studies. There are various methods or techniques used to measure the journey time. Coifman (2002) in his research presented a method for estimating link journey time using data from an individual dual loop detector without requiring any new hardware. The estimation technique uses basic traffic flow theory to extrapolate local conditions to an extended link. A research done by Nagoaka (1999) measured the journey time based upon data from the detector. The movement of vehicles from starting point to the end point is traced on the time distance diagram and the journey time is obtained from the diagram. However these approaches require raw loop detector data as opposed to a typical 20s to 30s cumulative data.

Besides that, journey time can also be measured by using the ANPR system. The measurement of journey time using ANPR system differs from estimation via information from classical stationary detector such as induction loops where this classical device can only measure the volume and local speed and they do not allow to measure journey time for long distance. There are several researches concerning the development of ANPR system for journey time measurement and the core difference among them is the technique that has been employed in the processing algorithm (Bertini *et al.*, 2005; Kanayama *et al.*, 1991). The technique is much influenced by various factors such as number plate format as every country has a different format, traffic conditions, hardware setup, and climate condition. In this research, the developed ANPR software is used to measure the vehicle journey time which can suit with the traffic environment in Malaysia and it is discussed in details later on in chapter 6.

CHAPTER 3: INTELLIGENT TRANSPORTATION SYSTEM

3.1 Introduction

Intelligent transportation system (ITS) is a term for a range of technologies including processing, control, communication, and electronic that are applied to the transportation system. It also includes an advanced approach to traffic management (http://www.roadtraffic-technology.com/glossary/intelligent-transportation-sysytems.html, 29/06/2009). The involvements of the mentioned technologies in ITS is in an attempt to save lives, money and time. Besides that, it covers several disciplines such as transportation engineering, telecommunications, computer science, financing, electronics, commerce etc. It can be mentioned that the intention of ITS is to obtain the benefit of the proper technologies to produce more intelligent roads, vehicles, and users (Figueiredo *et al.*, 2001). Since a computer has the potential to eliminate human error, ITS will soon underlie on the technology of computers. Nowadays, there is technology which is able to guide humans to their destinations, away from congestion and this kind of technology will be expended in the future. Even though ITS sound a little bit futuristic, actually it soon will become a reality and this situation makes the future of ITS is promising. The uses of advanced technologies make humans live become more pleasant and productive and it is important for the transportation industry to take benefit from the technology. ITS has a possibility to go beyond a transportation system which is currently being control of the four-way traffic signal as a primary technology.

Based on the history, the first large scale application of a computerized signal control system in the world was implemented in Metropolitan Toronto during the early 1960s but this ITS field started to mature only in the early 1990s (Abdulhai and Kattan, 2004). ITS field has been driven by several forces. The transportation researchers realized that road building can never keep pace with the increasing demand for travel. Some countries which have invested billions of dollars in building the road networks and infrastructure are currently faced with the challenge of refreshing or renewing this huge network and making the best use of the existing networks and infrastructure before expending the network and infrastructure. Besides that, environment also has become the factor that contributes to the ITS field. The traffic emissions produced by the vehicles are increasing drastically and it brings damage to the environment. For all these reasons, more road building actually is not always desirable. However, the use of high and advanced technologies of computer, electronic and communication is able to offer an attractive and promising approach to the current ITS field.

The ITS field also provides other benefits which are not related to the traffic society such as creation of new markets and jobs. Therefore, ITS is more than just intelligent solutions on the road. It has also brought solutions for national and international economies through the creation of markets and jobs. The transportation industry is no longer restricted to the civil engineers or to a single department of agency and this situation has become one important of the important contribution of the transportation industry shaped by ITS. Since the ITS field is involved by the broad range of technologies, so it becomes multi agencies and it is involved the public, private and academic sectors. This broadness will certainly enhance the potential, widen the scope and give new ideas to handle the transportation systems.

3.2 ITS Subsystems

One of the ITS's aims is to enhance the utilization of the existing roadway capacity. It is achieved through the improvement of traffic distribution and dynamically sending traffic away from the congested hotspot areas to reduce the segments use of the network. Besides that, ITS also aims to increase the existing roadway capacity. This aim is possible through automation of driving and eliminate the human behaviour element overall. The automated highway systems have the potential to double or triple the number of vehicles that a single lane can handle.

The entire results related to the ITS groups are too huge to be discussed in this thesis. As a result, in this sub-topic, the overall features of the several ITS major groups are discussed. One of the ITS groups is advanced traffic management systems (ATMS). ATMS is the basic part of ITS. It is used to improve the quality of traffic condition and to reduce the traffic delay. ATMS operates through three main elements. Firstly, it monitors the traffic condition through the "collection data system". Then, the "support system" including cameras, sensors and electronic display helps the system operator to manage and control real-time traffic. Finally, the information which is provided by two previous elements is used by the "real-time traffic control system". This system can deliver the messages to the electronic display and control highway access.

Another category of ITS which is closed related to the ATMS is advanced traveller information systems (ATIS). The information gathered by ATMS is also provided to ATIS. The main aim of ATIS is to provide the traffic information to the drivers or travelers in real-time. This information including the transportation system traffic conditions are very useful to drivers because it can influence drivers to make better decision. This situation allows reducing the traffic congestion, optimizing the traffic flow and reducing the pollution. Through this system, the travelers can decide the best route to reach their destination, the suitable transportation services and the proper schedule to adapt. This kind of info can be given through electronic panels, radio system, handheld wireless device etc. Both categories, ATMS and ATIS are normally combined as ATMIS and it provides the wide traffic surveillance and assessment of frequent congestion which is happening due to the repetitive high demands traffic. ATMIS also detect the frequent congestion which is occurring due to the incidents, traffic information and route guidance distribution to drivers and adaptive optimization of control systems such as traffic signals and ramp meters. The current trends in ATMIS more likely to be relying on the centralization of management in the traffic management centre. These trends also seem to be the future trends in ITS. The traffic management centre or in short called TMCs, measure the traffic conditions by receiving the information from vehicle detector throughout the network and the vehicle. The received information device act as probes originates control, then measures in the centre and after that, spread the control of the field devices. The field devices act as information and guidance to drivers. The main unique characteristics of ATMIS are real-time operation and network wide implementation. Based on the evaluation of ATMIS which is done by Booz Allen Hamilton Inc. (2004), it is concluded that by having TMC, and reducing the amount of fuel and time necessary to go to the field, the city estimates a 20% cost saving over its previous configuration of ATMIS toward ITS field.

Besides that, there is another ITS category called advanced vehicle control systems (AVCS). It works through the joining of sensors, computers and control system. This system used to help and alert drivers or to take part of the vehicle driving (Shaladovers, 1995). In other words, AVCS provides better control of the vehicle itself either by assisting the driver or by automating the driving process like auto pilot mode in order to increase capacity and enhance the safety. The main purpose of AVCS is to increase safety, to decrease congestion on roads and highway and to improve road system productivity. The full automation of an automated highway system (AHS) can result higher speed at smaller or lesser headways and therefore can result in higher lane capacity. The automation process can be applied to the individual vehicles which are acting as free agents either in non-automated mix traffic or as fully automated lanes which carrying units of electronically linked vehicles. The use of vehicle build-in sensors enable the drivers to obtain visual and hearing information regarding traffic, dangerous and the vehicle situation while automatic control permits to reach in dangerous conditions in a fast and efficient way such as trigger in the breaking or acceleration system. This is very useful for aged driver or driver with little practice.

Even though AVCS and AHS are something that technically promising, there are several unsettled issues still remain. The examples of the remaining issues are legal liabilities in the event of an incident due to potential failure of automatic controller, technical reliability issues and social issues. Goldsmith, T. C. (1998), in his white paper has discussed the liability issue where the exposure of liability of AVCS or AHS have became questioned either the liability will increase for vehicle manufacturers of highway provider. For these reasons, at the current stage of ITS, the AHS is still considered as futuristic. For this moment, the possible alternative is to use the technology to assist the driver. In this case, the driver still remains control the vehicle and the use of technology is to make the vehicle smarter. The use of technology is able to produce intelligent vehicles which are able to detect the obstacles on the road and to detect the obstacles in the blind spot and then warn the driver about the detected obstacles, maintain the constant distance from the vehicle ahead and alert or aware the sleepy driver who is going off the road. As the technology improves further, the function of intelligent vehicle can move from simple warning to full interference and accident prevention maybe by applying the brakes or overriding the faulty steering decision.

There is difference between ATMIS and AVCS. The main difference between both categories is the ATMIS focus on smoothing out the traffic flow in the network by helping the driver to make the best route choice decisions and optimizing the control system in the network. In this research, the development of ANPR software for journey time measurement is able to contribute to the success of smoothing the traffic flow in the network and it is discussed in details in chapter 6. In other hand, AVCS focus on the driver, the operation of the vehicle, and the traffic movements in the immediate surrounding area of vehicle. It focuses on enhancing the driver's awareness, aiding the decision making by providing early warning and potential initial action and using sensory inputs and computer control in the replacement of human sensory reaction and control. However, both ITS categories are so important because they are able to enhance the utilization of the existing roadway capacity and increase the existing roadway capacity.

3.3 ITS Technologies

In this modern world, there are various kinds of technologies had been applied for the intelligent transportation systems. The variety of the ITS technologies including basic management, monitoring application and more advance application that integrates the real-time data and feedback from other sources. The examples of basic management are car navigation system, traffic signal control system, variable message sign system and automatic number plate recognition (ANPR) system while the example of monitoring application is security CCTV systems and the example of the more advanced applications are parking management systems, weather information system and many more.

Recently, in sequence to permit the advanced modelling and the evaluation with the historical data, the predictive techniques are being developed. There are several elements or parts of technologies that typically involved in the ITS such as wireless communication, sensing technologies, inductive loop detection and video vehicle detection. These elements of technologies involved in ITS are discussed in the following sub-topics.

3.3.1 Wireless Communications

The conventional wired technologies have numerous disadvantages as it had been used especially in the transportation system. The wiring is costly, physically heavy and the extra layers give the complexity of the original design. If the wiring is damaged then the lines of communication are literally cut and still-operating machinery on the other side is inaccessible or even possible causes to be useless (Lebold *et al.*, 2005).

However, in this modern world, the broadband wireless technologies are getting its popularity especially after the successful global operation of the Wireless Personal Area Networks (WPAN), Wireless Local Area Networks (WLAN) and Wireless Metropolitan Area Networks (WiMAX). These wireless technologies are also implemented in ITS field. The wireless communication allowed the users to enjoy the high-speed networking and internet access without wire (wire-free) and the Bluetooth devices are allowed users to be mobile and communicate hand-free and wire-free at the same time. Actually, there are a variety of forms of wireless technologies have been suggested and have been implemented in ITS. Among the wireless technologies, the long range communication is implemented using infrastructure networks such as WiMAX (IEEE 802.16). This IEEE 802.16 standard protocol had been approved by the IEEE in June 2004 (Dhawan, 2007) and the use of WiMAX may have a great impact over the next few years especially in ITS field. Besides that, the longer range communication also can be implemented using Global System for Mobile (GSM), 3G, 3.5G or 4G. If the distance range is less than 250 meters, the short range communication can be used. The most popular of short range communication protocol are Bluetooth (IEEE 802.15.1) and WiFi (IEEE 802.11n). The uses of long range communications actually are well established, but dissimilar with the short range protocols, the long range communication methods need extensive and very expensive infrastructure operation.

3.3.2 Sensing Technologies

Nowadays, different sensing technologies such as piezoelectric sensor, ultrasonic sensor, microwave radar, laser scanner, Radio Frequency Identification (RFID), and computer vision can be used in ITS field. The example use of the mentioned sensing technologies is for the pedestrian detection. For the application of pedestrian detection, piezo-cables with piezoelectric material are usually fabricated into a mat. When a person steps onto the mat, an electrical signal is generated until the person leaves the mat (Bu *et al.*, 2005). Besides that, the technological advances in telecommunications and information technology are combined with RFID and it is used in order to enhance the technical capabilities that will smooth the progress of motorist safety. Normally, the sensing systems used for ITS are vehicle and infrastructure based networked systems such as intelligent vehicle technologies.

The permanent devices such as in-road reflectors are installed or embedded on the road or surrounding the road. This kind of sensor is categorized as infrastructure sensors and it may manually distribute during the preventive road construction maintenance or by sensor injection machinery for rapid deployment of the embedded RFID in-ground road sensors. In addition, the deployments of vehicle sensing systems are used for identification communication and it may also utilize the benefit of ANPR technology at the desired interval in order to increase the monitoring of suspect vehicles operating in critical zones.

3.3.3 Inductive Loop Detection

The inductive loop detector is undoubtedly the most common form of detector which is used in ITS especially for traffic counting and traffic management purposes. Inductance loops are widely used in detector systems because they are known for their reliability in data measurement, flexibility in design, and relatively low cost. Basically, the components of loop detector consist of one or more turns of insulated wire buried in a narrow, shallow saw-cut in the roadway, lead-in cable that connects the loop to the detector via a roadside pullout box and the detector unit (amplifier) that reads changes in the electrical properties of the loop when a vehicle passes over it.

Whenever car passing over the inductive loop which is buried in the pavement, the detector unit sends an electric current through the cable, creating a magnetic field in the loop and the loop system becomes active. Then, when a vehicle passes over the loop, the metal of the vehicle disturbs the magnetic field created by the loop, which causes a change in the loop’s inductance. Inductance is an electrical property that is proportional to the magnetic field. The induced magnetic field increases the frequency of oscillation that is sensed by the detector unit. The loop sensor thus detects a vehicle.

The data that can be determined from the inductive loop detectors include vehicle classification (Gajda *et al.*, 2001; Bajaj *et al.*, 2007), lane occupancy, traffic densities, traffic composition, average and instantaneous vehicle velocities, presence of congestion, and length and duration of traffic jams. Besides that, inductive loop detectors can be used to identify rear-end collision risks which is normally used for accident analysis (Oh *et al.*, 2005). Actually, the data determination processes are depending on the technology used and these data can be directly or indirectly determined by the inductive loop detectors. The inductive loop detectors can be placed in a single lane or across multiple lanes, and they work with very slow or stopped vehicles as well as vehicles moving at high speed.

3.3.4 Video Vehicle Detection

Nowadays, the traffic development worldwide is increasing rapidly and most modern technologies are involved in the utility of traffic supervision and control. One of the most widely used methods is the video vehicle detection (VVD) and this method has advantages of better real-time performance, higher accuracy and ease maintenance (Anan *et al.*, 2006). Most of the VVD systems are known as non-intrusive method of traffic detection because they do not involve installing any components directly into the road surface or roadbed. The example of VVD system is ANPR system. Basically, when vehicle pass through the cameras, the video from black and white cameras or color cameras is fed into the processing unit and the processing unit will analyse the changing characteristics of the video image. The cameras are typically mounted on poles or on the structures above or adjacent to the roadway. Most video detection systems require some initial configuration to train the processor of the baseline background image. This step usually involves inputting known measurements such as the distance between the lane lines or the height of the camera above the roadway. The typical outputs of a video detection system are vehicle speeds, counts, and lane occupancy readings. Some systems provide additional outputs including gap, headway, stopped vehicle detection, and wrong way vehicle alarms.

CHAPTER 4: HARDWARE CONFIGURATION

4.1 Introduction

The selection of suitable hardware is crucial in order to make sure the success of a system. Without proper selection of the hardware, the possibility of a system to fail is high. There are two major systems involved in this research which are automatic number plate recognition (ANPR) system and the journey time measurement system. Technically, ANPR system and the journey time measurement system actually have similar hardware components where in this case, the ANPR based journey time measurement system consists of two sets of ANPR system hardware component which are installed or located beside the roadways at two different locations. Details are described in section 4.2 and 4.3.

In brief, the hardware components of the ANPR system consist of a high resolution digital camera, motorized zoom lens, infrared illuminator and computer. The camera is used to capture the image of vehicle that pass through the camera and continuously send the images to the computer for further processing. In this research, higher resolution digital camera is used in order to obtain high quality images. The quality of image plays an important role to avoid the processing problem with the software part. Proper illumination is significant to an image system and inappropriate illumination can cause a variety of image difficulties. As an example, blooming or hot spots are able to hide the essential image information. In order to solve this kind of problem and to avoid or prevent it to happen, the infrared illuminator is installed together with the camera. The infrared is some kind of technology for the night time function of video analysis or video processing. It eliminates the poorly-lit, noisy images typically seen under low light conditions and these noisy images actually represent the poor data. The present of infrared improves the quality of the image dramatically and enabling high resolution performance and these images serve as useable data. The darkness condition produces negative effects includes noisy image, shadow and blur image and the darkness images become unusable. It is clear that lighting is a key consideration which determines the effectiveness of ANPR system under low light and no light conditions. However, since the test of the ANPR software in this research is performed during the sunny day, so the infrared illuminator has not been used. The hardware components of the journey time measurement system is consists of two sets of ANPR system where each set of ANPR system is installed at two different locations as what had been mentioned in earlier discussions. The configurations of both systems are discussed in details in the next sub-topic.

