ELECTRONIC NUMBER PLATE GENERATION FOR PERFORMANCE EVALUATION

Soodamani Ramalingam
School of Engineering, Physics and Computer Science
University of Hertfordshire
Hatfield, UK AL10 9AB.
s.ramalingam@herts.ac.uk

William E. Martin
School of Engineering, Physics and Computer Science
University of Hertfordshire
Hatfield, UK AL10 9AB.
w.e.martin@herts.ac.uk

Michael Rhead
School of Engineering, Physics and Computer Science
University of Hertfordshire
Hatfield, UK AL10 9AB.
m.rhead@herts.ac.uk

Robert Gurney
School of Engineering, Physics and Computer Science
University of Hertfordshire
Hatfield, UK AL10 9AB.
r.gurney@herts.ac.uk

***Abstract*—The authors have been involved in real world analysis of Automatic Number Plate Recognition (ANPR) data and systems particularly for law enforcement applications. As a result of such work with Law Enforcement Agencies, contributions have been made to the revision of the British Standards for ANPR. This led to the research team developing performance evaluation measures from an end-to-end system perspective. One such measure was the generation of synthetic image datasets suitable for ANPR performance evaluation. The prime requirement for any ANPR system is data accuracy. This paper reports the initial work and progress made using defined synthetic images to test and assess ANPR engines using a structured methodology.**

Keywords— ANPR, machine learning, artificial intelligence, neural networks, synthetic image generation, opacity, image synthesis, noise generation.

I. INTRODUCTION

Law enforcement agencies (LEA) require Automatic Number Plate Recognition (ANPR) systems to capture and correctly read all vehicles. Data accuracy is a stringent requirement under United Kingdom General Data Protection Regulation legislation [1]. An ANPR camera's software engine and associated optical character recognition (OCR) algorithm must be reliable and accurate. The software engine must operate precisely under almost all conditions including variability in weather, illumination during the day and night, vehicle speed, reflectance of registration plates, format and syntax of UK, EU and Schengen registration plates, noise and clutter on registration plates and ANPR software capability.

This demands high performance image sensors, ANPR algorithms and correct camera setup. Fail to capture and incorrect reads are detrimental to ANPR and have implications. For example, to detect an uninsured vehicle, ANPR capture the plate image and read the image correctly. A fail to capture results in the vehicle's registration plate not being compared with a list of uninsured vehicles. When comparing an ANPR read with a list of uninsured vehicles and one of the following will be recorded:

i)	Unknown vehicle:	unknown	✓ or ✗
ii)	Vehicle has insurance:	correct read	✓
iii)	Vehicle has insurance:	incorrect read	✗
iv)	Vehicle has no insurance:	correct read	✓
v)	Vehicle has no insurance:	incorrect read	✗
vi)	Image fails plate test rules:	discarded	✗

Results in category iii are false positives (has insurance) and in category v false negatives (has no insurance).

Recent work [2] demonstrates the issue that shows that 130,000 images were subjected to AI and ML algorithms-based software to determine make, model and colour. They claimed that machine learning proved successful in identifying false plates from ANPR images. However, the OCR result needs to be compared with a list of registration marks, make, model and colour (about 40 million vehicles) to find variances in make, model or colour. The comparison determined that 1,237 vehicles were likely to be cloned.

A review of the 1,237 cloned vehicles found:

- 1,202 (97%) false positive results relating to misreads, poor image standard and misclassification.
- 35 (3%) results were deemed worthy of further investigation to determine if they were true clones.

A. Proposed Work

Our work on ANPR as part of security and countermeasures, is a specific research area. A significant problem identified was the lack of centralised, objective, comparative and independent assessment process for benchmarking ANPR systems. We are continuing to develop a centre for benchmarking ANPR systems. We expect that this centre would act as an independent body for objective evaluation of ANPR performance. Such improvements would help to make cloned and falsified plates for purpose of testing. Examples include:

- Crime (all aspects)
- Congestion charge and low emission zone avoidance
- Toll, bus, and taxi lane/zone charge avoidance
- Innocent members of the public being sent penalty notices for illegal parking, congestion charge etc.

Attempts to disguise a vehicle to avoid detection would be much less worthwhile.

To help improve the capability of ANPR we have generated key data sets through a simulation process that generates vehicle number plate images. The images can have variables that allow additional signals of noise, brightness, contrast, plate clutter (all printing reduces net reflectivity), plastic laminates (reduce net reflectivity), viewing angle (increased angle reduces retro reflectivity). They can also determine character spacing [3], fonts, fixings (size and locations) [4] and focus or blur (based on vehicle speed and camera setup) [6-7].

