DESIGN AND DEVELOPMENT OF ROAD SURFACE TO CAMERA IMAGE PLANE ESTIMATION SYSTEM FOR OBJECT MEASUREMENT

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To my beloved father and mother
Who always give me courage to finish this thesis

Also, to those people who have guided and inspired me throughout my journey.

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ABSTRACT

Under the International Road Assessment Programme (iRAP, sponsorship of UK charity organization FIA Foundation for the Automobile and Society), led by AAM, JKR, JKJR, and Malaysia Institute of Road Safety Research (MIROS), a series of road safety assessment activity over 3600 km of road in Malaysia has been carried out. The system (road images acquisition and Graphical User Interface (GUI) for road safeness rating) being used to carry out the road safety assessment was found not adequate by MIROS (poor imaging quality and high cost). Using off-the-shelf modules (Industrial grade Internet Protocol enabled Cameras, Microsoft Visual Studio, and open source computer vision software), a Malaysia made cost effective, reliable and robust road survey data collection and analysis system shall be jointly designed and developed to measure the road surface physical length and hence improve the road safety in Malaysia. The main aim of this project is to provide a GUI enabled road surface physical length measurement system to MIROS. The developed GUI consists of the function to capture the camera image and take the physical length between two points on the road surface. The relationship of the road surface and the camera image plane can be determined by using the correspondences on both the planes through the designed calibration process. Planar homography estimation method, using least squares as the standard approach to approximate the solution of an over determined system, is used to linearly minimize the error produced during the calibration process. The GUI facility provided by Microsoft Visual Studio and the linear algebra enabled homography estimation method in the OpenCV are used to develop the system. This system can estimate the physical length between two points on the road plane in the range of 10 meters until 22 meters from the camera with the relative error of up to 2%. The physical length measurement between two points can be increased by using more correspondences during planar homography estimation process.

ABSTRAK

Di bawah International Road Assessment Programme yang diketuai oleh AAM, JKR, JKJR dan MIROS, satu siri penilaian keselamatan jalan raya di Malaysia sebanyak 3600 km telah dijalankan. Sistem (pengambilalihan gambar jalan dan antara muka grafik pengguna (GUI) untuk pentaksiran keselamatan jalan raya) yang digunakan untuk menjalankan penilaian keselamatan jalan raya didapati kualiti pengimejan yang kurang memuaskan dan kos yang tinggi oleh MIROS. Dengan menggunakan kamera Protokol Internet gred industri, Microsoft Visual Studio dan sumber terbuka perisian visi computer, satu sistem yang kos rendah, dipercayai dan mempunyai fungsi pengumpulan dan penganalisisi data yang mantap hendaklah dicipta untuk mengukur jarak atas permukaan jalan dan dengan itu meningkatkan keselamatan jalan raya di Malaysia. Tujuan projek ini adalah untuk menyediakan satu GUI yang mempunyai fungsi pengukuran jarak atas permukaan jalan kepada MIROS. GUI ini berfungsi untuk memaparkan imej kamera dan mengukur jarak antara dua titik atas permukaan jalan. Hubungan antara permukaan jalan dan permukaan imej kamera boleh didapati dengan menggunakan titik perhubungan antara kedua-dua permukaan tersebut. Kaedah anggaran *planar homography*, menggunakan kuasa dua terkecil sebagai pendekatan standard bagi menjangka solusi dari sistem ditentu lebih. telah digunakan untuk meminimumkan ralat-ralat yang dihasilkan dalam proses penentukuran. Kemudahan pereka GUI dalam Microsoft Visual Studio dan fungsi anggaran homography dalam OpenCV telah digunakan untuk mereka dan mencipta system pengukuran ini. Sistem ini dapat menganggarkan jarak fizikal antara dua titik atas permukaan jalan raya dalam lingkungan 10 hingga 22 meter jauh daripada kamera dengan ralat nisbi sebanyak 2%. Pengukuran jarak antara dua titik boleh ditingkatkan dengan menggunakan lebih bilangan titik perhubungan dalam proses anggaran nilai homography.