4.2 Hardware Configuration for ANPR System

The ANPR system consists of hardware components and software component. It is crucial to configure the hardware component of ANPR system properly in order to make sure the system is successful. Figure 4.1 shows the schematic diagram of the hardware configuration for ANPR system which had been used in this research. Basically, for hardware configuration, the higher resolution digital camera is mounted beside the roadway and motorized zoom lens attached to the camera. Then, the camera is connected to the computer and the obtained video acquired by the camera is saved and stored in the computer for further processing.

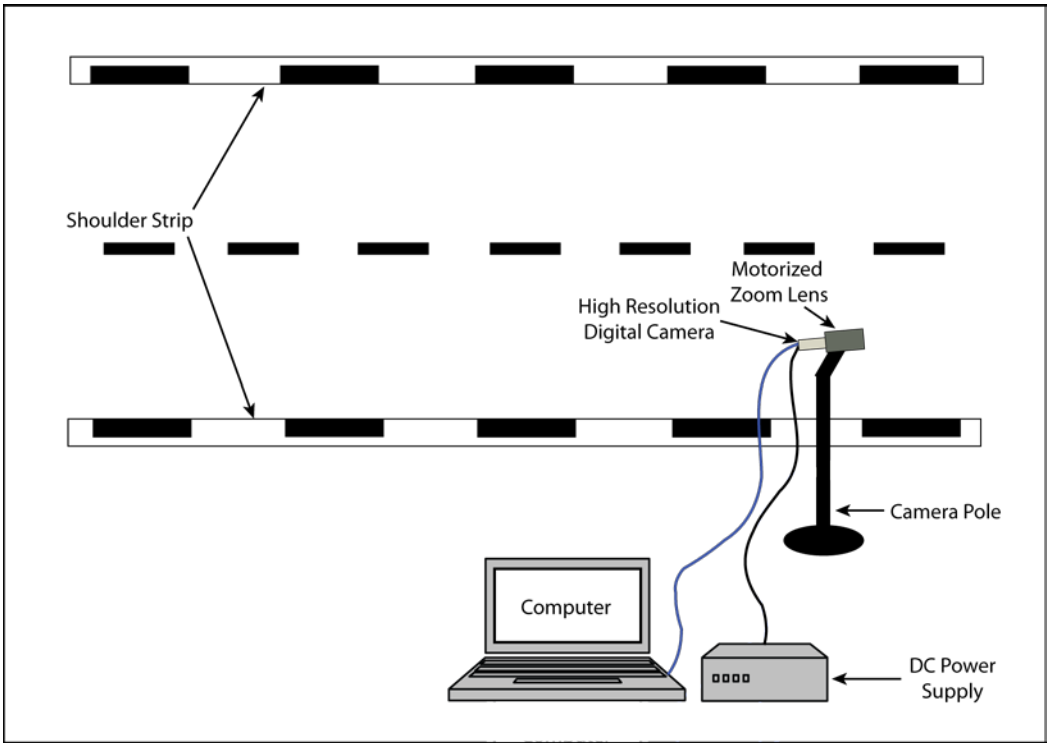

Figure 4.1: Schematic diagram of the hardware configuration.

Actually, the camera is the main hardware component of the ANPR system. It is important to know that the start of ANPR capture actually highly depends on the selection of the imaging hardware component that is camera because the function of the camera in this system is to capture the vehicle image which contained the number plate either from the front view or from the rear view. In most of the situations, the initial image capture is a crucial part of the ANPR system. This condition is according to the "garbage in, garbage out" of computing principle and it will often determine the overall performance of the ANPR system. In the other words, if the camera which is used for the ANPR system is not selected properly, so the probability and possibility of obtaining low quality image is high. Consequently, the low quality image which is captured by the camera will be processed by the ANPR software. Most of the cases, the ANPR software will not be able to recognize the number plate in the low quality image and even worse, the software will make false recognition. The ANPR system normally uses a camera that is specially designed for the task or in the other words, camera with high specification which can suit the application of ANPR system. There are several factors that influence the selection of camera for ANPR system such as the speed of the vehicles being recorded, varying ambient lighting conditions, headlight glare and harsh environmental conditions. Because of these factors, the ANPR system can’t be performed using the normal imaging hardware or normal camera.

In this research, a high resolution digital camera is used to capture the vehicle image. The digital camera was chosen over the analog camera because digital camera has a variety of sensors for high speed or higher resolution while the analog camera has a small footprint and typically low resolution. Besides that, the digital camera is typically has progressive scan output while the analog camera is typically has interlaced output. The camera is powered from the power source through the DC power supply. The camera cannot be connected directly from the power source because the voltage carried out from the power source in Malaysia is 240 VAC while the camera required voltage input between 12 VDC to 24 VDC. The DC power supply is able to convert the 240 VAC voltages from the power source to DC voltages and the voltages can be adjusted as required by the camera. The type of sensor used in this camera is the Sony ICX267 Progressive Scan CCD with 1392 x 1040 pixel sensor size.

This camera is a progressive scan type of camera where the method of display, storing or transmitting the moving images in which all the lines of each frame are drawn in sequence. All the image data are recorded in a single exposure. This method is in contrast to the interlacing method used by most of traditional television system or analog camera where in the interlacing method, the chip is divided into two fields which are odd field and even field. Firstly, it scans the odd row (1,3,5…) then scans the even row (2,4,6…) and the scanned fields are integrated to produce the full frame. The maximum frame rate for this digital camera at maximum resolution (1392 x 1040 pixels) is 17 frames per second (fps). Since the resolution of the captured image required by the developed ANPR software is 640 x 480 pixels, so by setting the camera resolution to 640 x 480 pixels, the frame rate of the camera can be set to higher fps. Frame rate is the measurement of frequency (rate) at which a camera produces frames. The frame rate is normally expressed 1 frame per second (fps). This camera uses the Gigabit Ethernet interface where the image or video is transferred to the computer via gigabit Ethernet Local Area Network (LAN) cable.

The camera lens is used in conjunction with the camera either it is permanently attached to the camera or it might be interchangeable. The main function of lens on the camera is to direct the light source to the camera sensor and also to focus the viewed image. The selection of suitable camera lens is normally based on several factors and it also depends on the application. It is important to keep your mind on that all lenses are not produced equally. The performance of a camera lens relies on the engineering and manufacturing technology that is used to build it. The lenses may have same identifying characteristics such as focal length, aperture, and operating features but bring radically differing results in resolution, color correction, and uniformity. In the ANPR application, the camera lens is selected based on the distance to view the vehicle number plate which is called working distance. This distance is measured from the front end of the lens to the subject and the lens angle will be influenced by working distance. The longer the distance between the camera lens and the subject, the angle will become smaller. The size of the number plate and actual characters will need to be of the certain size when see by the camera lens so that the captured image can be used by the ANPR software without any problem. In this research, the motorized zoom lens is used in conjunction with the high resolution digital camera. The motorized zoom lens is connected directly to the standard controller and the iris, zoom and focus is controlled through the standard controller.

A computer is used as a platform to store videos acquired by the camera and the video is transferred from the camera to the computer through the gigabit Ethernet LAN cable. In real-time application, the ANPR software is installed in the computer and the video received from the camera is processed directly by the ANPR software in real-time. However, in this research, the ANPR is developed for off-line purpose. In this case, a simple software is developed to record the vehicle image that acquired by the camera and the computer is the platform to store the recorded video. Figure 4.2 shows the complete hardware configuration for the ANPR system.

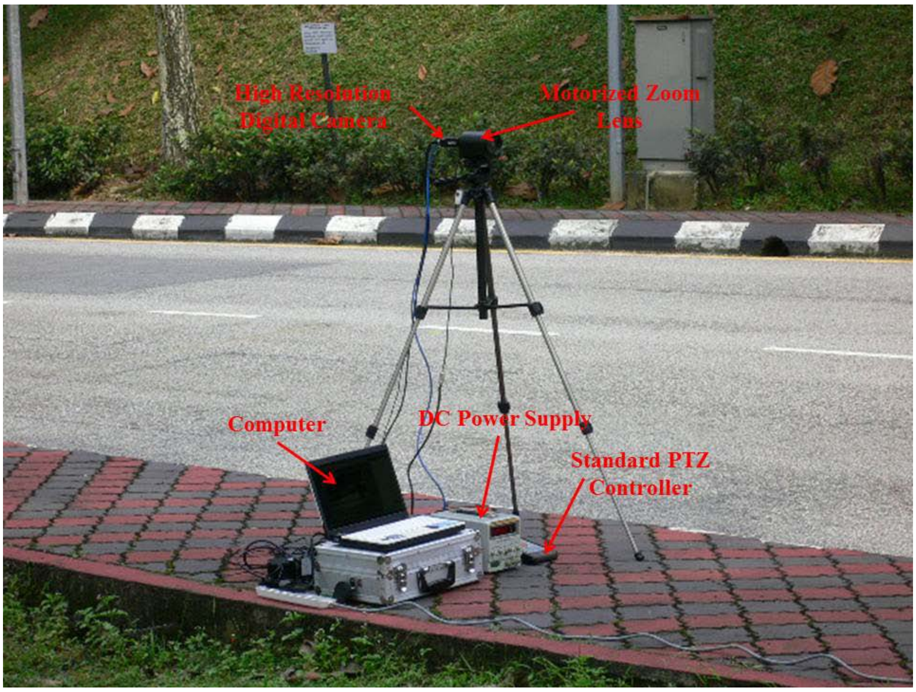

Figure 4.2: Hardware configuration for ANPR system.

In this research, both camera and lens are mounted on a camera tripod and placed beside the roadway which is approximately 2.7 meters from the center of road lane. The height of the tripod is set to be 0.63 meters from the ground. The camera is focused on the moving vehicle at the working distance 25.5 meters where this distance is calculated between the ends of the lens to the subject. The lens fully zooms at 10 times magnification of the image so that the number plate occupied approximately 18% of the scene width. Then, the camera is connected to the computer through the gigabit Ethernet LAN cable. In order to supply power to the camera, a set of DC power supply is connected to the camera. This DC power camera used to convert the 240 VAC voltages to the 12 VDC to 24 VDC voltages as required by the camera. The videos acquired by the camera are saved and stored in the computer for further processing.

4.3 Hardware Configuration for Journey Time Measurement System

In the introduction part, it is mentioned that the hardware components for both ANPR system and journey time measurement system are very similar because the journey time measurement system consists of two sets of ANPR system hardware component. Besides that, the hardware configurations of both systems also have not much difference. Figure 4.4 shows the hardware configuration for the journey time measurement system. The detailed description of the hardware components was discussed in the previous sub-topic. Based on Figure 4.4, the journey time measurement system consists of two ANPR systems located beside the roadway which is approximately 2.7 meters from the center of road lane at two different locations in the University of Malaya. The distance between first ANPR systems and the second ANPR system is set to be 19.35 meters. Actually, this hardware configuration is set up to measure the journey time for the short segment. For both ANPR systems, the cameras are focused on the moving vehicle at the working distance 25.5 meters where this distance is calculated between the end of the lens to the subject. The lens fully zooms at 10 times magnification of the image so that the number plate occupied approximately

18% of the scene width. Each system will record the video acquired by the camera and store the video into the computer for further process.

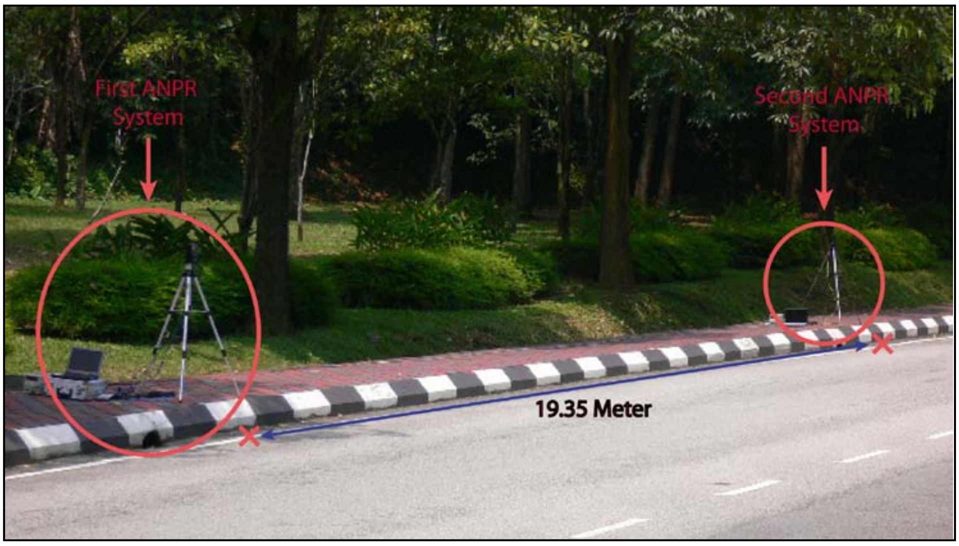

Figure 4.3: Hardware configuration for journey time measurement system.

4.4 Summary

The proper selection of hardware components brings lots of benefits to the ANPR system such as reduce the dependency on the software capability which is not only depend on the software wise. Besides that, the ANPR system is able to obtain higher accuracy and reduce the percentage error because if the system is depending more on software, the result will be varied based on the environmental conditions. It is important to configure the hardware such as the position of the camera because in order to maximize the effectiveness of the number plate capture, the camera position of the camera relative to the target capture area should be considered carefully.

CHAPTER 5: SOFTWARE DEVELOPMENT

5.1 Introduction

Basically, the ANPR software includes the following sequence of operations: vehicle detection, number plate localization, number plate extraction, character segmentation and character recognition. Figure 5.1 shows the flowchart of the sequence of operation in ANPR software. The sequences of operation were adopted from publication number 2 in the Appendix A.

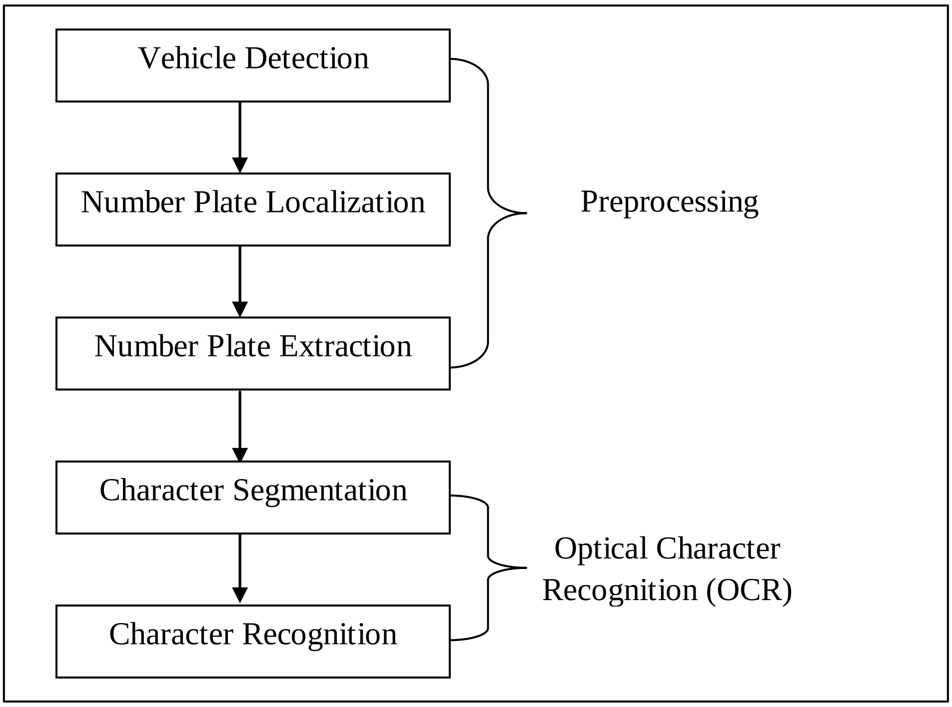

Figure 5.1: Flowchart of sequence of operation of ANPR software.

In many cases, the ANPR system relies more on the software part rather than the hardware part. The better the algorithms are, the higher the quality of the ANPR software is such as it will able to recognize at the highest accuracy rate, process the number plate at the fastest speed, detect and recognize the various of number plate type, process the number plate at the widest range of the picture quality and etc. The processing steps in ANPR software are discussed in details in the following sub-topic.

5.2 Vehicle Detection

Vehicle detection is the first step in ANPR software. ANPR software acquires the video from the camera installed at the desired location. In this research, the presence of the vehicle is detected using the hardware triggered method. Data acquisition (DAQ) device is used to trigger the signal acquired from the mechanical device. Firstly, the ANPR software acquires recorded video from the selected path or directory. Whenever the vehicles pass through the detection area in the display window, the mechanical switch is triggered in order to acquire the image of the vehicle's front view. The mechanical switch wires to the DAQ device. Since the mechanical switch used in this research consists of two terminals, so one of the switch's terminals is wired to the ground channel on the DAQ device and another terminal is wired to one of the digital I/O channels on the DAQ device. The ground terminal has become the reference point for the digital signal and the connection at the digital I/O terminal is set to be a digital input. Once the mechanical switch is triggered, the signal is sent to the DAQ device. The DAQ device sent the digital signal to the ANPR software for further processing. Once the signal is received by the ANPR software, the software will capture the vehicle image in the display window. Figure 5.2 shows the example of the front vehicle number plate that is successfully captured by the ANPR software through the vehicle detection step.