Our simulation software has been developed to create datasets of number plate images with defined noise, brightness, contrast etc. It can generate number plates relating to any country that comply or fail to comply with each country's specification for number plates. The system can determine best-in-class ANPR engines, improves product selection or helps to pair software with hardware. Furthermore, it will help to reduce or enhance resource intensive and variable field trials to test performance that is the case with LEAs.

This research is specifically for real world problems related to ANPR and has not been carried out previously, to the best of our knowledge. Hence, this work may be considered as a key initial stage of analysis specifically targeted towards benchmarking ANPR image sensors and OCR algorithms particularly well suited for LEA applications.

II. Background Research

A. Selecting a Template (Heading 2)

Rendering procedures for computer graphics are an important field of synthetic image production. The aim is to create an image that is indistinguishable from a real-world image.

Such rendering procedures model light reflection and use algorithms or techniques and are used in entertainment and medicine, pilot training, and automotive design, to name a few. The light reflectance models involve the study of how light reflects or transmits when it impinges on a surface. Some of the photometric optics terminology relevant to image processing is discussed in this section. They are applicable to radiometric units such as Watts/metre^2 (W/m^2).

B. Brightness and Illumination

Brightness refers to the overall lightness or darkness of an image. The term *brightness* is a qualitative measure in the context of physiological sensations. Brightness is the relative intensity as perceived by the human eye. Intensity is the absolute measure of a light wave's power density. Brightness can refer to luminance shown in Fig. 1.

Table I provides a comparison of photometric and radiometric terms. The units are defined as lm = lumen, m = metre, sr = steradian (a unit of solid angle), and W= watts. In photometry, the energy from a light source measured as luminous flux (lumens) and the luminous intensity (candela) is the amount of light that travels in a particular direction.

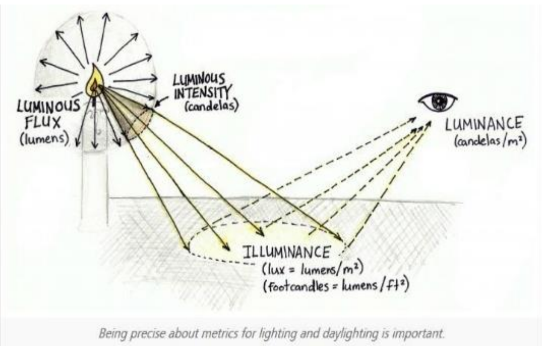

Fig. 1. The measurement and perception of light[1]

TABLE I. COMPARISON OF PHOTOMETRIC AND RADIOMETRIC UNITS

Photometric *Visible electromagnetic spectrum*		**Radiometric** *Electromagnetic spectrum*	
Luminous flux	lm	Radiant power	W
Illuminance (Lux)	lm/m^2	Irradiance	W/m^2
Luminance	lm/m^2/sr	Radiance	W/m^2/sr
Luminous Intensity (Candela)	lm/sr	Radiant intensity	W/sr

The energy falling onto a surface area is measured as illuminance (lux). The luminance of daylight falls from 10,752 lux to 0.0011 lux under starlight, a ratio of 9,774,545:1. The amount of light reflected off a surface and reaches the human eye (sensor) is measured as luminance.

The UK standard [9] for retroreflective registration plates refers to retroreflectivity as candela/lux/metre^2 but requires constant contrast in the near infrared (<1,000nm). Strictly speaking photometry only relates to the visible spectrum. Radiometric units may be preferred to ensure consistency of definition.

C. Fog, Snow and Blur Effects

A synthetic scene generator for car toll and rail transport is described in the work by Yu Cheng et. al.[11]. Their **fog synthesis** procedure considers the fog strength modelled as a Gaussian distribution and depth of the pixels determined by geometry. Various types of fogs have been modelled as patches and blended into the noise-free image *I*.

Variable contrast is achieved through a defined control parameter or patch. It has options to vary scale, shape and illumination level via patch definition. The synthesis of **snow** involves understanding the scene to be generated. To achieve this a library of snow blocks has been pre-built and can be adjusted to mimic a wide variety of conditions.

Recent developments in image restoration techniques model the original image, blur and noise process in the image. An image scene $f(\mathrm{x},\mathrm{y})$ degraded by **motion blur** is defined as follows [12]:

$$g(\mathrm{x},\mathrm{y}) = \iint h(x-x',y-y')f(x',y')\,dx'dy' + n(x,y) \quad (2)$$

where:

$f(\mathrm{x},\mathrm{y})$ is the ideal image,
$g(\mathrm{x},\mathrm{y})$ is the degraded image,
$h(x,y)$ is the point spread function (PSF) of the blur,
$n(x,y)$ is a random noise.

