FACTORS THAT INFLUENCE THE GEOMETRIC DETECTION PATTERN OF VEHICLE-BASED LICENCE PLATE RECOGNITION CAMERA SYSTEMS

MC RADEMEYER, MJ BOOYSEN* **and A BARNARD****

Department of Electrical and Electronic Engineering, Stellenbosch University
Private Bag X1, Matieland, 7602, South Africa
Tel: 021 808 4936; Email: martinrademeyer@gmail.com
*Tel: 021 808 4013; Email: mjbooysen@sun.ac.za
**Tel: 021 808 4006; Email: abarnard@sun.ac.za

ABSTRACT

Licence plate recognition (LPR) systems are used to automatically extract the characters from licence plates positioned in front of a camera. The geometric detection pattern is the region within which the system can accurately recognise licence plates and is of special interest when the system is mounted in a moving vehicle. In this research, the theory surrounding camera optics was investigated and used as the basis of a software simulation model. Inspired by the simulation measurements, a real-world experimental test was conducted to further explore the influence various factors have on the geometric detection pattern. Analysis of these measurements provided greater insight how multiple factors individually contribute to the shape and size of the geometric detection pattern and serves as a guide in the design of vehicle-based LPR systems.

1 INTRODUCTION

Over recent years, the automated recognition of vehicle licence plates has become a tremendous tool for authorities across the world. Licence plate recognition (LPR) systems extract the characters from licence plates positioned in front of a camera, allowing a specific vehicle to be matched with time and place of sighting. When mounted on a vehicle, such a system can log sightings of other vehicles it passes, allowing a vast road network to be covered. This application is especially useful to law enforcement agencies, who may want to locate and monitor the movement of a wanted vehicle.

The geometric detection pattern is chosen as a significant performance metric for this LPR system. The geometric detection pattern is the geometric region designed in front of the camera in which licence plates can accurately be recognised. This pattern is of special interest when considering vehicle-based LPR systems, as licence plates will appear at different positions and angles relative to the camera as the vehicle drives through traffic.

The exact dimensions and shape of the geometric detection pattern is determined by the combined in influence of many different factors, including camera specifications, licence plate orientation and lighting conditions. This paper evaluates the influence of these factors on the detection pattern, the result of which serves as a guide for the design of vehicle-based LPR systems.

2 LITERATURE REVIEW

A generic LPR system consists of a camera and recognition software running on a computational unit. The camera captures a scene of the road and passes it as an image le to the recognition algorithm, which in turn extracts the characters from the licence plate within the image. This research will focus on the influence of camera and environmental factors, making use of existing LPR algorithms and commercially available computational units (Istvan, 2016).

An LPR system can be mounted in a static position, such as a lamp pole overlooking a busy intersection, an automated tolling platform or the entrance to a parking garage. Such a mount is simple to configure and may offer significant recognition accuracy and speed, mainly due to the constant and predictable position of licence plates relative to the camera. On the other hand, vehicle-based systems are continually faced with licence plates at various distances and angles, stressing the importance of a well designed detection pattern.

The detection pattern is the product of many different factors. Some of these factors, such as camera specifications, can be controlled to manipulate the detection pattern into the desired shape and size for the required application. Other factors, such as ambient lighting, cannot be controlled but nevertheless strongly influence the detection pattern. This literature review will focus on LPR camera optical theory and recognition algorithms.

2.1 LPR Cameras

The specifications of an LPR camera determines the extent and quality of the captured image. Based on the camera specifications, geometric properties can be derived which are useful in analysing the detection pattern of the system. Commercial LPR cameras typically offer a detection range of up to 12 meters at a relative speed of 70 kilometres/hour (HTS Vehicle Recognition Solutions, 2015).

2.1.1 Camera Specifications

Focal length is an inherent property of each camera lens and describes to what degree the lens bends incoming light from the scene. It is measured as the distance in millimetres at which a lens concentrates light from an object infinity far away. Zoom lenses employ a special combination of individual movable lenses to adjust the overall effective focal length.

The image sensor is positioned behind the lens. It is covered in an array of photosensitive transistors, each producing a voltage level proportional to the intensity of light falling on it. Image sensors come in a variety of sizes and resolutions and generally employ either CMOS or CCD technology. CMOS sensors are typically used in cost effective compact cameras, while CCD sensors are used in professional-grade cameras.