Figure 5.2: Example of the front vehicle number plate.

5.3 Number Plate Localization

The second step in ANPR software is to find or detect the area of vehicle number plate. This problem includes the algorithm that is able to detect the rectangular area of the number plate in the captured image. Human define the number plate in a natural language as “small plastic or metal plate attached to a vehicle for official identification purposes” (Martinsky, O., 2007). However, machines or computers do not understand this definition as well as they does not understand what “road”, “vehicle” or whatever else is. In order to solve this problem, there is a need to find an alternative definition of a number plate based on descriptors that will be comprehensible for machines and computers. In this research, let’s define the number plate as “rectangular area with a set of characters”. The importance of vehicle number plate location has been just searching an area that shows the set of characters of the number plate in the captured image. In order to fully use the character’s information, a new method of pattern matching is proposed in this research. It is known that the number plate area can be located in the area where the set of characters is found.

Pattern matching is a technique used to quickly locate a greyscale template within a region of greyscale image that a known reference pattern (National Instruments, 2003). A template is a shape or pattern that is trying to be matched with an image using the pattern matching function. A template can be a region selected from an image or it can be an entire image. However, the templates used to perform the pattern matching in this research are consisting of several number plate characters' images (refer Figure 5.3). These templates were created to be presented as objects which the algorithm is searching. In this research, the image number “1” to “9” and “H” are used as a template. The template images “1” to “9” are used because in Malaysia, the number plate typically begins by one or more letters followed by up to four numerical digits. The image number “0” is not included because none of the number plate in Malaysia is leading by zeros after the letter. Unlike the standard vehicles, taxi number plates have black characters on white background and most new Malaysian taxi start with letter “H”. That is why the template image “H” with black character on a white background is used in this research.

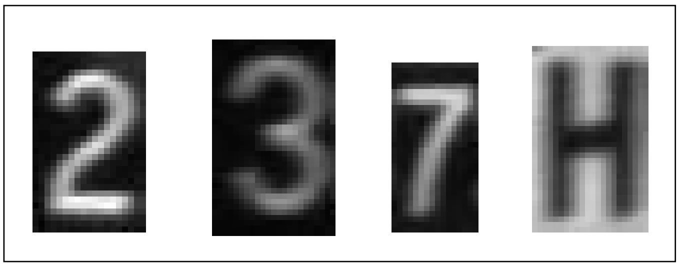

Figure 5.3: Samples of templates.

In order to successfully implement this method, the number plate angle of the captured image should be corrected. This is an important sub-step in the number plate localization step. In this sub-step, it is important to know the number plate angle θ. This sub-step is performed once every time the camera angle is changed. The calculation of the number plate angle θ is based on the angle between the y-Axis and the bottom of the number plate as shown in Figure 5.4. It can be clearly understood by referring Figure 5.5. After obtaining the value of the number plate angle θ, the value is compared with the reference angle value. In this case, the reference angle is 90°. After both number plate angle θ and reference angle are obtained, it is important to calculate the rotating angle ϕ. The rotating angle ϕ can be calculated by using the Function 5.1 as follows:

$$\phi = \begin{cases} \theta - 90^{\circ}, & \text{for } \theta \neq 90^{\circ} \\ 90^{\circ}, & \text{for } \theta = 90^{\circ} \end{cases} \tag{5.1}$$

If the rotating angle ϕ is positive, the captured image will rotate counter-clockwise and if the rotating angle ϕ is negative, the captured image will rotate clockwise. The rotated image is shown in the Figure 5.6 where the original captured image is shown in Figure 5.3.

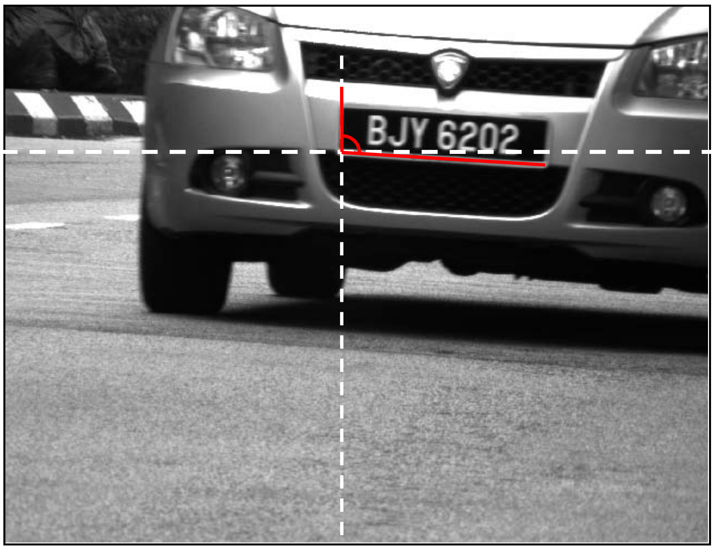

Figure 5.4: Number plate angle.

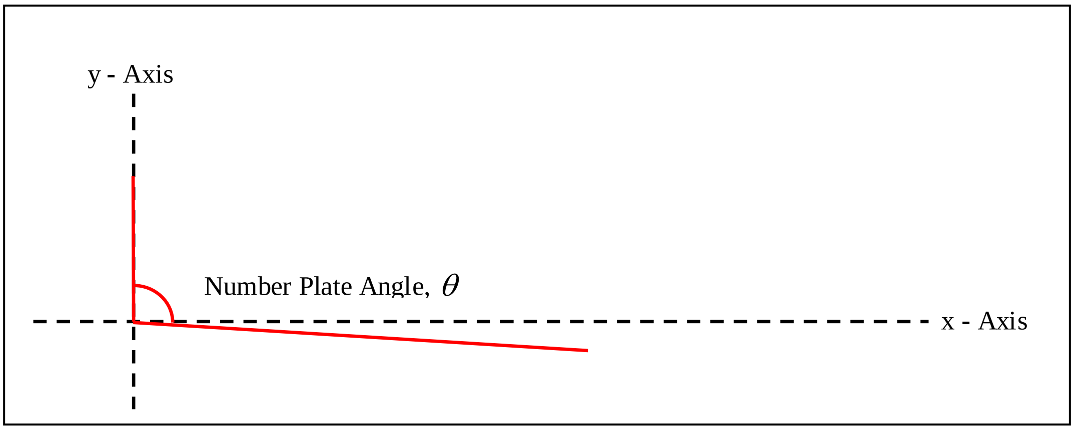

Figure 5.5: Details of number plate angle.

Figure 5.6: Number plate angle.

After performing the angle correction, the ANPR software will match the template images with the rotated image. In this sub-step, the algorithm searches for instances of the template in each captured image and calculating the score for each match. The score is calculated based on the settings match parameters. The number plate area will be defined based on the matching score where the matching score should be exceeding 800 out of 1000 scores. The matching process is stopped and the algorithm is trying to obtain the region of interest (ROI) of number plate when it found the matched image in the number plate. The algorithm finds the template matches regardless of contrast variation, image blur, noise and geometric transformations such as shifting, rotation or scaling of the templates. This is the advantage of the proposed number plate localization method.

Based on the matched coordinate, the algorithm will define the region of interest (ROI) of the number plate. Generally, number plates in Malaysia consist of two rows and one row of the number plate. In this research, the algorithm will define the ROI for both conditions. The ROI dimension of the first row is set to be 200x45 pixels and the ROI dimension of the second row is set to be 275x38 pixels depending on image hardware setting. The calculation of ROI is very important because if the algorithm is missed calculate the ROI, it will provide wrong detection of the location of the number plate. The need to provide correct and quality image in this sub-step is very crucial for the success of proceeding step in ANPR algorithm.

5.4 Number Plate Extraction

The crucial and complicated step in ANPR software is to extract the characters of number plate from the vehicle image background. The procedure for extracting is done in several stages. The number plate extraction is started with the horizontal and vertical edge detection techniques that are based on the characteristics of the edge displayed by the edges of the character on the vehicle’s number plate. In order to enable a good number plate extraction process, the thresholding technique was implemented. Noise is eliminated and the small particles are filtered out according to the measurements such as the area, bounding height and bounding width. As far as it is concerned, in real life, the light condition will always change with the time and weather. So, adaptive thresholding is introduced in this research. Briefly, thresholding is used to segment an image into two regions: a foreground region and a background region. The pixels intensity above a threshold value belongs to foreground and the remaining pixels intensity value belongs to background. For conventional thresholding technique, it uses global threshold for pixels while for adaptive thresholding, it changes the threshold value dynamically over the image. In this research, the threshold value will be specified according to the average greyscale value of the image which we have to determine before thresholding process. In order to determine the relation between greyscale value and threshold value at lane location, a suitable test is performed. In this test, the optimal threshold value is determined based on the greyscale value. The process is repeated for 50 samples and the graph greyscale value against optimum threshold value has been plotted and the relationships are given in Function 5.2 as follows:

$$V(t) = \begin{cases} V(g) + a, \text{ for } V(g) < 55 \\ V(g) + b, \text{ for } V(g) \geq 55 \end{cases} \tag{5.2}$$

Where *V (g)* is greyscale value and *V (t)* is a threshold value. *a* and *b* are constant values. In this case, *a* equals to 10 and *b* equals to 25. The next stage for number plate extraction is an image enhancement process. The main purpose of enhancement process is to remove noise in number plate image. The noise defined here is Gaussian noise. After the noise is removed it is ready for the next process.

5.5 Character Segmentation

Segmentation process is used to find the individual characters on the number plate. In this research, segmentation of characters is performed using the thresholding technique. It is segmented by finding the characters in the image and bounded each character with the rectangle to separate them as shown in Figure 5.7.

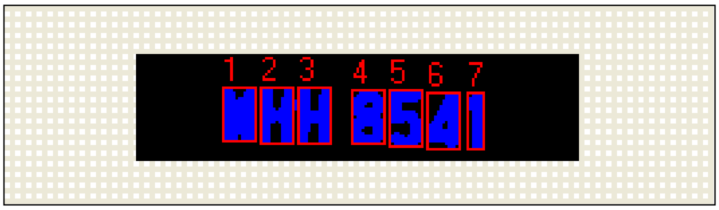

Figure 5.7: Segmented characters.

5.6 Character Recognition

Optical Character Recognition (OCR) is the process by which the machine vision software read text and/or characters in an image. This OCR software is commercial software included in the graphical programming software that used to develop this ANPR software. The OCR software is used in order to convert the segmented characters to the ASCII code. Before the conversion process is started, the OCR software is trained in order to enhance its ability to recognize the characters. Many samples with various angles are collected and trained to make the OCR software intelligent enough to recognize all the characters from A to Z and from 0 to 9. All the characteristic of characters is analysed and stored into the database. All the characters that sent to the OCR software are matched with the characters in the database through pattern matching process. The one with the highest score is chosen and it will be converted into the ASCII code. Figure 5.8 shows the converted characters in the ASCII code.

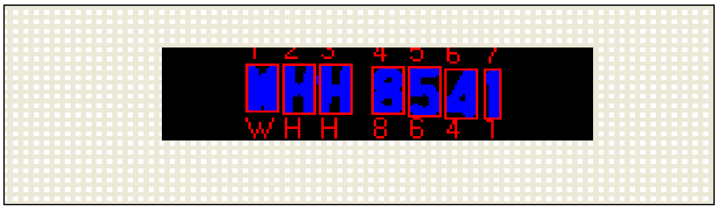

Figure 5.8: Recognized characters.

5.6 Summary

After performing the entire process step as discussed in the previous sub-topics, the vehicle number plate is displayed on the user interface front panel together with other important information such as record number, date and time. The sample of user interface front panel of the developed ANPR software is shown in Figure 5.9

Figure 5.9: Sample of user interface front panel.

CHAPTER 6: JOURNEY TIME MEASUREMENT SYSTEM

6.1 Introduction

There is numerous data collection methods can be used to calculate journey times. These methods are used to calculate the journey times on selected roadway sections. Normally, the resulting journey time and speed data are much different than spot speeds because these methods vary from point-based speed measurement. The examples of the journey time measurement techniques are test vehicle technique (floating car), number plate matching technique, probe vehicle technique, emerging and non-traditional technique. The general overview of the mentioned techniques is provided in the following paragraphs.

A test vehicle technique which is often referred as floating car (Garber and Hoel, 2003) is the most familiar journey time measurement methods. This technique consists of a vehicle that is purposely sent off to drive with the traffic flow for the journey time measurement and data collection. The driver or passenger of the test vehicle controls the speed of the vehicle according to the set driving procedure either average car, floating car of maximum car. The passenger in the test vehicle can manually record the data at chosen check-points using a stop-watch. Besides that, the computer can be used to record vehicle speed, journey time or distances at preset check-points or gaps between the check-points. An electronic Distance Measuring Instrument (DMI) connected to the vehicle's transmission may be paired with a portable computer to record speeds and distances travelled up to every half-second or less. A Global Positioning System (GPS) receiver paired with a portable computer may be used to record the test vehicle's location and speed at time gaps as frequently as every second.

The number plate matching technique consists of collecting vehicle number plate characters and arrival or stamped time at different check-points, then matching the number plates between successive check-points, and calculating the journey times from the difference between arrival or stamped times. Number plate matching for Journey times can be carried several ways. The manual technique engages recording number plate characters using the recorders, and after that the number plate is typed into a computer for the matching process. A portable computer-based technique depend on the human viewer to record the number plate into the computer in the field, and then match the number plates by computer later on. Besides that, video cameras or camcorders can be used to collect number plates with manual record into a computer being performed by humans at a later date. The most advanced method is the use of automatic number plate recognition (ANPR) system where the ANPR system collects number plate images, and depends on character recognition algorithms or software to recognize the character. Then, it will be automatically recorded into the computer for the matching process. This kind of technique is used in this research in order to measure or collect journey time data. The detailed discussion of the journey time measurement using the number plate matching techniques specially ANPR system is discussed in the sub-topic.

The probe vehicle techniques which use the passive instrument vehicle in the traffic flow as well as the remote monitoring devices are implemented in order to calculate journey times. It can be embedded in personal, public transports, or commercial vehicles for the journey time data collection. It typically sends the data to a transportation management centre (TMC) in real-time. Besides, it may be equipped with numerous different types of electronic transponders or receivers. In other hand, automated vehicle identification (AVI) transponders is normally placed inside a vehicle and are used in electronic toll collection applications.

Last but not least, emerging or non-traditional technique is currently being developed. It may be considered non-traditional when compared to existing methods. This technique uses a variety of methods, such as inductive loops, weigh in motion (WIM) stations, or aerial video to estimate or calculate journey times. Most of the emerging techniques are currently in development or testing stages and have not been extensively field tested or applied. The knowledge of these emerging techniques is provided just for information.

6.2 Definitions

Garber and Hoel (2003) in their book defined journey time as total time to traverse a given highway segment or road segment. In other words, journey time is the time required to pass through a route between any two locations. Journey time can be directly measured by passing through the two or more locations. It is consisted of running time and stopped delay time. Besides that, in certain cases, journey time can also be estimated by assuming the average speed at a particular point is constant for a short distance. The assumption of consistent speeds over a short roadway part is most applicable to uninterrupted flow facilities with stable traffic flow patterns.

Generally, journey time between these points can be calculated based on two average speed definitions which are time mean speed and space mean speed (Dalgleish and Neil, 2008). Time mean speed is the average speed of all vehicles for a specified period of time (6.1). It can be understood as the average speed of vehicles for a specific time period and it is normally calculated by adding up the average speed of all the observed individual vehicles and dividing by the number of observed vehicles. Time mean speeds are normally associated with spot speed measurements and it is associated with a single point along a roadway over time. One more definition of average speed is space mean speed. Space mean speed is the average speed of vehicles travelling a given segment of roadway during a specified period of time and is calculated using the average journey time and length of the roadway segment (6.2). It can be understood as average speed of vehicles which are using a segment of roadway during the specified period of time and it can be calculated by multiplying the number of vehicles by the distance of the link and dividing the sum of all individual average speed. Space mean speed is associated with a specified length of roadway and it is normally used when reducing and analysing journey time data.

$$Time\_Mean\_Speed, v_{TMS} = avg.\_speed = \frac{\sum v_i}{n} = \frac{\sum \frac{d}{t_i}}{n} \qquad (6.1)$$

$$Space\_Mean\_Speed, v_{SMS} = \frac{dist.\_traveled}{avg.\_travel\_time} = \frac{d}{\frac{\sum t_i}{n}} = \frac{n \times d}{\sum t_i} \qquad (6.2)$$

Based on equation (6.1), v_{TMS} is Time Mean Speed, v_i is speed of individual vehicles and n is number of observed vehicles. In equation (6.2), V_{SMS} is Space Mean Speed, n is number of observed vehicles, d is distance of the link and t_i is time taken to travel for individual vehicles.

Commonly, for both cases, in order to be practical, it is important to include only vehicles that complete the journey within three standard deviations of the mean. This condition isn't included the vehicles which are joining and leaving a route network between the measurement points. In the other meaning, it excludes vehicles which are making partial journeys. The condition also designs to exclude vehicles that stop on the journey for more than three standard deviations of the mean. However, in this research, there will not be any conditions where the vehicles joining and leaving a route network between the measurement points and vehicles that stop on the journey for more than three standard deviations of the mean as mentioned above because the distance between the measurement point is short distance and there are no junction or exit in between these points.