Blur (or focus) characteristics include direction, extent and shape due to the relative motion between the camera and object. A one-dimensional blur model is sufficient for most applications. The blur effect is considered to be linear, space invariant and the original image stationary [12]. Such a model appears to be suitable for the design of motion in ANPR cameras using a standard Gaussian blur function. An example is shown in Table II.

TABLE II. EFFECT OF MOTION USING GAUSSIAN BLUR ON FRONT AND REAR PLATES

Front Plates

Origianl Image	***Blurred Image***
	

Rear Plates

	

D. *Great Britain Number Plate Character Format Considerations for Simulation*

The simulation of vehicle number plates include EU, Schengen and UK registration plate rules. It is also possible to generate non-compliant (illegal) registration plates. A vehicle's front and rear plate are usually 520 x 111mm although other plate sizes can be incorporated.

The registration plate contains other markings ("clutter") such as country logo, coach lines, supplying outlet, BS identifier and fixings. The current GB format [13] for registration plates is given in Fig.2. The legal dimensions of spacing between characters is given in Fig.3 and Table III [8]. The first two alpha-characters represent the area code, where the vehicle was first registered. The two numeric characters identify vehicle registration date. The final group consists of three random alpha characters.

The software can generate specific or randomly generated registration marks that conform to or contravene specific syntax rules (font, spacing, size, coachlines and their proximity to characters).

Variation in vehicle speed affects the imaging process. The interconnected elements with vehicle speed are the rate of the image grabber software and the speed of the camera processor. Given that a vehicle is travelling at 30 mph and a camera operating at 50 frames/sec with a shutter speed $1/50^{th}$ second, the vehicle would have covered 0.268m for that shutter speed. The resulting image is blurred and not suitable for OCR.

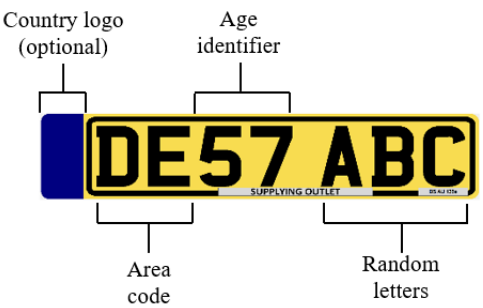

Fig. 2. Great Britain number plate character format [13] plus emblem, coachline, supplying outlet and BS identifier

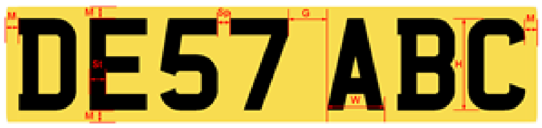

Fig. 3. GB number plate character format [13] including emblem, coachline, supplying outlet and BS identifier

TABLE III. LEGAL DIMENSIONS OF UK NUMBER PLATES WITH CHARLES WRIGHT FONT

Characters	Registered or replaced after 1st Sep. 01	Registered before 1st Sep.01	
Charles Wright font	***(mm)***	***Group 1 (mm)***	***Group 2 (mm)***
Height, H	79	89	79
Width, W	50	64	57
Stroke Width, St	14	16	14
Character Spacing, Sp	11	13	11
Group Spacing, G	33	38	33
Margins, M	11 (all)	13 (side)	11 (side)

Setting the shutter speed to $1/1000^{th}$ second, the vehicle would have travelled $1/20^{th}$ of the distance or just 0.0134m. The UK CCTV advisory service [15] has provided an indication of the relation between the distance covered by a vehicle versus the distance it would have covered for specific shutter speeds part of which is indicated in Table IV. There are further complications to consider such as illuminance at night and variable the reflective properties of registration plates [5], [16].

TABLE IV. DISTANCE TRAVELLED AT DIFERENT SPEEDS

Miles per hour	Metres per sec	Distance travelled (mm) by vehicle at the following shutter speeds	
		1/50th sec	**1/1,000th sec**
30	13.41	268	13.41
50	22.35	447	22.35
100	44.70	894	44.7

III. SYNTHETIC NUMBER PLATE GENERATION

This section considers the generation of synthetic vehicle number plates to the correct UK specification [8], [9]. It also considers the effect of specific weather conditions on the appearance of the generated plates. The image is altered further due to varying speed of the vehicle. This effect is also superimposed on the existing weathered plates. The system was implemented using C#.NET programming under Visual Studio 2012 IDE.

There are two key stages of development involved namely Reflectance Analysis, and External Noise generation. These include the implementation of Reflectance effects and later we demonstrate the effects of noise such as rain, grime and snow on the number plate.