In-Focus Distance is not an intrinsic specification, but instead a setting which is adjusted to ensure the subject of a photograph is within focus. Some lenses include an auto-focus mechanise, which automatically adjusts lens position as to put the subject in sharp focus. For the application of this system, a fixed-focus lens will be ideal as it does not possess moving parts which may be damaged by vehicle vibrations.

Aperture size determines the amount of light which is projected onto the image sensor. Depending on lighting conditions, it may be necessary to open the aperture wide to allow sufficient light to be captured. It not, the image will be too dark for accurate recognition to be possible.

2.1.2 Derived Properties

Angle of view is the solid angle describing the extent of the scene captured by the camera, and becomes smaller as the photograph becomes more zoomed in. The formula for angle of view is given below and is dependent on the diagonal size of the image sensor (S_D) and the lens focal length (f) (Nofziger, 2016).

$$\alpha = 2\arctan\left(\frac{S_D}{2f}\right)$$

Viewing angle is also considered as an influential factor. Many LPR algorithms are unable to recognise a licence plate when viewed at an angle greater than 45 degrees (Truter, 2016).

The depth of field is the region in which objects will be sufficiently focused when photographed. The sharp in-focus distance can be set by adjusting the distance between the lens and image sensor. This relationship is known as the thin lens equation and is shown here (Bortner, 2013).

$$\frac{1}{S_{focus}} + \frac{1}{S_{sen}} = \frac{1}{f}$$

It is dependent on the focal length (f) and the distances between the lens and in-focus object (S_{focus}), and lens and image sensor (S_{sen}). As an object deviates from the in-focus distance, light from the projected object will no longer perfectly converge on the image sensor. This results in points in the object being imaged as large circles, called circles of confusion. As long as these circles are smaller than a 1500th the size of the image sensor, the object will appear in-focus to the human eye (Nasse, 2010). This circle of confusion factor (C), together with the lens focal length (f) and F-number (N), determine the hyperfocal distance (H), as shown below (Barsky, 2005).

$$H = f + \frac{f^2}{NC}$$

The hyperfocal distance and the in-focus distance can then be used to calculate the near and far boundaries of the depth of field, shown here (Barsky, 2005).

$$D_N = \frac{HS_{focus}}{H + S_{focus}}$$

$$D_F = \frac{HS_{focus}}{H - S_{focus}}$$

A **pixel density** of 4000 pixels per licence plate was selected, as recommended based on the typical requirements for reliable recognition (Truter, 2016).

2.2 LPR Algorithms

Many recognition software packages are available for LPR systems, ranging from commercial to open source. Some algorithms rely on full-colour images for accurate recognition (Shi et al, 2005), while others only consider the brightness intensity (Ha and Shakeri, 2016). Most algorithm however, employ some form of edge detection, loosely grouped into three basic stages (Babu and Raghunadh, 2016).

Firstly, the licence plate is detected and located by searching the rows and columns of the image's pixels for the distinctive black-to-white contrast of a licence plate's rectangular border. Once this stage is passed, the licence plate region is searched horizontally for the white spaces between characters, allowing the characters to be separated. Finally, each character is classified based on a library of character images. The result is a character string matching than of the actual image plate. This information can then be stored or communicated.

Since the focus of this work is the geometric detection pattern, an existing LPR algorithm with known requirements and limitations is chosen and considered a constant factor throughout the analysis.

3 DETECTION PATTERN MODEL

The evaluation of influential factors underwent two stages of analysis. Firstly, a software simulation was used to identify the impact of camera hardware specifications on the detection pattern. Following on this, controlled experimental tests were conducted with an actual camera to validate the simulation findings and identify further factors.

3.1 Software Simulation

The simulation was specifically developed to evaluate the influence of camera settings, such as focal length and sensor resolution. Analysis of these settings is essential as they greatly determine how the scene in front of the camera is captured, and consequently whether an LPR algorithm will be able to correctly recognise the licence plate within the photo. It should be noted that the simulation was aimed at the detailed analysis of a specific handful of factors and is by no means a complete model.

3.1.1 Design

The characteristics of a photo change as camera settings vary. Four of these characteristics are of special interest in analysing the geometric detection pattern, namely angle of view, viewing angle, depth of field and critical apparent angle. Together these properties describe the shape of the detection pattern, as illustrated in Figure 1.