6.3 Individual Journey Time

In order to verify data collected by individual vehicles, the equipment on the individual vehicles should be calibrated correctly. Otherwise, the verified data will not be correct and the verification of data by external method will be impossible. Nevertheless, the individual driver's behaviour such as stopping or making a deviation within the route can affect the journey time. Though, this condition can be identified and removed if a complete track is being recorded. The data also can be discarded because these data are not indicating the actual traffic problem.

For a passive journey time, the form of verification will depend heavily on the installation of the devices. As an example, if the stations are widely dispersed, there is no opportunity to carry out verification at the in-station because there may be no dedicated communication network including the video. In general, there are two methods for verifying journey time measurement system that is normally used. Each time the verification process takes place, it uses the combination of automatic and manual vehicle number plate recognition in order to track vehicles through the route.

The two verification method mentioned are in-station based and out-station based. For in-station based method, a communication system including video is used. The verification process depends on the parallel processing of the image data and comparison of the population survey with the system under test sample. On the other hand, for out-station based, no video communication is available and the records of data should be collected on-site.

6.4 Number Plate Matching Technique

Generally, number plate matching methods consist of collecting the vehicle number plates and arrive or stamped times at different check-points. After that, the number plates between the check-points are matched and journey times from the difference in arrival times are computed. There are four basic methods of collecting and processing number plates; manual method, portable computer method, video with a manual record method and video with character recognition method (known as ANPR). The details of the methods are discussed in the following sub-topic.

6.4.1 General Advantages and Disadvantages

Number plate matching for journey time collection has several advantages and disadvantages. The advantages of the number plate matching technique are: The number plate matching technique can obtain journey times from a huge sample of vehicles. These data are useful toward understanding the variability of journey times between vehicles within the traffic flow. Besides, it gives a range of journey times data during the collection phase and has the ability to analyse within short time periods. In addition, between the observation sites, the equipment for data collection are portable.

The disadvantages of the number plate matching techniques are: Journey time data restricted to places where observers or video cameras can be installed. Also, there is restricted geographic coverage on a single day. Moreover, the manual method and portable computer-based method is less practical for high speed freeways or long parts of the roadway with a low percentage of traffic flow. Last but not least, this technique requires data collection personnel skills especially for manual methods of number plate matching.

6.4.2 Manual Methods of Number Plate Matching

The manual method for number plate matching requires the human resources to read number plates at the sites and record the number plates into a computer system after the data collection activities. Number plates can be collected at sites using pen and paper or a tape recorder.

6.4.3 Portable Computer-Based Number Plate Matching

The portable computer-based method for number plate matching requires the observer to record data directly into the portable computers such as laptops at the sites. Number plates can be entered into the portable computer and it is depending on the typical vehicle speeds. In this method, the computer program provides the time-stamp automatically. Through this method only the number plate matching is performed in the office.

6.4.4 Video with Manual Record

Through this method, the number plate matching process depends on video cameras in order to gather number plates at the sites. This method needs human resources to record the number plates into a computer in the office after the actual time of data collection. Actually, a video collection of number plates is preferred compared to the manual collection because of several factors. One of the factors is that video gives a lasting evidence of number plates and traffic situations. The video also lets the reading of number plates in controlled surroundings where the characters of number plate can be closely checked.

6.4.5 Video with Character Recognition (ANPR)

Typically, ANPR system consists of two important components which are hardware component and software component. The hardware components including camera and lens while software component including the OCR software. The number plates are recognized and matched by a computer using hardware/software that performs OCR. Several ANPR systems allow manual evaluation of the unrecognized number plates. ANPR systems have mainly been used in critical applications because these systems are relatively high costs.

The collection and matching of number plates using ANPR systems in real-time has been implemented rapidly in the European countries such as United Kingdom. These real-time number plate reading and matching techniques are being utilized to provide information to the travellers. This kind of method is used in this research in order to measure and collect journey time data.

CHAPTER 7: EXPERIMENTAL RESULTS AND DISCUSSION

In order to test the performance of the developed ANPR software, several tests had been performed. The tests were conducted using the recorded mode at 5 different angles where the pan angle θ_h (horizontal angles) is fixed to 1.4° and the tilt angles θ_v (vertical angles) are changing. The selected tilt angles θ_v were tested are 6.08°, 8.12°, 10.16°, 12.00° and 13.61°. The configuration of pan angle θ_h is shown in Figure 7.1 while the configuration of tilt angle θ_v is shown in Figure 7.2. A video for each selected angle was recorded for approximately 10 minutes. The tests were performed during the sunny day and it is divided into 5 samples based on angle setting (refer Table 7.1). The complete test data of the ANPR software is shown in Appendix B. Besides that, a test was performed in order to test the capability of developing ANPR software to measure journey time. The complete experimental setup was explained in details in chapter 4. In this chapter, data obtained from the tests are presented. Data analysis and discussion are also included in this chapter. The collected data are shown in the following section.

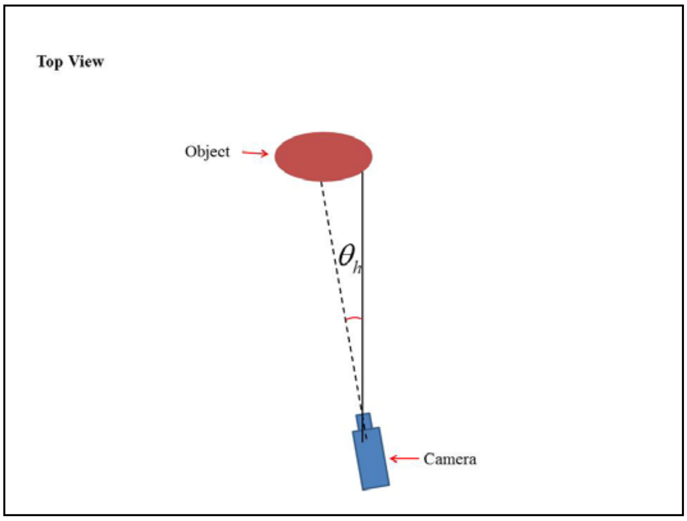

Figure 7.1: Camera configuration of pan angle.

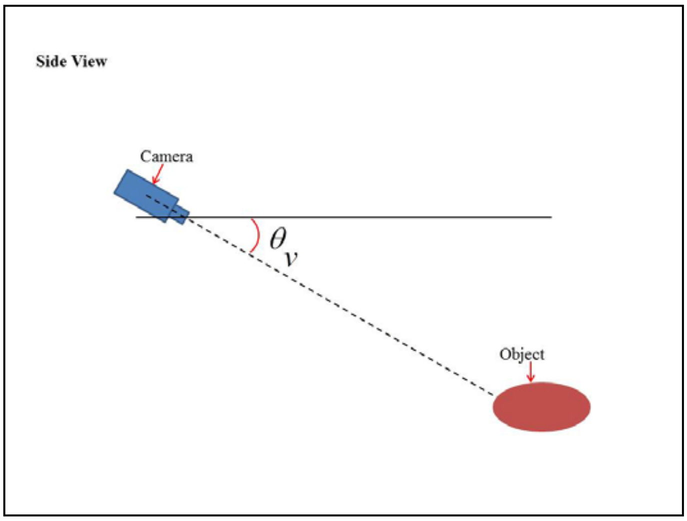

Figure 7.2: Camera configuration of tilt angle.

Table 7.1: ANPR software test details.

Sample	Pan Angle, θ_h	Tilt Angle, θ_v	Recording Duration (MM:SS)
1	1.4	6.08	9:42
2	1.4	8.12	11:38
3	1.4	10.16	11:20
4	1.4	12.00	10:52
5	1.4	13.61	10:02

7.1 Automatic Number Plate Recognition (ANPR) Tests Results

The ANPR tests were done in order to evaluate the ability of the developed ANPR software to find the location of the number plate and read the localized number plate.

7.1.1 Number Plate Localization Performance Rate and Discussion

Table 7.2: Number plate localization result.

Sample	Actual Number of Cars	Number of Cars Localized by the Algorithm	Rates of Cars Localized by the Algorithm (%)
1	73	69	94.52
2	76	69	90.79
3	54	49	90.74
4	50	40	80.00
5	44	42	95.45
		Average	90.30
		Standard Deviation	3.05

Table 7.2 shows result for number plate localization. Based on Table 7.2, it can be found that the average number plate localization rate is 90.30% with a standard deviation of 3.05%. In order to know the performance of the number plate localization rate, the Confidence Interval of the Mean (CIM_p) was calculated by using the Formula 7.1 (Dalgleish and Hoose, 2008):

$$CIM_p = \pm t_{p,n} \times SDSM = \pm t_{p,n} \times \frac{SD}{\sqrt{n}} \quad (7.1)$$

Where n is the number of observations in each sample, $t_{p,n}$ is the value of the "student's t-statistic" for probability p, $SDSM$ is standard deviation of survey mean and SD is standard deviation. From the data in Table 7.2, it is known that the test has 5 samples and requires a 95% confidence level so that the interval has a 95% chance of containing the true parameter value. Based on calculations using the equation 7.1, the $CIM_{95\%}$ for number plate localization performance rate is ± 3.79. This means that the overall localization rate for all vehicles lays between 94.09% and 86.51% at a confidence level 95%. So, the developed ANPR software is able to locate the vehicle number plate at more than 86.51% of legal number plate in good condition and properly presented with confidence level 95%. This means that for a sample of 100 number plates, it is only expected the performance of number plate localization to drop below 86.51% about 5% of time.

The sample of images that successfully localized is shown in Figure 7.3 and Figure 7.4. In the other hand, the sample of unsuccessfully localized is shown in Figure 7.5. Based on figure 7.5, the algorithm was unable to find the location of this number plate. It was due to the failure of the vehicle detection algorithm to capture the vehicle image at the right position as shown in Figure 7.6. As described in Chapter 2, sub-topic 2.1.1.2 Localization, the new method called pattern matching was implemented in this ANPR software to find the location of the number plate. If the captured image doesn't contain the number plate character, the ANPR software will not be able to detect the location of number plate since the software cant' match the template. This situation caused the localization algorithm failed to find the location of number plate because there is no number plate in the image. Based on Figure 7.4, the proposed number plate localization method is able to detect the location of the number plate in the defected number plate.

Figure 7.3: Successfully localized for the good number plate condition.

Figure 7.4: Successfully localized for broken number plate condition.

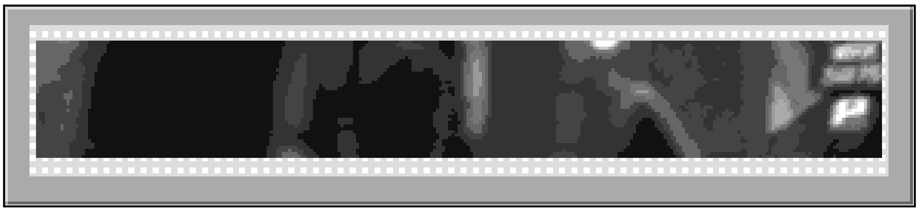

Figure 7.5: Unsuccessfully localized.

Figure 7.6: Wrong vehicle detection.

Besides that, a chi-square test was done for number plate localization result in order to gauge the significance of the data obtained and to demonstrate that there is no significant difference between two set of measurement. From the Table 7.2, the chi-square test is applied as follows:

1. Let H_O: The actual number of car is the same as the number of cars localized by the algorithm, for all sample i,

   H_A: The actual number of car is different with the number of cars localized by the algorithm for at least one sample i.

2. Chi-square test with 4 degrees of freedom.

Table 7.3: Chi-square value test for number plate localization.

Sample, i	Number of Cars Localized by the Algorithm, o_i	Actual Number of Cars, e_i	$\frac{(o_i - e_i)^2}{e_i}$
1	69	73	0.22
2	69	76	0.64
3	49	54	0.46
4	40	50	2.00
5	42	44	0.09
		$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i}$	3.41

From Table 7.3, χ^2 = 3.41. Based on the chi-square table, $\chi^2_{0.05,4}$ = 9.488. Since 3.41 < 9.488, H_O is not rejected at level 0.05. The number plate localization result obtained from the developed ANPR software is accepted for the defined significance level of 0.05.

7.1.2 Number Plate Recognition Performance Rate and Discussion

Table 7.4: Number plate recognition result.

Sample	Number of Cars Localized by the Algorithm	Number of Plates Recognized without error by the Algorithm	Number of Plates Recognized with One Character Error by the Algorithm	Total Number of Plates Recognized by the Algorithm	Total Number of Plates Recognized by the Algorithm Rates (%)
1	69	41	15	56	81.16
2	69	39	19	58	84.06
3	49	27	15	42	85.71
4	40	23	10	33	82.50
5	42	28	7	35	83.33
				Average	83.35
				Standard Deviation	2.83

Table 7.4 shows number plate recognition result. The calculation of number plate recognition rate is based on the number of cars localized by the algorithm and total number of plates recognized by the algorithm value which is the sum of number plate recognized without error by the algorithm value and number plate recognized with one character error by the algorithm value. For travel time system, number plate with no errors or one error are acceptable as valid matches (Dalgleish and Hoose, 2008). Data from Table 7.4 shows the average number plate recognition rate is 83.35% with a standard deviation of 2.83%. The calculation of performance of number plate recognition was done using the Formula 7.1. From the data in the Table 7.4, it is known that the test has 5 samples and requires a 95% confidence level so that the interval has a 95% chance of containing the true parameter value. Based on calculations, the $CIM_{95\%}$ for number plate recognition performance rate is ± 3.51. This means that the overall number plate recognition rate for all vehicles lies between 86.86% and 79.84% at a confidence level 95%. So, the ANPR software is able to read and recognize more than 79.84% of legal number plate in good condition and properly presented with confidence level 95%. This means that for a sample of 100 number plates, it only expects the performance of number plate recognition to drop below 79.84% about 5% of time. Based on observation through tests, the algorithm sometimes confuses with characters “0” and “D”, “Q” and “8” and “B”, “H” and “M” and “W”. These problems occurred due to the shapes of those characters are very similar in binary form.

A chi-square test was also done for number plate recognition result in order to gauge the significance of the data obtained and to demonstrate that there is no significant difference between two set of measurement. From the Table 7.4, the chi-square test is applied as follows:

1. Let H_O: The number of cars Localized by the algorithm is the same as the total number of plates recognized by the algorithm, for all sample i,

   H_A: The number of cars Localized by the algorithm is different with the total number of plates recognized by the algorithm, for at least one sample i.

2. Chi-square test with 4 degrees of freedom.

Table 7.5: Chi-square value test for number plate localization.

Sample, i	Total Number of Plates Recognized by the Algorithm, o_i	Number of Cars Localized by the Algorithm, e_i	$\frac{(o_i - e_i)^2}{e_i}$
1	56	69	2.45
2	58	69	1.75
3	42	49	1.00
4	33	40	1.23
5	35	42	1.17
		$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i}$	7.60

From Table 7.5, χ^2 = 7.60. Based on the chi-square table, ${\chi^2}_{0.05,4}$ = 9.488. Since 7.60 < 9.488, H_O is not rejected at level 0.05. The number plate recognition result obtained from the developed ANPR software is accepted for the defined significance level of 0.05.

7.2 Journey Time Measurement Test Results and Discussion

Table 7.6 shows the journey time measurement data using the developed ANPR based journey time measurement software. The data consists of seven 2 minute samples. Basically, the data in the Table 7.6 consists of number of sample, time duration, number of plates matched by ANPR software, average journey time by ANPR software, average speed by ANPR software, number of plates matched by manual method, test car's journey time and test car's speed. The average journey time data were calculated by ANPR based journey time measurement software. The recorded video was run in the computer with the developed ANPR based journey time measurement software running on it. Since the developed ANPR based journey time measurement software designated to measure journey time of two point of location, therefore, the software consist of two ANPR software (1st ANPR software and 2nd ANPR software) . Basically, the ANPR software collects the vehicle number plates and arrival times at different check-points, 1st point and 2nd point. Then, the number plates between the check-points were matched and journey times from difference in arrival time were computed. After that, based on the calculated journey time data and the data of the distance between each camera during the recording process, the average speeds were calculated by the developed ANPR based journey time measurement software. The complete test data of the journey time measurement is shown in Appendix C.

Table 7.6: ANPR journey time measurement data.

Sample	Time Duration (minute)	Number of Plates Matched by ANPR Software	Average Journey Time by ANPR Software (s)	Average Speed by ANPR Software (Km/h)	Number of Plates matched by Manual Method	Test Car's Journey Time (s)	Test Car's Speed (Km/h)
1	0-2	6	2.94	23.68	7	2.78	25.00
2	2-4	9	2.85	24.49	10		
3	4-6	8	2.94	23.71	10		
4	6-8	9	2.82	24.75	10		
5	8-10	8	2.91	24.71	12		
6	10-12	5	2.84	24.50	8		
7	12-14	4	2.90	24.04	8		

In order to validate the accuracy of measured journey time data, comparison between measurement by the developed ANPR software and a test car that was running on the tested route where ANPR journey time system is in operation during the data collection process was carried out. The test car's journey time was 2.78s at an average speed 25km/h. By comparing with the reference value measured manually, the measured values obtained from the ANPR journey time system are within the acceptable range.