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CHAPTER 1

INTRODUCTION

1.1 Project Background and Motivation

At year 2000, the Road Assessment Programmes (RAPs) was initiated by the Automobile Association in Europe to upgrade the road safety in low and middle income countries. An umbrella organization, the International RAP (iRAP) is setup to promote and overlook the consistency of the globally implemented RAPs [1]. With the strong will and commitment demonstrated by the government of Malaysia for road safety improvement, Malaysia was selected as pilot country for the iRAP in the Asia region. Under the sponsorship of UK charity organization FIA Foundation for the Automobile and Society, led by AAM, JKR, JKJR, and Malaysia Institute of Road Safety Research (MIROS)[2], technology and system were provided by the member of RAPs and up to 3600km of road has been inspected at year 2007[3]. Several countermeasures have been proposed [3, 4] to improve the road safety through the analysis of the recorded video images. However, the system being used for road safety survey video images collection and analysis can be improved in term of the video quality and further enhanced with the feasibility to integrate various sensors, in cost effective manner (see Table 1 for cost breakdown). By leveraging the off-the-shelf equipment (sensors, Windows based embedded PC, and high performance tablets), a cost effective camera based road survey data collection system shall be jointly designed and developed by MIROS and UTeM team to support the iRAP.

Certain numbers of camera mounted on the road survey vehicles' roof to capture the image on the road. From the image captured, it is hard to estimate how much the length of an object on the road plane is.

Therefore by using the planar homography estimation method among the projection of the image captured with the surface plane on the road, the width of the road can be estimated more accurately with the actual value.

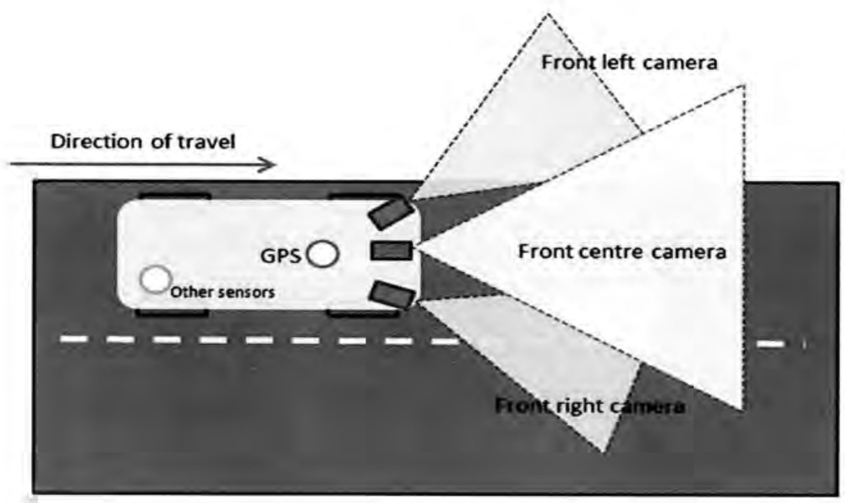

Figure 1.1: MIROS Road survey vehicle

1.2 Objectives

The objectives of this project are;

- To study the estimation method for road surface to camera image plane projection.
- To design a touch screen based Graphical User Interface (GUI) to perform the road physical length measurement.
- To analyse the result of the designed and implemented road surface measurement system for useability improvement.

1.3 Problem Statement

From the image captured by the camera, it is very hard to estimate the width of a hole on the road. The width of the hole on the road can be easily obtained by using a measuring tape to measure it. Since the road survey vehicle normally will be used on the highway, therefore, it is impossible to measure the hole on the highway by using the measuring tape. A physical length measurement system needs to design and develop to help the MIROS to overcome this problem.