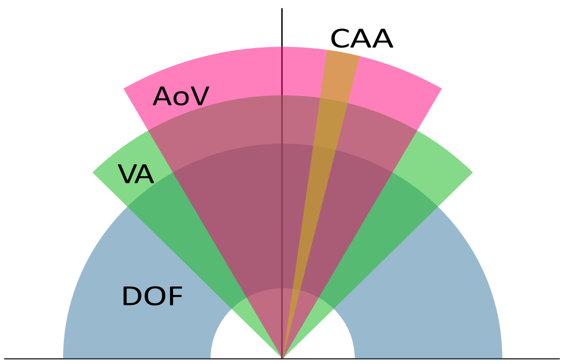


Figure 1: The properties which describe the simulation detection pattern

In order to observe these properties, the camera was modelled as a multidimensional system which produced a set of photo photographic properties based on the combination of camera settings. This was achieved by defining a spectrum of realistic values for each specification and mathematically calculating the properties for each possible combination of camera specifications.

3.1.2 Performance Metrics

For the simulation, the successful recognition of a licence plate had to be mathematically determined. This was done across a virtual test range consisting of a forty meter long, three lane road, with licence plates distributed along the centre of each lane. In order to determine the detection pattern for a given setting combination, the corresponding photographic properties were calculated, and each position evaluated to determine whether all four properties allow it to be by recognisable. These validation checks were based on requirements of existing LPR algorithms.

The first check for whether recognition is possible is whether the entire licence plate falls within the camera's **angle of view**. Of particular interest is the horizontal component of the angle of view, which can be obtained by substituting the diagonal sensor size in the angle of view equation with the sensor width. This angle will determine to what extent adjacent lanes enter the field of view and whether both vertical edges of the licence plate is included in the image.

In the simulation the **viewing angle** was defined as the angular difference between the line joining the camera and the licence plate, and the forward axis of the licence plate. For LPR to be possible the captured licence plate should not be excessively stretched or squashed, a distortion which occurs when the licence plate is viewed at too sharp an angle. This typically occurs when driving past nearby vehicles in adjacent lanes, and when passing vehicles parked perpendicular to the road. A licence plate with a viewing angle greater than 45 degrees is considered unrecognisable.

Depth of field is also identified as a significant performance metric for this LPR system. For licence plates to be detected and accurately recognised, the plate and character edges must be sufficiently sharp. This requires that the licence plate must be positioned within the depth of field. The simulation will verify whether the licence plate position is indeed between the near and far depth of field boundaries for it to be classified as recognisable.

Lastly, the number of **pixels occupied** by the licence plate should be high enough to allow its characters to be accurately recognised. Initially, it was expected that the resolution of the image sensor would determine the maximum range at which a licence plate occupies the sufficient number of pixels. However, as the angle of view shrinks, a smaller area of the scene occupies the same amount of sensor pixels, effectively allowing the licence plate to positioned at a greater distance.

Instead, both these properties were used to calculate the minimum solid angle to be occupied by a licence plate. Given the sensor resolution and amount pixels required for recognition, the fraction of the image sensor which should be covered by the licence plate was calculated. Given this fraction and total angle of view, the critical apparent angle of the licence plate could be determined. If a licence plate is too far away from the camera its apparent angle will be less than this value and it will not be recognisable. A small critical apparent angle will therefore offer the greatest detection pattern range.

3.2 Experimental Test

The second stage of analysis consisted of a series of experimental tests with an actual camera and licence plate. Simulated conditions were replicated, and additional factors were introduced. This provided a validation of factors included in the simulation and further investigation into factors previously excluded.

3.2.1 Design

The selected camera was chosen based on the simulated specifications producing the greatest detection area. Additionally, it was highly adjustable to allow the testing of various specification settings. It featured a 1/3.2" 8-megapixel sensor (3264x2448 pixels) and a manual zoom lens with adjustable focus, 3 to 12 millimetre focal length and maximum aperture of f/1.8. The camera was mounted on a tripod and connected to a Raspberry Pi via USB. The Raspberry Pi ran a Python script which captured the image, passed it to an open-source LPR algorithm and stored the result on an on-board SD card.