A chi-square test was done for number plate matching result in order to gauge the significance of the data obtained and to demonstrate that there is no significant difference between two set of measurement. From the Table 7.7, the chi-square test is applied as follows:

1. Let H_O: The number of plates matched by manual method is the same as the number of plates matched by ANPR Software, for all sample i,

   H_A: The number of plates matched by manual method is difference with the number of plates matched by ANPR Software, for at least one sample i.

2. Chi-square test with 6 degrees of freedom.

Table 7.7: Chi-square value test for number plate matching.

Sample, i	Number of Plates Matched by ANPR Software, o_i	Number of Plates matched by Manual Method, e_i	$\frac{(o_i - e_i)^2}{e_i}$
1	6	7	0.14
2	9	10	0.10
3	8	10	0.40
4	9	10	0.10
5	8	12	1.33
6	5	8	1.13
7	4	8	2.00
		$\chi^2 = \sum \frac{(o_i - e_i)^2}{e_i}$	5.20

From Table 7.5, $\chi^2 = 5.20$. Based on the chi-square table, $\chi^2_{0.05,6} = 12.592$. Since $5.20 < 12.592$, H_o is not rejected at level 0.05. The number plate recognition result obtained from the developed ANPR software is accepted for the defined significance level of 0.05.

Figure 7.5 shows the frequency diagram for vehicles' space mean speed (SMS). The vehicles' space mean speed was calculated based on journey time data and the data of the distance between each camera during the recording process. Based on Figure 7.5, the vehicles traversed the tested route at regular speed between 21km/h to 24km/h.

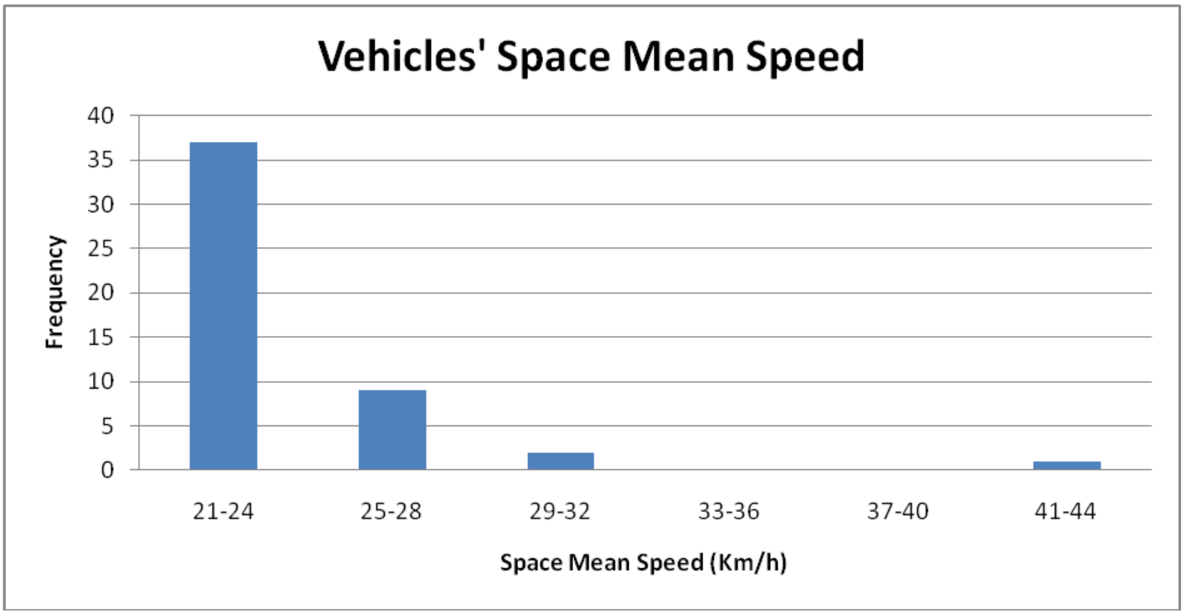

Figure 7.5: Vehicles' space mean speed.

7.2.1 Journey Time Verification

Table 7.7 shows journey time verification data. In the Table 7.7, the statistics for the percentage error of journey time were calculated and based on the Table 7.7, the average journey time error for the test is +3.80%, while the standard deviation is 1.82%.

From this, the average journey time error for all vehicles was calculated using student's *t* from the standard statistical tables for 7 samples which is 6 degrees of freedom using the Formula 7.1, Confidence Interval of the Mean formula.

Thus, the true mean journey time for all vehicles is between +3.8% -1.69% and +3.8% +1.69% (i.e., between +2.11% and +5.49%) of the average journey time which was calculated from the test data with confidence level 95%.

Table 7.8: Journey time verification.

Sample	Time Duration (minutes)	Average Journey Time by ANPR Software (s)	Test Car's Journey Time (s)	Error	Percentage (%)
1	0-2	2.94	2.78	0.16	5.90
2	2-4	2.85		0.07	2.36
3	4-6	2.94		0.16	5.81
4	6-8	2.82		0.04	1.33
5	8-10	2.91		0.13	4.61
6	10-12	2.84		0.06	2.28
7	12-14	2.90		0.12	4.31
			Average	0.11	3.80
			Standard Deviation	0.05	1.82

7.2.2 Space Mean Speed Verification

The space mean speed verification data is shown in Table 7.8. Based on Table 7.8, the statistics for the percentage error of space mean speed were calculated. Based on Table 7.8, the average space mean speed error for the test is -2.92%, while the standard deviation is 1.82%. From this, the average journey time error for all vehicles was calculated using student's *t* from the standard statistical tables for 7 samples which is 6 degrees of freedom using the Formula 7.1, Confidence Interval of the Mean formula.

Thus, the true mean space mean speed for all vehicles is between -2.92% -1.69% and -2.92% +1.69% (i.e., between -4.61% and -1.23%) of the average space mean speed which is calculated from the test data with confidence level 95%.

Table 7.9: Space mean speed verification.

Sample	Time Duration (minutes)	Average Speed by ANPR Software (Km/h)	Test Car's Speed (Km/h)	Error	Percentage (%)
1	0-2	23.68	25.00	-1.32	-5.27
2	2-4	24.49		-0.51	-2.04
3	4-6	23.71		-1.29	-5.17
4	6-8	24.75		-0.25	-0.98
5	8-10	24.71		-0.29	-1.16
6	10-12	24.50		-0.50	-1.98
7	12-14	24.04		-0.96	-3.85
			Average	-0.73	-2.92
			Standard Deviation	0.46	1.82

CHAPTER 8: CONCLUSION AND RECOMMENDATION

8.1 Conclusion

In this study, a new number plate localization method called pattern matching was proposed. This method was able to provide the good and promising result based on results and analyses in the Chapter 7. From the ANPR test data, it shows that the camera tilt angle θ_h between 6.08° and 13.61° do not really affect the capability of the developed ANPR software to locate the vehicle number plate.

Besides that, the developed ANPR software able to locate and read the number plate with high average rates. From the test result, the developed software obtained high average rates which are more that 80% of average rates. It was tested at 5 different angles and the obtained results are promising. It shows that the developed ANPR software has a capability to locate and read the Malaysian number plate and this software is suitable for the real-time purpose during the sunny day since the localization and recognition rate are high enough.

Furthermore, the measurement capability of the developed ANPR software can be extended to be used for measuring vehicle journey time and other traffic parameter. From the journey time test data, it shows that this software capable of measuring vehicle journey time and space mean speed as well. The achievement and capability of the developed ANPR software are promising.

8.2 Recommendation for Future Work

Numerous of improvements and suggestions can be done in order to obtain the best and reliable result of the tests. To reduce the false and wrong character recognition due to similarity of characters' shape, more training needed to be done with the optical character recognition (OCR) to make it intelligent enough to differentiate each character. The OCR needs to be trained with as many characters as possible. Through this process, this false and wrong character recognition problem can be reduced and the number plate recognition rate can be increased.

Instead of using the basic template images (template images "1" to "9") for number plate localization step, more template images can be used. By adding up the quantity of template images, it should be able to increase the capability of the developed ANPR software to recognize more patterns and at the same time it should be able to increase the number plate localization rate.

In this study, the manual control motorized lens was used as a part of the hardware. The problem with the manual control lens is that this type of lens needs to be controlled manually. In the other word, when the change of light condition occurs, the lens needs to be adjusted manually in order to control the quality of video. Image processing is very sensitive to the change of light intensity as well as change of weather. In order to solve this issue, the manual lens can be changed or replaced with auto iris lens because the auto iris lens has the capability to automatically adjust the lens and also maintain and improve the quality of the video during the change of light condition.

In future, the capability of this developed ANPR software will be extended for other weather conditions such as cloudy days, night time and raining time and more set of data could be collected so that additional statistical tests could be performed to prove the efficiency of the ANPR software. This is a good future remark toward the development of robust ANPR software which can be used for multiple weather conditions. After that, the developed ANPR software will be extended for online or real-time system. This is good future plan in order to implement the real-time ANPR system. Last but not least, the developed ANPR software has high potential to be used in transportation planning, traffic engineering and traffic operation especially for Malaysian environment. It is a good idea to implement the ANPR based journey time measurement in Malaysia because this research is able to reduce several traffic problems especially related to the traffic congestion problem that also contribute to the delay problems by providing information on current traffic condition and this information can help the drivers make the best route choice based on journey time information and expected delays.

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APPENDIX A

List of Publications

1. Amri Mohd Yasin, Mohamed Rehan Karim, Ahmad Saifizul Abdullah (2010). Travel Time Measurement in Real-Time using Automatic Number Plate Recognition for Malaysian Environment. *Journal of Eastern Asia Society for Transportation Studies*. Vol. 8. Online ISSN: 1881 – 1124. Dec 24, 2010. pp. 1738 – 1751.

2. Amri Mohd Yasin, Mohamed Rehan Karim, Ahmad Saifizul Abdullah (2009). Development of Automatic Number Plate Recognition Software for Malaysian Environment. *Proceeding of International Conference for Technical Postgraduate 2009 (TECHPOS 2009)*. 14 – 15 December 2009.

3. Amri Mohd Yasin, Mohamed Rehan Karim, Ahmad Saifizul Abdullah (2008). Algorithm Development for Automatic Number Plate Recognition System. *EASTS International Symposium on Sustainable Transportation incorporating Malaysian Universities Transportation Research Forum Conference 2008(MUTRFC08)*. 12 – 13 August 2008.

4. To be submitted to ISI Journal:

   Authors: Amri Mohd Yasin, Mohamed Rehan Karim, Ahmad Saifizul Abdullah

   Title: Pattern Matching Method to Locate Vehicle Number Plate.

APPENDIX B

Automatic Number Plate Recognition (ANPR) Tests Data

A. First Angle: Pan Angle $\theta_v = 1.4^\circ$, Tilt Angle $\theta_h = 6.08^\circ$

Table B1: First angle test result.

Record	Date	Time	Number Plate (Software)	Number Plate (Actual)	Number Plate Localization	Rate	Status
1	8/26/2009	8:28:39 PM	CN9987	CN9987	SUCCESSFUL	6/6	YES
2	8/26/2009	8:28:46 PM	BJY6202	BJY6202	SUCCESSFUL	7/7	YES
3	8/26/2009	8:29:16 PM	WPY9247	WPV9247	SUCCESSFUL	6/7	YES
4	8/26/2009	8:29:18 PM	WJU7276	WJU7276	SUCCESSFUL	7/7	YES
5	8/26/2009	8:29:21 PM	BKF1224	BKF1224	SUCCESSFUL	7/7	YES
6	8/26/2009	8:29:31 PM	NBF6842	NBF6842	SUCCESSFUL	7/7	YES
7	8/26/2009	8:29:38 PM	WJK4847	WJK4847	SUCCESSFUL	7/7	YES
8	8/26/2009	8:29:56 PM	WJH6259	WJH6259	SUCCESSFUL	7/7	YES
9	8/26/2009	8:30:05 PM	BJL5225	BJL5225	SUCCESSFUL	7/7	YES
10	8/26/2009	8:30:11 PM	AGP221	AGP221	SUCCESSFUL	6/6	YES
11	8/26/2009	8:30:13 PM	HB560	HB5602	SUCCESSFUL	5/6	YES
12	8/26/2009	8:30:17 PM	BKB839	BKB839	SUCCESSFUL	6/6	YES
13	8/26/2009	8:30:20 PM	WGT5918	WDT5918	SUCCESSFUL	6/7	YES
14	8/26/2009	8:30:23 PM	W	HWC7035	SUCCESSFUL	1/7	NO
15	8/26/2009	8:30:29 PM	5	HB5136	SUCCESSFUL	1/6	NO
16	8/26/2009	8:30:32 PM	?W	JBJ6802	SUCCESSFUL	0/7	NO
17	8/26/2009	8:30:36 PM	WDA5560	WDA5560	SUCCESSFUL	7/7	YES
18	8/26/2009	8:30:38 PM	WRA54	WRA64	SUCCESSFUL	4/5	YES
19	8/26/2009	8:30:42 PM	JKK8781	JKK8781	SUCCESSFUL	7/7	YES
20	8/26/2009	8:31:01 PM	WCB4490	WPB4490	SUCCESSFUL	6/7	YES
21	8/26/2009	8:31:14 PM	WDG1035	WQG1035	SUCCESSFUL	6/7	YES
22	8/26/2009	8:31:32 PM	BDC3730	BDC373	SUCCESSFUL	7/6	YES
23	8/26/2009	8:31:36 PM	WCU8852	WCU8852	SUCCESSFUL	7/7	YES
24	8/26/2009	8:31:48 PM	JKH4103	JKH4103	SUCCESSFUL	7/7	YES
25	8/26/2009	8:31:52 PM	J?M5190	JJM5190	SUCCESSFUL	6/7	YES
26	8/26/2009	8:32:07 PM	W1WPM?	WRM4784	SUCCESSFUL	1/7	NO
27	8/26/2009	8:32:10 PM	W0M653	WQM653	SUCCESSFUL	5/6	YES
28	8/26/2009	8:32:17 PM	F	HWB4433	SUCCESSFUL	0/7	NO
29	8/26/2009	8:32:21 PM	WGJ8040	WGJ8046	SUCCESSFUL	6/7	YES
30	8/26/2009	8:32:23 PM	WJW3825	WJW3825	SUCCESSFUL	7/7	YES
31	8/26/2009	8:32:26 PM	AGF8086	AGF8086	SUCCESSFUL	7/7	YES
32	8/26/2009	8:32:30 PM	WKF2961	WKF2961	SUCCESSFUL	7/7	YES
33	8/26/2009	8:32:32 PM	?A?		FAILED	-	-

34	8/26/2009	8:32:42 PM	WV?4J02	WMF4392	SUCCESSFUL	3/7	NO
35	8/26/2009	8:33:09 PM	WFX9337	WFX9337	SUCCESSFUL	7/7	YES
36	8/26/2009	8:33:24 PM	AAG8888	AAG8888	SUCCESSFUL	7/7	YES
37	8/26/2009	8:33:25 PM	??9?		FAILED	-	-
38	8/26/2009	8:33:32 PM	WNC206	WNC206	SUCCESSFUL	6/6	YES
39	8/26/2009	8:33:34 PM	AFT5995	AFT5995	SUCCESSFUL	7/7	YES
40	8/26/2009	8:33:42 PM	WQS4657	WQS4657	SUCCESSFUL	7/7	YES
41	8/26/2009	8:33:51 PM	?W?9452	WML9452	SUCCESSFUL	5/7	NO
42	8/26/2009	8:33:59 PM	WVYJ??1		FAILED	-	-
43	8/26/2009	8:34:00 PM	BHE2803	BHE2803	SUCCESSFUL	7/7	YES
44	8/26/2009	8:34:07 PM	WQR1984	WQR1984	SUCCESSFUL	7/7	YES
45	8/26/2009	8:34:17 PM	BGJ2572	BGJ2572	SUCCESSFUL	7/7	YES
46	8/26/2009	8:35:00 PM	BEB1633	BEB1633	SUCCESSFUL	7/7	YES
47	8/26/2009	8:35:26 PM	C54	HWC6345	SUCCESSFUL	1/7	NO
48	8/26/2009	8:35:30 PM	BJH9673	BJH9673	SUCCESSFUL	7/7	YES
49	8/26/2009	8:35:36 PM	CBN1858	CBN1958	SUCCESSFUL	6/7	YES
50	8/26/2009	8:35:42 PM	WMF7847	WMF7847	SUCCESSFUL	7/7	YES
51	8/26/2009	8:35:44 PM	WKT2543	WKT2543	SUCCESSFUL	7/7	YES
52	8/26/2009	8:35:53 PM	WJK5721	WLK5721	SUCCESSFUL	6/7	YES
53	8/26/2009	8:35:57 PM	D?491?		FAILED	-	-
54	8/26/2009	8:36:01 PM	BGY3154	BGY3164	SUCCESSFUL	6/7	YES
55	8/26/2009	8:36:05 PM	WJJ?39	WJJ8139	SUCCESSFUL	5/6	YES
56	8/26/2009	8:36:08 PM	BGT8311	BGT8311	SUCCESSFUL	7/7	YES
57	8/26/2009	8:36:13 PM	WPK5888	WPK588	SUCCESSFUL	8/7	YES
58	8/26/2009	8:36:17 PM	BBQ7508	BBQ7508	SUCCESSFUL	7/7	YES
59	8/26/2009	8:36:26 PM	TAC7360	TAC7360	SUCCESSFUL	7/7	YES
60	8/26/2009	8:36:49 PM	AFB9291	AFB9291	SUCCESSFUL	7/7	YES
61	8/26/2009	8:36:52 PM	WPX1979	WPX1979	SUCCESSFUL	7/7	YES
62	8/26/2009	8:37:10 PM	WDB6838	WQB6838	SUCCESSFUL	6/7	YES
63	8/26/2009	8:37:18 PM	WQR4272	WQR4272	SUCCESSFUL	7/7	YES
64	8/26/2009	8:37:21 PM	PDL9771	PDL9771	SUCCESSFUL	7/7	YES
65	8/26/2009	8:37:24 PM	WW?51	WHW51	SUCCESSFUL	3/5	NO
66	8/26/2009	8:37:45 PM	J?VJ?JL	BFV3992	SUCCESSFUL	0/7	NO
67	8/26/2009	8:37:58 PM	W?8320	WPQ5426	SUCCESSFUL	1/7	NO
68	8/26/2009	8:38:01 PM	WHN7405	WHN7405	SUCCESSFUL	7/7	YES
69	8/26/2009	8:38:04 PM	NW?5868	WLK5868	SUCCESSFUL	4/7	NO
70	8/26/2009	8:38:07 PM	NKM9807	WKM9807	SUCCESSFUL	6/7	YES
71	8/26/2009	8:38:11 PM	WNM4070	WNM4070	SUCCESSFUL	7/7	YES
72	8/26/2009	8:38:13 PM	WQX9271	WRX9221	SUCCESSFUL	5/7	NO
73	8/26/2009	8:38:16 PM	CCG7375	CCG7375	SUCCESSFUL	7/7	YES