Many types of sensor can be used to calculate the width on the road. The most famous one is the ultrasonic sensor but the sensor is very expensive. Since MIROS want to provide a cost effective system beside the usage of the ultrasonic sensor, a road surface to camera image plane estimation system for object measurement with a touch screen based Graphical User Interface (GUI) can fulfil the requirement of the MIROS.

1.4 Scope of Project

The five major scopes of this project are as follow:

- The project is developed based on the object measurement system with the projection of the image plane captured by the camera and the plane on the road.

- The system is used by the vehicle with vehicle height around 1.40 to 1.45 meter.

- The distance of the image captured is about 8 meters from the vehicle. The area region taken is 8m x 8m.

- Making use of the available Microsoft Windows based toolkit to design and develop a road images capturing and physical length estimation system.

- The accuracy of the road physical length measurement system is in the range of ±0.25 meter.

CHAPTER 2

LITERATURE REVIEW

The fundamental theory of how the camera image is formed in the image plane of the camera and the process of calibrating the camera to obtain the parameters representing the camera model is firstly studied. The planar homography which expressed the projection of road surface to camera image plane projection and the estimation method to accurately calculate the planar homography is presented in the end of this chapter.

2.1 Camera Calibration System for 3D Vision and the 2D image

Camera calibration system is a necessary step in 3D computer vision in order to extract metric information from 2D images (see Figure 2.1).

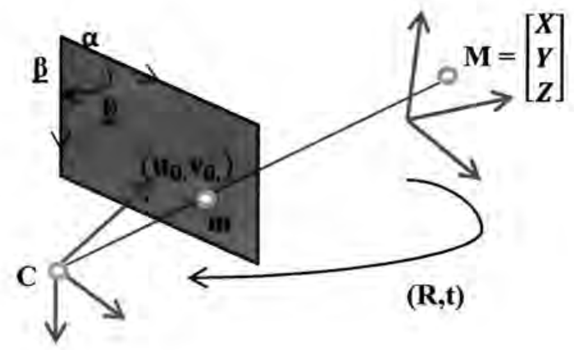

Figure 2.1: 2D point is denoted by m and 3D point is denoted by M. The C is the view point for the user. M is the world plane and m is the image plane.

The camera calibration only is a step to make sure the camera is in the best condition to capture the desired image. In this project, the projection of the plane of image captured with the plane on the road play a very important role to find out the homography value for both of the planes.

$$m = H \times M \tag{2.1}$$

where m is the pixel coordinate on the camera image plane, M is the grid coordinate of the 3D planar object and H is the homography value[7-8]. There are the planar homography estimation method, homogenous estimation or least square method and the physical length between two point's measurement method which will be used to design and develop the road surface physical length measurement system in GUI form.

The Harris corner detector is the method that used to determine whether a pixel coordinate observed is flat, edge or corner.

2.1.1 Matlab Camera Calibration Toolbox

Matlab Camera Calibration Toolbox is the toolbox that usually used as the reference for the calibration of the camera by the research community [11]. This toolbox consists of a flow of progress provided as a tutorial. Two types of operation mode which are the standard mode and the memory efficient mode (see Figure 2.2). In standard mode, all the images used for calibration are loaded into memory once and never read again from disk. This minimizes the overall number of disk access, and speeds up all image processing and image display functions. However, if the images are large, or there are a lot of them, then the OUT OF MEMORY error message may be encountered. If this is the case, the new memory efficient version of the toolbox may be used. In this mode, every image is loaded one by one and never stored permanently in memory. 16 choices blocks can be found inside the standard version operation mode of camera calibration (see Figure 2.3).

Figure 2.2: The program window for the Camera Calibration Toolbox. Two types of operation modes. The first one is the standard one and the second one is the memory efficient type.

Figure 2.3: The standard version of operation mode. Standard operation version consists of 16 blocks which each of them consists of their own function.