As in the simulation, analysis was performed on a three-lane road analogue with the camera positioned in the centre lane. A test would consist of a licence plate being placed at various positions along the lanes and the Python script executed at each position. This occurred under different controlled conditions for each test, allowing the influence of each factor to be identified and measured. The factors analysed included in-focus distance, focal length, aperture size, ambient lighting and viewing angle.

To provide reliable and repeatable results, tests were conducted under controlled conditions. Full control over lighting conditions were achieved by conducting tests in-doors and at night, allowing ceiling lights to be adjusted as desired and no variance in outside lighting to influence the test.

3.2.2 Performance Metrics

In the experimental test, the boundary of the detection region was empirically determined by whether a chosen LPR algorithm correctly recognise the licence plate at a given position. For this, the openALPR algorithm package was selected due to being open source, compatible with the Raspberry Pi and simple to use. This provided accurate real-world detection pattern benchmarks for various conditions, allowing the influence of individual factors to be thoroughly analysed.

3.3 Limitations and Approximations

In both the simulation and experimental test the focus was on static use cases. As such there was not relative motion between the camera and licence plates, allowing the analysis to only distil the factors which influence the geometry of the detection region.

In order to maintain a reasonable simulation time, the detection region was limited to a 40 meter long, 3-lane road. Likewise, to facilitate the experimental test indoors, the road analogue was similarly limited. To ease the implementation of the simulation, the detection region was discretized into evenly spaced points along the centre of each lane, on the same plane as the camera and orientated perpendicular to the camera's principle axis. The trajectory of light passing through the lens was also simplified to allow simpler analysis in the case of narrow angle lenses.

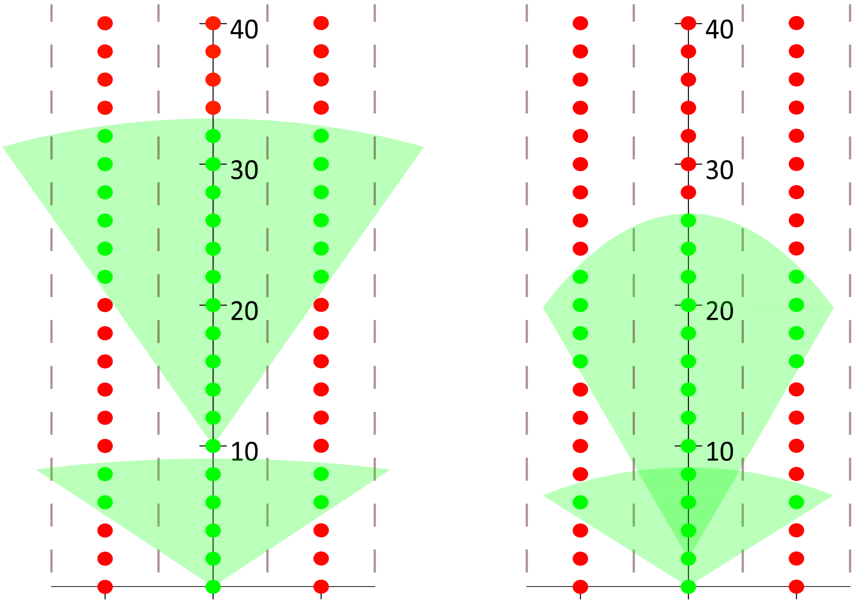
Throughout the analysis, European Union (EU) licence plates were used. Likewise, the algorithm used in the experimental tests was trained for EU licence plates. Keeping the licence plate format and recognition algorithm constant, allowed the analysis of various other factors which are independent of the licence plate format used.

4 MEASUREMENTS AND DISCUSSION

The simulation and experimental test produced detection patterns for various sets of conditions. Adjusting these conditions allowed for thorough analysis of how individual factors influence the detection pattern. The two independent analysis models also afforded validation for the accurate analysis of measurements, something which proved to be of great value when defining the influence of a specific factor.