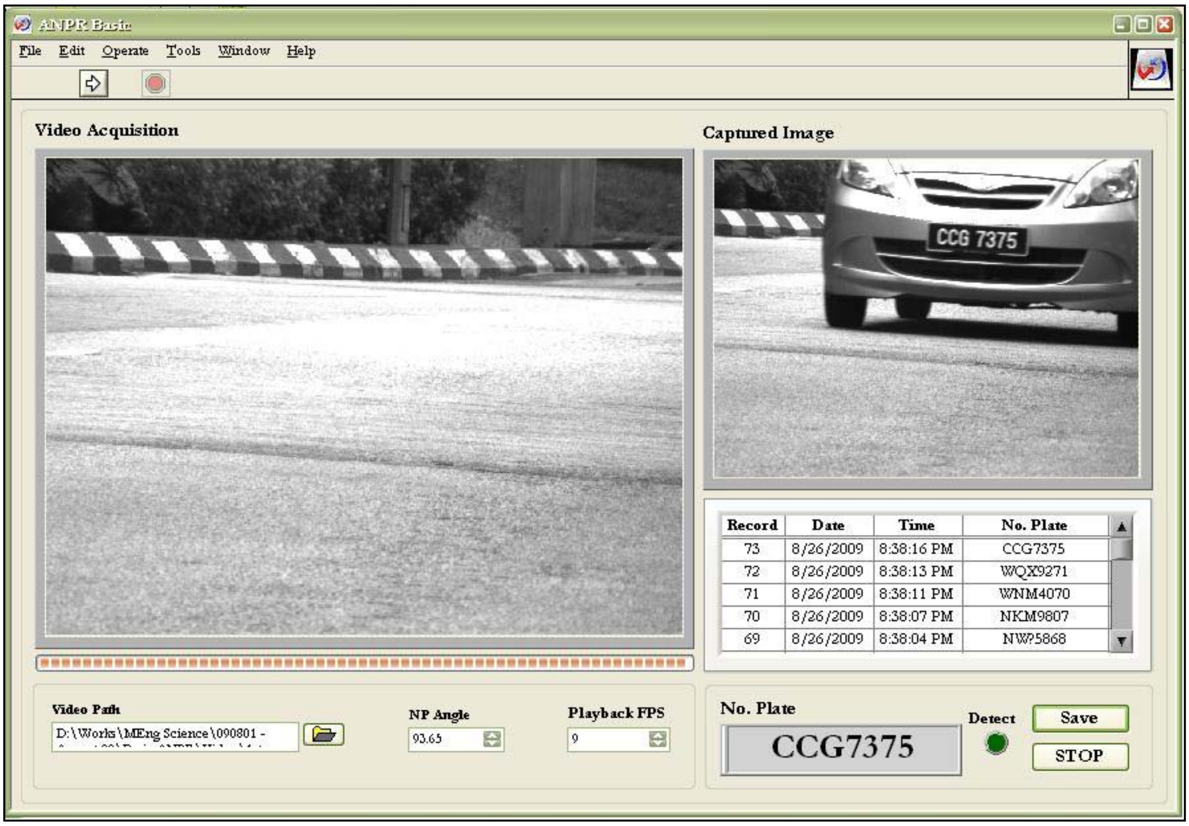

Figure B1: First angle front panel.

B. **Second Angle: Pan Angle** $\theta_v = 1.4^{\circ}$**, Tilt Angle** $\theta_h = 8.12^{\circ}$

Table B2: Second angle test result.

Record	Date	Time	Number Plate (Software)	Number Plate (Actual)	Number Plate Localization	Rate	Status
1	8/26/2009	9:30:28 PM	WLQ563	WEQ563	SUCCESSFUL	5/6	YES
2	8/26/2009	9:30:39 PM	WQW7769	WQW7769	SUCCESSFUL	7/7	YES
3	8/26/2009	9:30:58 PM	WWM?		FAILED	-	-
4	8/26/2009	9:31:18 PM	WDG8888	WDG8888	SUCCESSFUL	7/7	YES
5	8/26/2009	9:31:23 PM	BCE13	BCE13	SUCCESSFUL	5/5	YES
6	8/26/2009	9:31:30 PM	W332	HWC8332	SUCCESSFUL	4/7	NO
7	8/26/2009	9:31:32 PM	PWRX8?	WRX8557	SUCCESSFUL	1/7	NO
8	8/26/2009	9:31:35 PM			FAILED	-	-
9	8/26/2009	9:31:40 PM	CAK766Q	CAK7660	SUCCESSFUL	6/7	YES
10	8/26/2009	9:31:46 PM	WSE7488	WSE7488	SUCCESSFUL	7/7	YES
11	8/26/2009	9:31:48 PM	FR9808	WFR9808	SUCCESSFUL	6/7	YES
12	8/26/2009	9:31:50 PM	WPL3900	WPL3900	SUCCESSFUL	7/7	YES
13	8/26/2009	9:31:53 PM	WKP0525	WKP9525	SUCCESSFUL	6/7	YES
14	8/26/2009	9:31:56 PM	BGM2221	BGM2221	SUCCESSFUL	7/7	YES
15	8/26/2009	9:31:59 PM	WHX8591	WHX8591	SUCCESSFUL	7/7	YES
16	8/26/2009	9:32:03 PM	BFP5566	BFP5566	SUCCESSFUL	7/7	YES
17	8/26/2009	9:32:07 PM	WLF7146	WLF7146	SUCCESSFUL	7/7	YES
18	8/26/2009	9:32:09 PM	W?N1991	WHN1991	SUCCESSFUL	6/7	YES
19	8/26/2009	9:32:33 PM	WMT9035	WMT9035	SUCCESSFUL	7/7	YES
20	8/26/2009	9:33:01 PM	WHW?607	WHW6607	SUCCESSFUL	6/7	YES
21	8/26/2009	9:33:09 PM	WB	HWB3738	SUCCESSFUL	2/7	NO
22	8/26/2009	9:33:22 PM	WJS1965	WJS1965	SUCCESSFUL	7/7	YES
23	8/26/2009	9:33:26 PM	T0Y0TA		FAILED	-	-
24	8/26/2009	9:33:29 PM	WCS2599	WCS2599	SUCCESSFUL	7/7	YES
25	8/26/2009	9:33:48 PM	WGM1C54	WGM1O54	SUCCESSFUL	6/7	YES
26	8/26/2009	9:33:56 PM	BEC6237	BEC6237	SUCCESSFUL	7/7	YES
27	8/26/2009	9:34:01 PM	BHM3582	BHM3682	SUCCESSFUL	6/7	YES
28	8/26/2009	9:34:04 PM	?CE8701	WCE8701	SUCCESSFUL	6/7	YES
29	8/26/2009	9:34:13 PM	BFJ8168	BFJ8168	SUCCESSFUL	7/7	YES
30	8/26/2009	9:34:15 PM	BZ71044	BKB271	SUCCESSFUL	0/6	NO
31	8/26/2009	9:34:19 PM	BFV6647	BFV6647	SUCCESSFUL	7/7	YES
32	8/26/2009	9:34:31 PM	WLNA352	WLN4352	SUCCESSFUL	6/7	YES
33	8/26/2009	9:34:35 PM	WEJ3814	WEU3814	SUCCESSFUL	6/7	YES
34	8/26/2009	9:34:44 PM	WQF8564	WQF8564	SUCCESSFUL	7/7	YES
35	8/26/2009	9:34:57 PM	??		FAILED	-	-
36	8/26/2009	9:36:09 PM	WJP7240	WJP7240	SUCCESSFUL	7/7	YES
37	8/26/2009	9:36:14 PM	WNS6973	WNS6973	SUCCESSFUL	7/7	YES
38	8/26/2009	9:36:19 PM	BHV7900	BHV7900	SUCCESSFUL	7/7	YES

39	8/26/2009	9:36:22 PM	DAD8828	DAD8828	SUCCESSFUL	7/7	YES
40	8/26/2009	9:36:28 PM	WSF5961	WSF5961	SUCCESSFUL	7/7	YES
41	8/26/2009	9:36:31 PM	WCA4562	WQA4562	SUCCESSFUL	6/7	YES
42	8/26/2009	9:36:33 PM	A668	HBA669	SUCCESSFUL	3/6	NO
43	8/26/2009	9:36:36 PM	BEV3905	BEV3905	SUCCESSFUL	7/7	YES
44	8/26/2009	9:36:37 PM	DAK3233	CAK3233	SUCCESSFUL	7/7	YES
45	8/26/2009	9:36:40 PM	?283		FAILED	-	-
46	8/26/2009	9:36:51 PM	WAD?	WAD5841	SUCCESSFUL	3/7	NO
47	8/26/2009	9:37:01 PM	B8	HB7518	SUCCESSFUL	1/6	NO
48	8/26/2009	9:37:41 PM	WFL3626	WFL3626	SUCCESSFUL	7/7	YES
49	8/26/2009	9:37:57 PM	BED5971	BED5971	SUCCESSFUL	7/7	YES
50	8/26/2009	9:38:07 PM	HBA56	HBA566	SUCCESSFUL	5/6	YES
51	8/26/2009	9:38:15 PM	WGD8320	WGU8320	SUCCESSFUL	6/7	YES
52	8/26/2009	9:38:24 PM	EDJ8831	BDJ8831	SUCCESSFUL	6/7	YES
53	8/26/2009	9:38:30 PM	Q?		FAILED	-	-
54	8/26/2009	9:38:35 PM	HCB018W	BHC8018	SUCCESSFUL	5/7	NO
55	8/26/2009	9:38:44 PM	WRD5008	WRQ5008	SUCCESSFUL	6/7	YES
56	8/26/2009	9:38:58 PM	WPV4433	WRY4990	SUCCESSFUL	2/7	NO
57	8/26/2009	9:39:00 PM	WHM127	WHM127	SUCCESSFUL	6/6	YES
58	8/26/2009	9:39:20 PM	CBV5887	CBV5887	SUCCESSFUL	7/7	YES
59	8/26/2009	9:40:32 PM	WGR3801	WGR3801	SUCCESSFUL	7/7	YES
60	8/26/2009	9:40:35 PM	AEM3882	AEM3882	SUCCESSFUL	7/7	YES
61	8/26/2009	9:40:37 PM	WPN90?	WPN8O42	SUCCESSFUL	5/7	NO
62	8/26/2009	9:40:40 PM	WQV6493	WQV6493	SUCCESSFUL	7/7	YES
63	8/26/2009	9:40:45 PM	WFY7177	WFY7177	SUCCESSFUL	7/7	YES
64	8/26/2009	9:40:49 PM	WPK4593	WRK4593	SUCCESSFUL	6/7	YES
65	8/26/2009	9:41:56 PM	WPD8914	WPD8914	SUCCESSFUL	7/7	YES
66	8/26/2009	9:41:59 PM		HWC3994	SUCCESSFUL	0/7	NO
67	8/26/2009	9:42:06 PM	PEU9667	PEU9667	SUCCESSFUL	7/7	YES
68	8/26/2009	9:42:11 PM	AGC7888	AGC7888	SUCCESSFUL	7/7	YES
69	8/26/2009	9:42:13 PM	QWNJ267		FAILED	-	-
70	8/26/2009	9:42:46 PM	BEJ6128	BEJ6128	SUCCESSFUL	7/7	YES
71	8/26/2009	9:42:49 PM	BJF3634	BJF3634	SUCCESSFUL	7/7	YES
72	8/26/2009	9:42:55 PM	WJK2087	WQK2087	SUCCESSFUL	6/7	YES
73	8/26/2009	9:43:02 PM	WL?1709	WLR1709	SUCCESSFUL	6/7	YES
74	8/26/2009	9:43:06 PM	BEB678	BEB6784	SUCCESSFUL	6/6	YES
75	8/26/2009	9:43:13 PM	WJA469	WJA469	SUCCESSFUL	6/6	YES
76	8/26/2009	9:43:21 PM	BCR8082	BCR8082	SUCCESSFUL	7/7	YES

Figure B2: Second angle front panel.

C. **Third Angle: Pan Angle** $\theta_v = 1.4^\circ$ **, Tilt Angle** $\theta_h = 10.16^\circ$

Table B3: Third angle test result.

Record	Date	Time	Number Plate (Software)	Number Plate (Actual)	Number Plate Localization	Rate	Status
1	8/26/2009	10:19:11 PM	BHA3119	BHA3119	SUCCESSFUL	7/7	YES
2	8/26/2009	10:19:25 PM	JBP3171	JBP3171	SUCCESSFUL	7/7	YES
3	8/26/2009	10:19:28 PM	KAH949	NAH949	SUCCESSFUL	5/6	YES
4	8/26/2009	10:19:34 PM	KCF5481	KCF5481	SUCCESSFUL	7/7	YES
5	8/26/2009	10:19:39 PM	BFU16?2	BFU1642	SUCCESSFUL	6/7	YES
6	8/26/2009	10:19:42 PM	BDW7708	BDW7708	SUCCESSFUL	7/7	YES
7	8/26/2009	10:19:47 PM	WBB5046	WSB5046	SUCCESSFUL	6/7	YES
8	8/26/2009	10:20:28 PM	?4		FAILED	-	-
9	8/26/2009	10:20:53 PM	BJC8860	BJS8860	SUCCESSFUL	6/7	YES
10	8/26/2009	10:20:59 PM	NWM?7		FAILED	-	-
11	8/26/2009	10:21:05 PM	WFK?620	WFK1620	SUCCESSFUL	6/7	YES
12	8/26/2009	10:21:10 PM	BKB9410	BKB9410	SUCCESSFUL	7/7	YES
13	8/26/2009	10:21:13 PM	JGR4693	JGR4693	SUCCESSFUL	7/7	YES
14	8/26/2009	10:21:21 PM	PFK934	PFK934	SUCCESSFUL	6/6	YES
15	8/26/2009	10:21:26 PM	W?206	WNC206	SUCCESSFUL	4/6	NO
16	8/26/2009	10:21:27 PM	F4	HWC477	SUCCESSFUL	1/6	NO
17	8/26/2009	10:21:30 PM	WDB6395	WQB6395	SUCCESSFUL	6/7	YES
18	8/26/2009	10:21:33 PM	BDG6923	BDG6523	SUCCESSFUL	6/7	YES
19	8/26/2009	10:21:36 PM	WNJ		FAILED	-	-
20	8/26/2009	10:21:38 PM	WNA8961	WNA8961	SUCCESSFUL	7/7	YES
21	8/26/2009	10:21:48 PM	WED1875	WED1875	SUCCESSFUL	7/7	YES
22	8/26/2009	10:22:25 PM	1		FAILED	-	-
23	8/26/2009	10:22:32 PM	WQB2818	WRB2818	SUCCESSFUL	6/7	YES
24	8/26/2009	10:23:21 PM	WKN5303	WKN5303	SUCCESSFUL	7/7	YES
25	8/26/2009	10:23:29 PM	WPY6787	WRY6787	SUCCESSFUL	6/7	YES
26	8/26/2009	10:23:36 PM	BDW6147	BDW6147	SUCCESSFUL	7/7	YES
27	8/26/2009	10:23:42 PM	WB?2548	WGG2548	SUCCESSFUL	5/7	NO
28	8/26/2009	10:23:46 PM	BJF5474	BJF5474	SUCCESSFUL	7/7	YES
29	8/26/2009	10:23:52 PM	BKC5171	BKC5171	SUCCESSFUL	7/7	YES
30	8/26/2009	10:23:56 PM	WPH9232	WRH9232	SUCCESSFUL	6/7	YES
31	8/26/2009	10:25:01 PM	MBB5913	MBB5913	SUCCESSFUL	7/7	YES
32	8/26/2009	10:25:05 PM	?WJ7523	WMJ7523	SUCCESSFUL	6/7	YES
33	8/26/2009	10:25:07 PM	CAQ2304	CAQ2304	SUCCESSFUL	7/7	YES
34	8/26/2009	10:25:30 PM	WQK6769	WQK6769	SUCCESSFUL	7/7	YES
35	8/26/2009	10:25:34 PM	WKR9267	WKR9267	SUCCESSFUL	7/7	YES
36	8/26/2009	10:25:38 PM	W27	AW2774	SUCCESSFUL	3/6	NO
37	8/26/2009	10:25:57 PM	HB	HB8950	SUCCESSFUL	2/6	NO
38	8/26/2009	10:26:03 PM	WGF1319	WGF1319	SUCCESSFUL	7/7	YES