A. *Random Number Generator*

As a first step, a random number generation is used to generate a vehicle number plate in accordance with legislation [8] and DVLA syntax rules [9], [13] for a standard UK registration plate size of 520mm x 111m Fig. 3. Additional markings or clutter can be added to the number plate such as country logo, supplying outlet and coachlines or borders. Legal font (Charles Wright) and spacing are the default setting but other plate sizes, fonts and spacing and clutter can be employed.

B. *Contrast and Brightness*

The block diagram in Fig.4 shows the process of generating synthetic vehicle number plates with specifications meeting the BS AU 145e standard for white front and yellow rear plates.

The software has the option to generate a set of vehicle number plates randomly or for a defined registration mark in colour or greyscale. Once the generic plates have been generated, contrast and brightness can be adjusted to alter the apparent reflective properties of the plate. In addition, a blur effect can be introduced to the plate image to simulate variable speed.

Other work [5], [16] has shown that the method and materials of construction can adversely reduce number plate reflectance by up to 30% (brightness) Fig.5. The greatest impact is at night when low energy illuminating sources are employed.

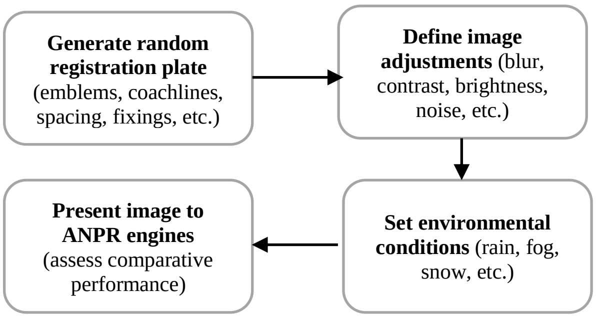

Fig. 4. High level block diagram for synthetic number plate generation and software performance assessment

Fig. 5. Attenuation of reflectance by plastic laminates

C. *Front and Back Plate Distinctions*

In the next stage, the background colour of the front and rear plates (black on white, black on yellow or white on black) can be set to the appropriately (colour or greyscale images).

The images are generated and the direct proportionality between the physical plate dimensions and number of pixels set. A conversion rate of 1 mm = 3.779527559055 pixels is applied. Our measurement results on previous image sets provide the same ratio of 1:3.7 between physical size and image resolution [17].

D. *Speed Variability*

As speed is inversely proportional to time, a time slider is included in the system simulation software. Elapsed time (shutter speed) can be adjusted using a **TrackBar** object in C#. Any length of time can be set to simulate the movement of a number plate at any defined speed **TrackBar** has a range of parameters that can be adjusted to obtain defined, variable conditions that are fully reproducible.

Blur effect due to vehicle speed variations is implemented using the Gaussian function in Section 2.3. A set of motion blur results for $1 \leq \sigma \leq 45$ for the front plate is shown in Fig. 6.

Fig. 6. Motion Blur with Gaussian Function

E. *Varibale Contrast and Brightness*

The effects of variable contrast have been applied to both front and back plates by adding two sliders called *Contrast* and *Brightness*. By adjusting the slider values the number plates implement various weather conditions and variable day and night illumination levels.

MS Visual C# does not have a direct means to implement brightness variations in this way. An alternative solution was implemented using the Direct3D High Level Shading Language (HLSL) [18] using a pixel shader that operates at a pixel level. Again, a slide mechanism is implemented to vary the brightness levels.

F. *Varibale Contrast and Brightness*

Fig.7 shows an image of a real front number alongside a similar synthetic image. Both the real and synthetic image do not have any defined noise or reflectance adjustments. Fig.8 is an example of synthetic front and rear number plates generated.

Fig. 7. Real plate image (left) and synthetic plate image (right)

Fig. 8. Synthetic Front and Rear Plates

An example of varying brightness and contrast plates is given in Fig. 9.

Fig. 9. Synthetic Front and Rear Plates with Varied Contrast and Brightness

G. *External Noise*

Three types of noise were considered for synthetic image generation and incorporated the effects of grime, rain and snow. Any other type of noise can be defined and set for a specific set of image testing.

As with reflectance analysis, noisy conditions deteriorate an input image if the speed of the vehicle increases. The rate at which rain, snow and grime increase the plate is controlled to vary at intermediary speeds.

The following control mechanisms are implemented:

- Noise levels – low, medium, high
- Scaling – full size and half size
- Weather conditions – rain, grime, snow
- Speed variation – {0, 10, 30, 50, 60, 70, 90} mph

Fig.10 shows a set of synthetic front and rear plate images generated with varied external noise superimposed on them. The lab-based software has the capability to vary the level of noise introduced in the images in a controlled and smooth manner.