4.1 Comparison of Measurements

The simulated and real-world detection patterns of a camera system is shown in Figure 2. This specific system has a 1/3.2" 8-megapixel sensor and a lens aperture of f/1.8. In both cases the further detection region was obtained with a focal length of 12 millimetres and the near region, with a focal length of 3 millimetres. The in-focus distance was adjusted so to obtain the greatest detection area.



a) Simulation **b) Experimental Test**

Figure 2: Measured detection patterns (unit in meters)

It is evident that some differences exist between the simulated and real-life output, especially for large focal lengths. However, this is to be expected and can be attributed mainly to the incomplete modelling of simulation factors. Despite the far region being 6 meters closer in the real-world pattern, the general shape of the patterns is very similar. Both the simulation and experimental test measurements offer a unique insight into how different factors influence these patterns. The simulation affords an in-depth look into how specific camera settings change the shape of the detection pattern, while the experimental test provides an accurate real-world detection pattern benchmark for a given combination of settings.

4.2 Lens Focal Length

Lens focal length was expected to greatly influence the shape of the detection pattern. A look at Figure 3 shows the amount of discretized positions which were determined as recognisable by the simulation, based on varying focal length and in-focus distance. This effectively conveys the total area of the detection pattern, due to the even distribution of licence plate positions along the test range. The multidimensional nature of the model necessitates that all but two of the specifications be fixed for a useful output to be displayed on a 3-dimensional graph. In this case, the sensor size, resolution and the F-number were fixed at values typically found in compact 8-megapixel cameras.

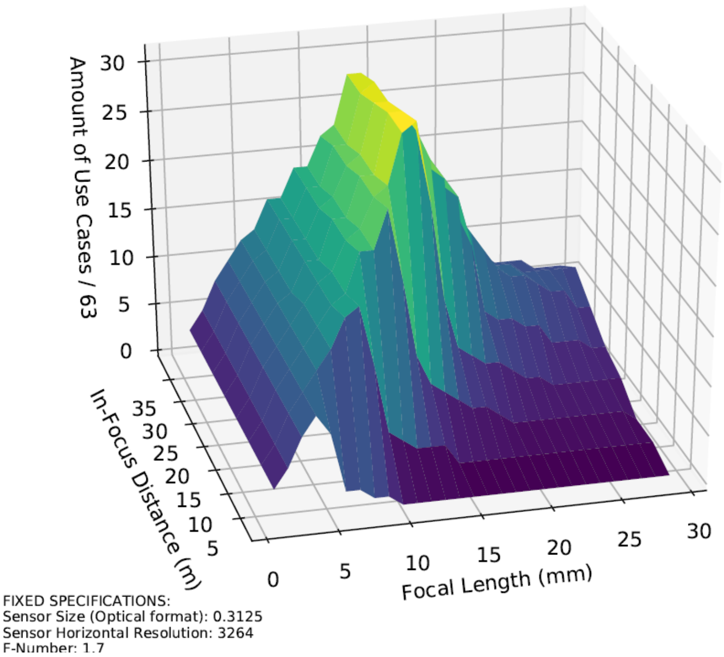


Figure 3: Simulated Amount of Use Cases

This graph demonstrates the sensitivity of the detection area to a change in focal length. A sharp peak occurs at a focal length of exactly 14 millimetres. An in-focus distance of minimum 18 meters is also required for this area to be obtained. This delicate relationship between focal length and in-focus distance also became evident during experimental tests, where both specifications had to be increased in unison to obtain the maximum detection.

The ability of focal length to drastically alter the overall detection area is mainly due to the role it plays in the angle of view. In the simulation it became evident that variation in focal length far outweighs that of sensor size as the dominate factor in the camera's angle of view, which increases dramatically as the focal length shortens. This effect was confirmed in the experimental tests. A short focal length allows the coverage of multiple lanes and effectively increases the detection area.

However, focal length also influences the critical apparent angle required for recognition. A short focal length and resultant wide angle of view, produces a large critical angle. This requires licence plates to be very close for recognition to be possible, effective decreasing the detection area. This explains the rise and fall of use cases as focal length increases. Short focal length offers coverage of nearby vehicles in adjacent lanes but lacks the long range of a narrow-angle system. A moderate focal length is therefore required to achieve the greatest detection area.

Experimental test also identified the problem of barrel distortion which prevented the recognition of extremely nearby licence plates by wide-angle systems. These licence plates were only recognised once pincushion correction was applied. This only occurred at a range of less than 30 centimetres and was deemed acceptable due to no licence plate coming this close to the vehicle's windshield.