39	8/26/2009	10:26:06 PM	WLG5549	WLG5549	SUCCESSFUL	7/7	YES
40	8/26/2009	10:26:11 PM	WB11	WHB11	SUCCESSFUL	4/5	YES
41	8/26/2009	10:26:17 PM	JHQ4759	JHP4759	SUCCESSFUL	6/7	YES
42	8/26/2009	10:26:29 PM	PEF4092	PEF4092	SUCCESSFUL	7/7	YES
43	8/26/2009	10:26:50 PM	WHL6655	WHL6655	SUCCESSFUL	7/7	YES
44	8/26/2009	10:27:43 PM	WAS3159	WAS3159	SUCCESSFUL	7/7	YES
45	8/26/2009	10:27:48 PM	W?M		FAILED	-	-
46	8/26/2009	10:27:54 PM	WWJ2058	WLJ2058	SUCCESSFUL	7/7	YES
47	8/26/2009	10:27:58 PM	WEE3155	WSE3155	SUCCESSFUL	6/7	YES
48	8/26/2009	10:28:23 PM	WDK92C4	WDK9204	SUCCESSFUL	6/7	YES
49	8/26/2009	10:29:13 PM	WFU1233	WFU1233	SUCCESSFUL	7/7	YES
50	8/26/2009	10:29:50 PM	GYS8554	BGY5855	SUCCESSFUL	5/7	NO
51	8/26/2009	10:30:05 PM	WPC9329	WPC9329	SUCCESSFUL	7/7	YES
52	8/26/2009	10:30:08 PM	WFG9828	WFG9828	SUCCESSFUL	7/7	YES
53	8/26/2009	10:30:11 PM	WPS6?	WPS6150	SUCCESSFUL	4/7	NO
54	8/26/2009	10:30:40 PM	BGX8419	BGX8419	SUCCESSFUL	7/7	YES

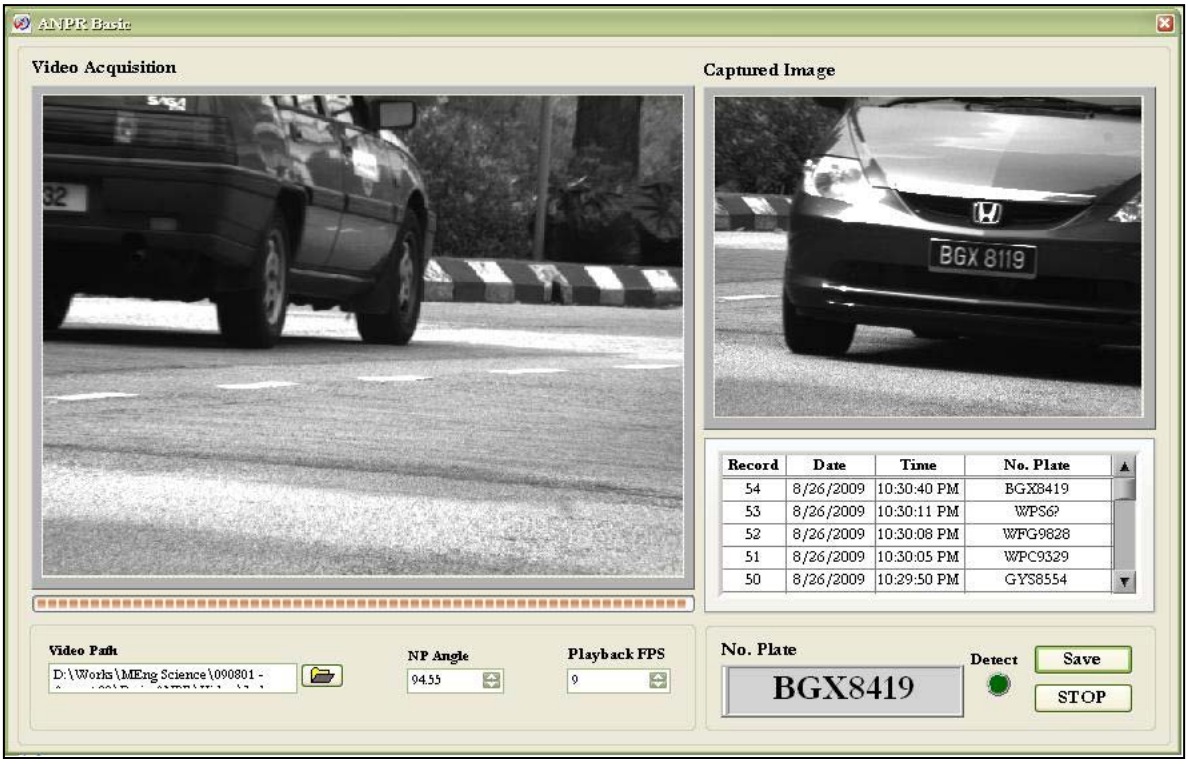

Figure B3: Third angle front panel.

D. **Fourth Angle: Pan Angle** $\theta_v = 1.4^{\circ}$ **, Tilt Angle** $\theta_h = 12.00^{\circ}$

Table B4: Fourth angle test result.

Record	Date	Time	Number Plate (Software)	Number Plate (Actual)	Number Plate Localization	Rate	Status
1	8/27/2009	1:03:09 AM	BJT55?9	BJT5599	SUCCESSFUL	6/7	YES
2	8/27/2009	1:03:59 AM	WHW4692	WHW4692	SUCCESSFUL	7/7	YES
3	8/27/2009	1:04:31 AM	CBY6338	CBY6338	SUCCESSFUL	7/7	YES
4	8/27/2009	1:04:33 AM	JJK9368	JJK9368	SUCCESSFUL	7/7	YES
5	8/27/2009	1:05:29 AM	BJG8860	BJS8860	SUCCESSFUL	6/7	YES
6	8/27/2009	1:05:33 AM	W?8073	WLF8073	SUCCESSFUL	5/7	NO
7	8/27/2009	1:05:35 AM	BGD7011	BGQ7011	SUCCESSFUL	6/7	YES
8	8/27/2009	1:05:45 AM	WLS7638	WLS7638	SUCCESSFUL	7/7	YES
9	8/27/2009	1:05:48 AM	PGW813	PGW913	SUCCESSFUL	5/6	YES
10	8/27/2009	1:07:25 AM	BJG8018	BJG8018	SUCCESSFUL	7/7	YES
11	8/27/2009	1:07:26 AM	WJN4295	WJN4295	SUCCESSFUL	7/7	YES
12	8/27/2009	1:07:58 AM	BQJ5W55	WQJ5755	SUCCESSFUL	6/7	YES
13	8/27/2009	1:08:00 AM	EED1992	BEP1892	SUCCESSFUL	4/7	NO
14	8/27/2009	1:08:15 AM	?1		FAILED	-	-
15	8/27/2009	1:08:48 AM	WCD8598	WCD8598	SUCCESSFUL	7/7	YES
16	8/27/2009	1:08:53 AM	WKH990	WKH990	SUCCESSFUL	7/7	YES
17	8/27/2009	1:08:54 AM	BEF7707	BEF7707	SUCCESSFUL	7/7	YES
18	8/27/2009	1:09:23 AM	ACG8416	ACG8416	SUCCESSFUL	7/7	YES
19	8/27/2009	1:09:29 AM	WQA913	WQA913	SUCCESSFUL	7/7	YES
20	8/27/2009	1:09:31 AM		HWC2033	SUCCESSFUL	0/7	NO
21	8/27/2009	1:10:09 AM	WBWM189		FAILED	-	-
22	8/27/2009	1:10:21 AM	HB	HWC5833	SUCCESSFUL	1/7	NO
23	8/27/2009	1:10:22 AM	WKM327B	WKN3278	SUCCESSFUL	5/7	NO
24	8/27/2009	1:10:25 AM	C8U8863	CBU8863	SUCCESSFUL	6/7	YES
25	8/27/2009	1:10:28 AM	BJB7393	BJB7393	SUCCESSFUL	7/7	YES
26	8/27/2009	1:10:31 AM	A	HBA392	SUCCESSFUL	1/6	NO
27	8/27/2009	1:10:33 AM	WFW6441	WFW6441	SUCCESSFUL	7/7	YES
28	8/27/2009	1:10:41 AM	WGF4311	WGF4311	SUCCESSFUL	7/7	YES
29	8/27/2009	1:11:15 AM	W	HWC1692	SUCCESSFUL	1/7	NO
30	8/27/2009	1:11:41 AM	WHT1075	WHT1075	SUCCESSFUL	7/7	YES
31	8/27/2009	1:12:06 AM	WPU4677	WPU4677	SUCCESSFUL	7/7	YES
32	8/27/2009	1:12:12 AM	WNP2341	WNP2341	SUCCESSFUL	7/7	YES
33	8/27/2009	1:12:17 AM	WCY9597	WCY9597	SUCCESSFUL	7/7	YES
34	8/27/2009	1:12:21 AM	111?		FAILED	-	-
35	8/27/2009	1:12:39 AM	WRQ3971	WPQ3971	SUCCESSFUL	6/7	YES
36	8/27/2009	1:12:41 AM	??		FAILED	-	-
37	8/27/2009	1:12:50 AM	??W1C?		FAILED	-	-
38	8/27/2009	1:13:23 AM	E?72??Q		FAILED	-	-

39	8/27/2009	1:13:29 AM	ECE937	BCE937	SUCCESSFUL	5/6	YES
40	8/27/2009	1:13:46 AM	90		FAILED	-	-
41	8/27/2009	1:13:52 AM	WQE2889	WQE2889	SUCCESSFUL	7/7	YES
42	8/27/2009	1:13:54 AM			FAILED	-	-
43	8/27/2009	1:13:56 AM	JCP9228	JCP9228	SUCCESSFUL	7/7	YES
44	8/27/2009	1:14:00 AM	WNJ6589	WNJ6589	SUCCESSFUL	7/7	YES
45	8/27/2009	1:14:03 AM	WNS60?6	WNS6036	SUCCESSFUL	6/7	YES
46	8/27/2009	1:14:05 AM	6A?		FAILED	-	-
47	8/27/2009	1:14:08 AM	WQE3429	WQE3429	SUCCESSFUL	7/7	YES
48	8/27/2009	1:14:21 AM	WMY9511	WMY9511	SUCCESSFUL	7/7	YES
49	8/27/2009	1:14:22 AM	?1708		FAILED	-	-
50	8/27/2009	1:14:45 AM	BHF880Z	BHF8802	SUCCESSFUL	6/7	YES

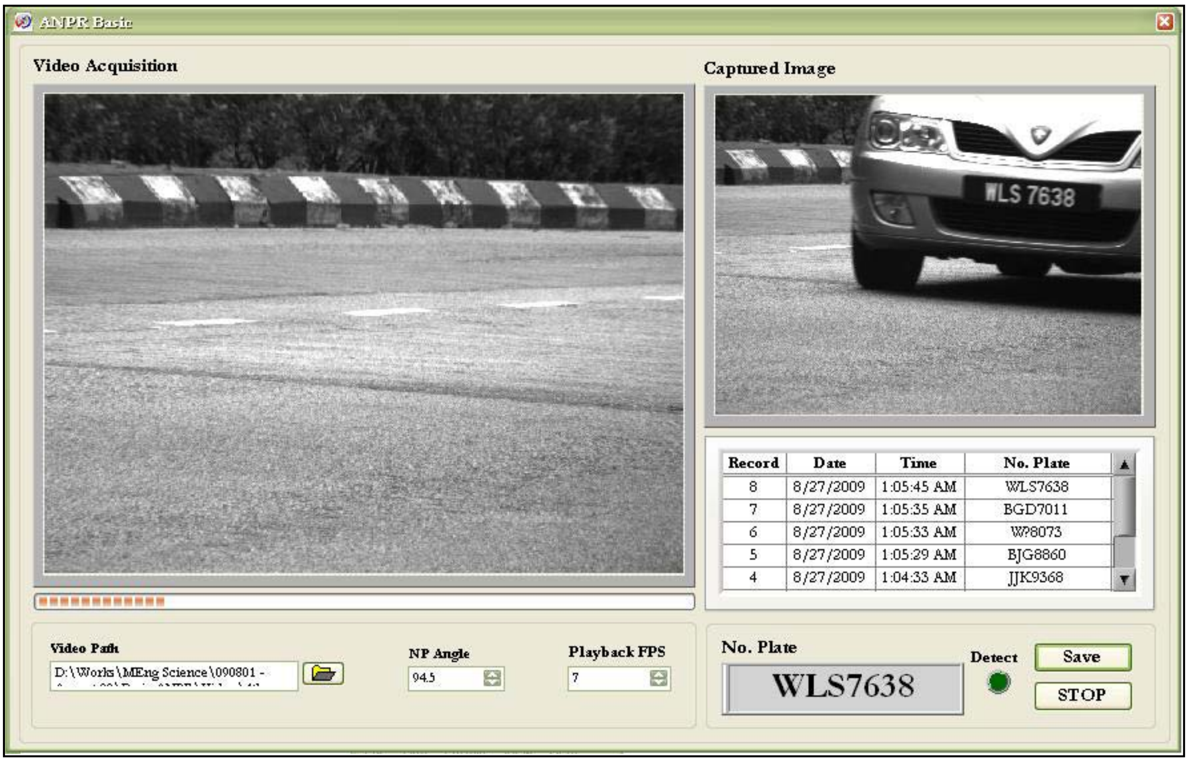

Figure B4: Fourth angle front panel.

E. **Fifth Angle: Pan Angle** $\theta_v = 1.4^\circ$**, Tilt Angle** $\theta_h = 13.61^\circ$

Table B5: Fifth angle test result.