From the figure 2.3, the image inside the toolbox folder will be read if we key in the image name on the Matlab window. For example, 5 images inside the folder and all of them had been load by the toolbox as shown in Figure 2.4.

Figure 2.4: Total of 5 Images inside the camera calibration toolbox had been read by the system. (Appendix C)

After read the images inside the folder, the grid corner extraction process need to be chosen. The uses of 4 points to draw a square region which the toolbox will run its corner detector automatically after the colour image changed into grey scale. The corner extraction engine includes an automatic mechanism for counting the number of squares in the grid. This tool is especially convenient when working with a large number of images since the user does not have to manually enter the number of squares in both x and y directions of the pattern. On some very rare occasions however, this code may not predict the right number of squares. This would typically happen when calibrating lenses with extreme distortions. At this point in the corner extraction procedure, the program gives the option to the user to disable the automatic square counting code. In that special mode, the user would be prompted for the square count for every image (Figure 2.5).

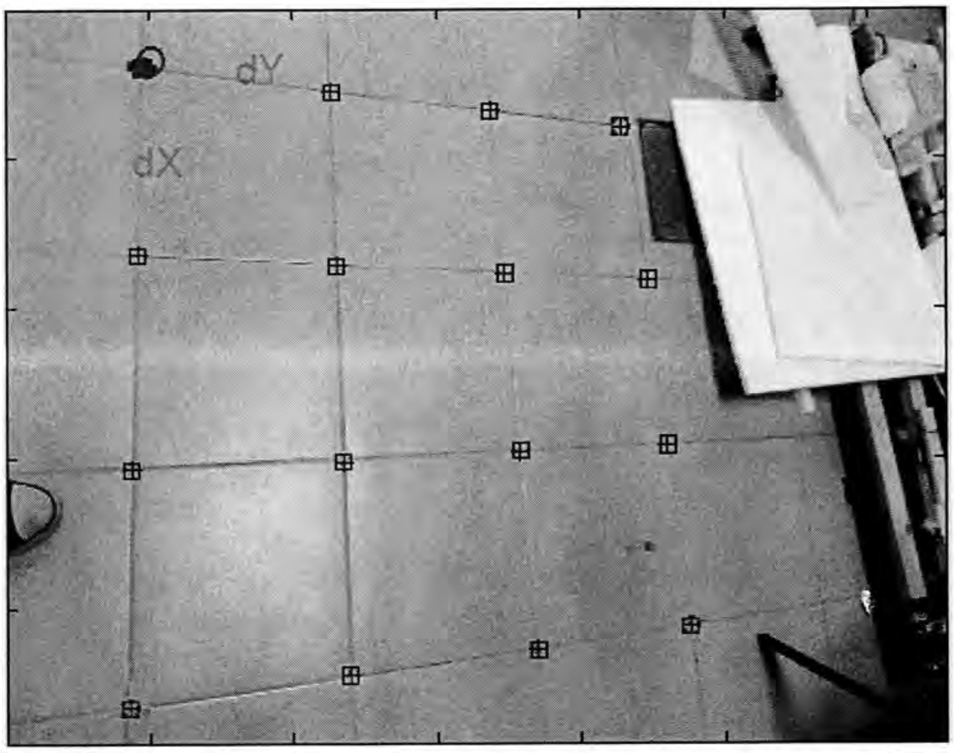

Figure 2.5: Grid corner extraction for one of the image that read from the Matlab camera calibration toolbox

The last operation is the calibration operation. Calibration is done in two steps: first initialization, and then nonlinear optimization. The initialization step computes a closed-form solution for the calibration parameters based not including any lens distortion. The non-linear optimization step minimizes the total projection error (in the least squares sense) over all the calibration parameters (9 DOF for intrinsic: focal, principal point, distortion coefficients, and 6 x 20 DOF extrinsic => 129 parameters). For a complete description of the calibration parameters, click on that link. The optimization is done by iterative gradient descent with an explicit (closed-form) computation of the Jacobian matrix.