4.3 Image Sensor

Through a search of existing CMOS image sensors, it became apparent that most sensors offer very little choice in size for a given resolution. This is due to sensors only being available in standard sizes and higher resolution sensors requiring a larger sensor. This consideration became important when realistically interpreting results from the simulation, which independently varied resolution and size.

Of the two factors, resolution is by far the most influential, decreasing the critical apparent angle significantly as the number of pixels increase, thereby extending the range of the detection pattern. A large sensor will slightly enlarge the angle of view, but in a way easily compensated for by a small change in focal length.

Experimental tests also confirmed sensor resolution as the limiting factor of detection range. Measurements taken from photos at the 27 meter detection edge showed that the licence plates occupied very close to 4000 pixels. This matches the pixel density threshold used in the simulation, confirming sensor resolution as the dominate factor influencing detection range. The 6 meter difference between the simulated and real-life detection range may be ascribed to inaccuracies in the modelling of the critical apparent angle.

4.4 In-Focus Distance

Extending of the in-focus distance extends the entire depth of field. The near boundary extends further when using a long focal length, while the far boundary extends further at short focal lengths. The maximum simulated detection area was achieved with an in-focus distance of 18 meters and produced a depth of field stretching from 8 to 43 meters.

However, during experimental tests not one licence plate failed to be recognised due to a lack of focus. The difference between the simulated and measured depth of field may be due to the simulation circle of confusion threshold being set to a value recommended for professional photography instead of LPR, resulting in a simulated depth of field shallower than what the algorithm can operate in. This observation confirms that such a system can operate optimally when fitted with a fixed-focus lens, a cheap and reliable alternative to a manual or auto-focus lens.

4.5 Viewing Angle

Simulation results were based on a theoretical maximum viewing angle of 45 degrees, as per the requirements of existing LPR algorithms. To test this, a license plate was positioned such where it was fully visible, in-focus and occupied an ample number of pixels. The licence plate was then gradually rotated to synthesise the increase of viewing angle. At approximately 45 degrees recognition failed, even though the licence plate still had sufficient pixel density. This confirms that even when the critical apparent angle is exceeded, a viewing angle greater than 45 degrees will produce a licence plate which is too "squashed" for accurate recognition.

4.6 Aperture Size

The simulated detection pattern showed very little sensitivity towards a change on aperture size. A large aperture slightly shortens the near depth of field boundary and lengthen the far boundary, but to a negligible degree in comparison to the lens focal length. However, the experimental test allowed the true significance of aperture size to come to the fore. Together with the camera's shutter and ISO speeds, aperture size determines how much light from the scene is captured, a measure collectively referred to as exposure. In all the tests, a large aperture produced brighter photos which were more accurately recognised. Although this does not affect the detection pattern shape, it does highlight the importance of lighting in LPR systems.

4.7 Lighting

During the experimental tests, it was not clear why very nearby licence plates failed to be recognised when using the narrow angle lens. Recognition was only achieved once the image was brightened using a photo editor. When coupled with the absence of lighting near the edge of the test area, it was concluded that insufficient lighting was the reason for recognition failure, a factor not previously analysed. Although it may not alter the detection pattern, lighting should nonetheless be considered a highly influential factor in the successful operation of an LPR system.

5 CONCLUSION

This work evaluates how many different factors individually influence the geometric detection pattern of a vehicle-based LPR system. A software simulation model provided a mathematical platform for the analysis of how individual camera specifications influence this detection pattern. The simulation confirmed the detection pattern's sensitivity to a change in any of the camera specifications. Lens focal length was identified as the most influential factor, due to its ability to significantly affect the angle of view and the relative ease with which a zoom lens can be adjusted.

The series of experimental tests provided detection pattern benchmarks under various controlled conditions, confirming and validating simulation results. The detection pattern was found to be remarkably insensitive to a variation in focus. This demonstrates that an LPR system may operate optimally even when equipped with a fixed-focus lens, a cheaper and reliable alternative to a lens with adjustable focus. The tests also identified the effect of lighting and barrel distortion, factors not analysed in the simulated model.

This analysis succeeded in identifying and measuring the influence of individual factors on the geometric detection pattern. It demonstrates that multiple factors determine the shape and size of the detection pattern, but that some factors more influential. Further research should consider the effect of a dynamic system and look to incorporate additional factors into the simulated model.

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