Record	Date	Time	Number Plate (Software)	Number Plate (Actual)	Number Plate Localization	Rate	Status
1	8/26/2009	11:35:30 PM	WQD3645	WQD3645	SUCCESSFUL	7/7	YES
2	8/26/2009	11:35:59 PM	WNU1287	WNU1287	SUCCESSFUL	7/7	YES
3	8/26/2009	11:36:06 PM	WKT2448	WKT2448	SUCCESSFUL	7/7	YES
4	8/26/2009	11:36:49 PM	W?6964	WRC6964	SUCCESSFUL	5/7	NO
5	8/26/2009	11:36:53 PM	JGSA700	JGS4700	SUCCESSFUL	6/7	YES
6	8/26/2009	11:37:00 PM	BFG999	BFQ9199	SUCCESSFUL	5/7	NO
7	8/26/2009	11:37:05 PM	JPA015?	BJP4015	SUCCESSFUL	5/7	NO
8	8/26/2009	11:37:09 PM	WFG1758	WFG1758	SUCCESSFUL	7/7	YES
9	8/26/2009	11:37:15 PM	WLN7242	WLM7242	SUCCESSFUL	7/7	YES
10	8/26/2009	11:37:57 PM	WKD693	WKD693	SUCCESSFUL	6/6	YES
11	8/26/2009	11:38:07 PM	NAF8837	NAF8137	SUCCESSFUL	6/7	YES
12	8/26/2009	11:38:47 PM	MBS3719	MBS3719	SUCCESSFUL	7/7	YES
13	8/26/2009	11:38:51 PM	WRJ7670	WRJ7670	SUCCESSFUL	7/7	YES
14	8/26/2009	11:39:13 PM	BGB8599	BGB8599	SUCCESSFUL	7/7	YES
15	8/26/2009	11:39:18 PM	WEK2456	WEK2456	SUCCESSFUL	7/7	YES
16	8/26/2009	11:39:20 PM	NHY6762	WHY6762	SUCCESSFUL	6/7	YES
17	8/26/2009	11:39:25 PM	56?	HWC5614	SUCCESSFUL	2/7	NO
18	8/26/2009	11:39:31 PM	DRE9055	RE9055	SUCCESSFUL	6/6	YES
19	8/26/2009	11:39:58 PM	WQJ7246	WQJ7246	SUCCESSFUL	7/7	YES
20	8/26/2009	11:40:04 PM	?BFM278	BFM278	SUCCESSFUL	6/6	YES
21	8/26/2009	11:40:31 PM	NBM		FAILED	-	-
22	8/26/2009	11:40:34 PM	WLB805?	WLB8059	SUCCESSFUL	6/7	YES
23	8/26/2009	11:40:55 PM	WMB3342	WMP3342	SUCCESSFUL	6/7	YES
24	8/26/2009	11:41:23 PM	F	MP3575	SUCCESSFUL	0/6	NO
25	8/26/2009	11:41:28 PM	WKN6512	WKN6512	SUCCESSFUL	7/7	YES
26	8/26/2009	11:41:31 PM	WNJ2612	WNJ2612	SUCCESSFUL	7/7	YES
27	8/26/2009	11:41:35 PM	WPN6869	WPN6869	SUCCESSFUL	7/7	YES
28	8/26/2009	11:41:39 PM	WNY7399	WNY7309	SUCCESSFUL	7/7	YES
29	8/26/2009	11:41:42 PM	PHB3683	PHB3683	SUCCESSFUL	7/7	YES
30	8/26/2009	11:41:45 PM	WDD8023	WQD8023	SUCCESSFUL	6/7	YES
31	8/26/2009	11:41:57 PM	WEF1533	WEF1533	SUCCESSFUL	7/7	YES
32	8/26/2009	11:42:04 PM	WNW5500	WMW5500	SUCCESSFUL	6/7	YES
33	8/26/2009	11:42:10 PM	??4		FAILED	-	-
34	8/26/2009	11:43:15 PM	WPU7721	WPU7721	SUCCESSFUL	7/7	YES
35	8/26/2009	11:43:41 PM	WFJ3226	WFJ3226	SUCCESSFUL	7/7	YES
36	8/26/2009	11:43:48 PM	??J	WMB4833	SUCCESSFUL	0/7	NO
37	8/26/2009	11:43:53 PM	BFW808	BFW808	SUCCESSFUL	7/7	YES
38	8/26/2009	11:43:54 PM	BJC7548	BJC7548	SUCCESSFUL	7/7	YES

39	8/26/2009	11:43:57 PM	JLC1584	JLC1584	SUCCESSFUL	7/7	YES
40	8/26/2009	11:44:02 PM	WPR8014	WPR8014	SUCCESSFUL	7/7	YES
41	8/26/2009	11:44:30 PM	?8	HWC8385	SUCCESSFUL	0/7	NO
42	8/26/2009	11:45:11 PM	JCQ1900	JCQ1900	SUCCESSFUL	7/7	YES
43	8/26/2009	11:45:50 PM	BEU9907	BEU9907	SUCCESSFUL	7/7	YES
44	8/26/2009	11:45:53 PM	KBY6555	KBY6555	SUCCESSFUL	7/7	YES

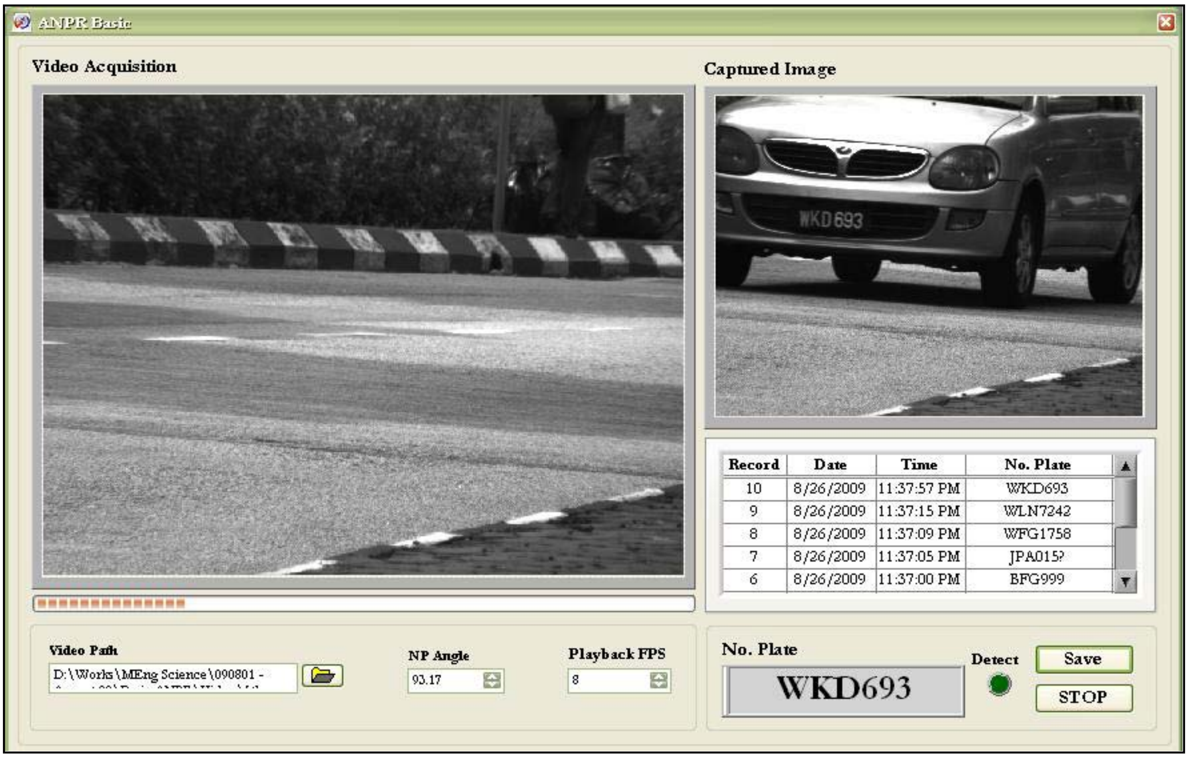

Figure B5: Fifth angle front panel.

APPENDIX C

Journey Time Measurement Tests Data

Table C1: Journey time measurement result.

Record	Time 1	Number Plate 1	Time 2	Number Plate 2	Journey Time (s)	Speed (Km/h)	Status	Time (m)
1	9:54:28 AM	CN9987	9:54:32 AM	CN9987	1.570	44.372	Match	0-2
2	9:55:06 AM	BJY6202	9:55:12 AM	BJY6202	2.323	29.992	Match	
3	9:55:09 AM	WPV9247	9:55:15 AM	WBY9247	Undefined	Undefined	Unmatched	
4	9:55:12 AM	WJU7276	9:55:18 AM	WJU7276	2.419	28.796	Match	
5	9:55:26 AM	BKF1224	9:55:32 AM	BKF1224	2.438	28.568	Match	
6	9:55:35 AM	NBF6842	9:55:41 AM	NBF6842	2.419	28.796	Match	
7	9:55:58 AM	WJK4847	9:56:04 AM	WJK4847	2.400	29.026	Match	
8	9:56:09 AM	WJH6259	9:56:15 AM	WJH6259	2.599	26.800	Match	2-4
9	9:56:16 AM	BJL5225	9:56:23 AM	BJL5225	2.657	26.216	Match	
10	9:56:19 AM	AGP221	9:56:25 AM	AGP221	2.676	26.027	Match	
11	9:56:29 AM	WGT5618	9:56:36 AM	WGT5918	2.902	24.000	Match	
12	9:56:46 AM	??JC?02	9:56:53 AM	??JC?02	2.837	24.552	Match	
13	9:56:49 AM	NDA5560	9:56:56 AM	WDA5560	2.876	24.221	Match	
14	9:56:54 AM	WRA54	9:57:01 AM	8WRA54	2.953	23.589	Match	
15	9:57:17 AM	JKK8781	9:57:24 AM	JKK8781	2.792	24.947	Match	
16	9:57:35 AM	WCB4J90	9:57:41 AM	WCB4J90	2.863	24.330	Match	
17	9:57:57 AM	W0G10?	9:58:04 AM	WDG1935	Undefined	Undefined	Unmatched	
18	9:58:02 AM	BDC373W	9:58:10 AM	BDC373W	3.024	23.036	Match	4-6
19	9:58:18 AM	WCU8852	9:58:25 AM	WCU8852	3.037	22.939	Match	
20	9:58:23 AM	JKH4103	9:58:30 AM	JKH4103	2.914	23.901	Match	
21	9:58:43 AM	??J	9:58:50 AM	1?M5190	Undefined	Undefined	Unmatched	
22	9:58:45 AM	W1WPM?	9:58:52 AM	W1WPM?	2.805	24.832	Match	
23	9:58:55 AM	WQN653	9:59:01 AM	?WDM653	Undefined	Undefined	Unmatched	
24	9:59:02 AM	WGJ8440	9:59:09 AM	WGJ8440	2.792	24.947	Match	
25	9:59:07 AM	WVW3825	9:59:14 AM	WVW3825	2.799	24.890	Match	
26	9:59:11 AM	AGF8086	9:59:17 AM	AGF8086	2.818	24.720	Match	
27	9:59:13 AM	WKF2961	9:59:20 AM	WKF2961	2.850	24.440	Match	
28	10:00:00 AM	WV?41MW	10:00:07 AM	WV?41MW	2.902	24.007	Match	6-8
29	10:00:19 AM	WFX9337	10:00:26 AM	WFX9337	2.953	23.588	Match	
30	10:00:21 AM	AAG8888	10:00:29 AM	AAG8888	3.159	22.051	Match	
31	10:00:30 AM	?4BW?	10:00:37 AM	??9?	Undefined	Undefined	Unmatched	
32	10:00:32 AM	WNC206	10:00:39 AM	WNC206	3.043	22.890	Match	
33	10:00:42 AM	AFT5995	10:00:50 AM	AFT5995	2.979	23.385	Match	
34	10:00:53 AM	WQS4657	10:01:01 AM	WQS4657	2.953	23.589	Match	
35	10:01:03 AM	WML9452	10:01:11 AM	WML9452	3.024	23.036	Match	

36	10:01:14 AM	BHE2803	10:01:21 AM	BHE2803	2.998	23.234	Match	
37	10:01:26 AM	WQR1984	10:01:34 AM	WQR1984	2.953	23.589	Match	
38	10:02:21 AM	1PA	10:02:29 AM	BGJ2572	Undefined	Undefined	Unmatched	8-10
39	10:02:54 AM	BEB1633	10:03:01 AM	BEB1633	2.870	24.276	Match	
40	10:03:07 AM	BJH9673	10:03:14 AM	BJH9673	2.780	25.062	Match	
41	10:03:15 AM	CBN1958	10:03:22 AM	CBN1958	2.734	25.475	Match	
42	10:03:17 AM	WMF7847	10:03:24 AM	WNF7847	2.831	24.606	Match	
43	10:03:28 AM	WKT2543	10:03:35 AM	WKT2543	2.818	24.720	Match	
44	10:03:33 AM	WJK5721	10:03:40 AM	WW?5721	Undefined	Undefined	Unmatched	
45	10:03:38 AM	??491W	10:03:45 AM	VM491F	Undefined	Undefined	Unmatched	
46	10:03:44 AM	BGY3154	10:03:50 AM	BGY3164	2.689	25.906	Match	
47	10:03:48 AM	WJJ?39	10:03:55 AM	WJJ?39	2.844	24.496	Match	
48	10:03:54 AM	BGT8311	10:04:01 AM	BGT8311	3.011	23.134	Match	
49	10:03:59 AM	WPK5880	10:04:07 AM	PKS880?	Undefined	Undefined	Unmatched	
50	10:04:11 AM	BBQ7508	10:04:18 AM	BBQ7508	2.792	24.947	Match	10-12
51	10:04:40 AM	TAC7360	10:04:47 AM	W?C7360	Undefined	Undefined	Unmatched	
52	10:04:44 AM	AFB9291	10:04:51 AM	AFB9291	2.902	24.007	Match	
53	10:05:06 AM	W?1979	10:05:13 AM	WPX1979	Undefined	Undefined	Unmatched	
54	10:05:18 AM	WDB6838	10:05:25 AM	WDB6838	2.831	24.608	Match	
55	10:05:21 AM	WQR4272	10:05:29 AM	WQR4272	2.979	23.385	Match	
56	10:05:24 AM	PDL9771	10:05:31 AM	PDL9771	2.921	23.849	Match	
57	10:05:51 AM	W?W51	10:05:58 AM	W1W61	Undefined	Undefined	Unmatched	
58	10:06:07 AM	J?VJ?JL	10:06:14 AM	J?VJ?JL	2.895	24.060	Match	12-14
59	10:06:11 AM	W??	10:06:19 AM	W?8320	Undefined	Undefined	Unmatched	
60	10:06:16 AM	WHN7405	10:06:23 AM	W?7405	Undefined	Undefined	Unmatched	
61	10:06:20 AM	WCX5868	10:06:26 AM	WLK5868	Undefined	Undefined	Unmatched	
62	10:06:23 AM	WKM9807	10:06:31 AM	WKM9807	3.017	23.086	Match	
63	10:06:27 AM	WNM407Q	10:06:34 AM	WNM4070	2.895	24.061	Match	
64	10:06:30 AM	WPX9?	10:06:37 AM	?W?X9?	Undefined	Undefined	Unmatched	
65	10:06:36 AM	KCG7375	10:06:43 AM	CCG7375	2.792	24.947	Match	

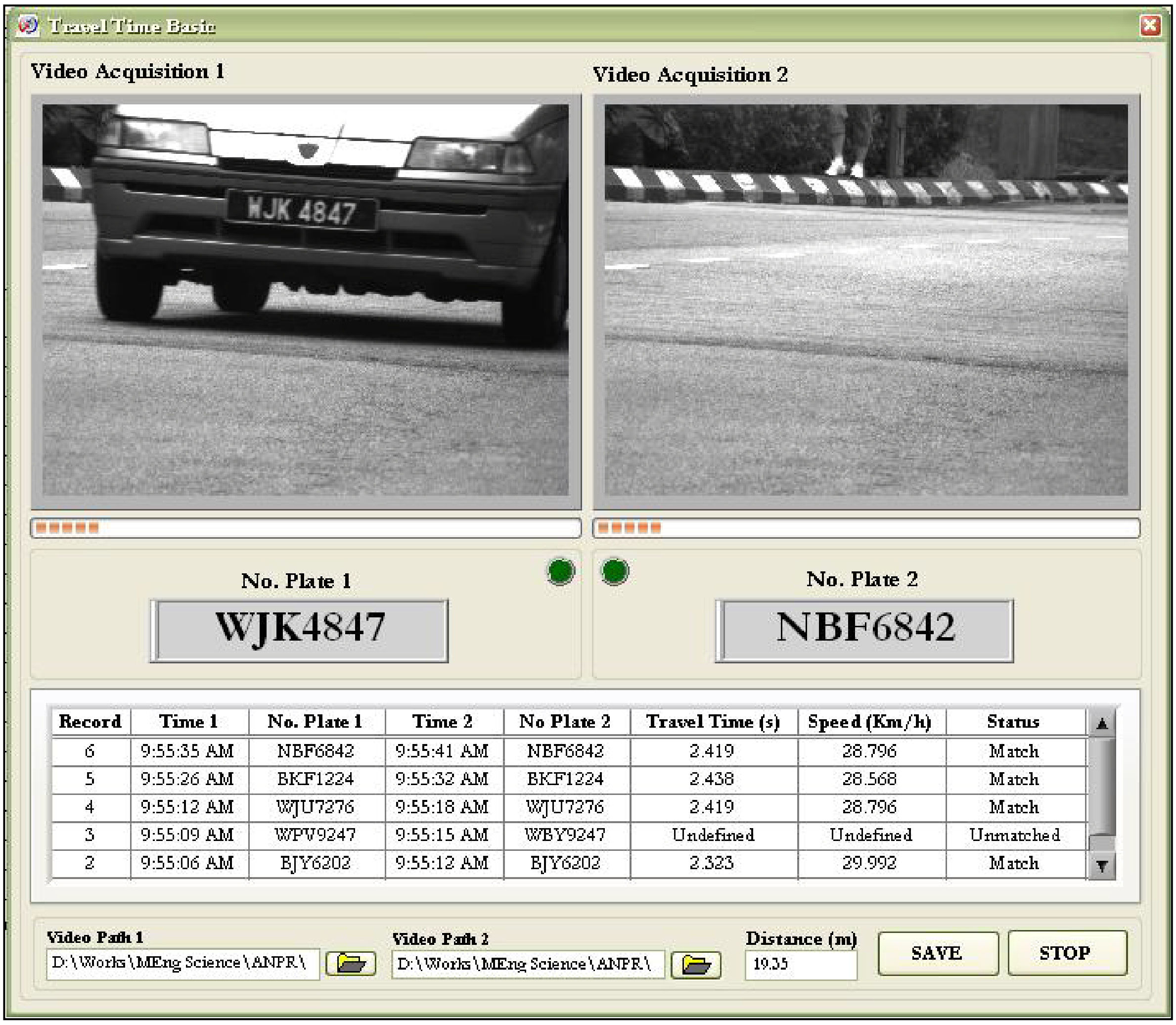

Figure C1: Journey time measurement front panel.