Fig.10. Synthetic Front and rear plates with defined noise

IV. Performance Evaluation of An ANPR Engine

A random set of 50 synthetic plates was generated and subjected to ANPR recognition tests. Three sets of tests were conducted:

- Images with reflectance variation [19],
- External noisy images [20], and
- Variation in speed.

ANPR recognition results are usually reported for the entire number plate. However, our tests were carried out on an individual character basis to understand the nature of the problem to be able to improve the algorithm tested. An online commercial system was used to test the recognition performance [21].

The process of recognition includes segmentation of characters and their feature extraction. It is evident that noise or clutter affected these pre-processing steps. Grime, rain and snow can alter the characters apparent shape and OCR performance can be adversely affected.

Fig.10 indicates that increasing speed may be problematic for ANPR plate recognition. Fig.11 shows the overall performance and broken down into two groups Group 1 relates to statistics of individual character recognition and Group 2 complete NP recognition. Group 1 (Result average for 50 images) for snow, rain and grime and Group 2 (Result average for 20 images) Blur effect (Speed). In these tests Group 1 had a higher recognition rate compared Group 2. Rain has the largest adverse effect on recognising individual characters, whereas grime adversely affected whole NP recognition. recognition and the second group to that of whole NP recognition.

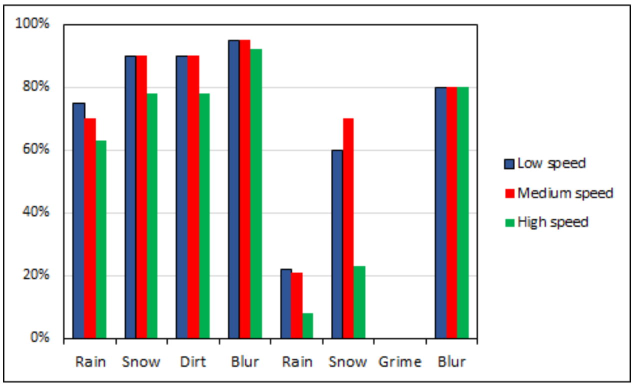

Fig. 11. OCR Performance with External Noise

Character recognition results are tabulated in Table 3. Whilst some of the images were recognised under varying reflectance levels, there were occasions when they fail to be recognised Table 3. A more extensive data set to benchmark ANPR engine performance can be generated.

An example of varying brightness and contrast plates is given in Figure 9. Character recognition results are tabulated in Table V. Whilst some of the images were recognised under varying reflectance levels, there were occasions when they fail to be recognised. A more extensive data set to benchmark ANPR engine performance can be generated.

TABLE V. OCR Results with Reflectance Images. The Character B in AB12 DEG is a misread

Plate	Nominal condition		Test image	Recognition result
FB87 TFC		Sunny	FB87 TFC	FB87 TFC
JH55 CMN		Sunny	JH55 CMN	JH55 CMN
AB12 DEG		Foggy	AB12 DEG	AB12DBG
KJ78 DJG		Night	KJ78 DJG	KJ78 DJG

The quality of the image has an influence on each character's correct read during the recognition process. Each character contributes to ~14% recognition (7 characters). The quality of the image influences each character's success rate during the recognition process. When noise or clutter are added to the plate image characters can be misread, particularly those that have similar shapes and a natural misclassification occurred.

The process of recognition includes segmentation of characters and extraction. It is evident that the quality of the plate is affected by these pre-processing results. Thus grime, rain and snow alter the characters of the number plate dramatically and hence their features. As a result, the OCR performance is affected.

V. Further performance Testing

Our technique of using manufactured but defined images has been used to:

A. Assess the impact of registration plate clutter on ANPR capture
B. Assess ANPR software that determines registration mark and make model and colour by separate algorithms.

A. Impact of registration plate clutter on capture rate

Unnecessary clutter and poor design are detrimental to ANPR. As markings or "clutter" are added to a registration plate the retroreflective area deceases. As the retroreflective area decreases radiance decreases (Figure 1). Reduced radiance results in reduced energy returned to the ANPR camera particularly at night. For an ANPR camera capture to take place the energy received by the camera's sensor must be greater that the activation threshold. For a standard 520 x 111mm plate with a 7-character registration the following indicates the reduction in retroreflective area:

Registration mark:	17.6% to 36.6%
5mm or 6mm coach line with emblem:	9.9% to 11.8%
5mm or 6mm coach line without emblem:	10.8% to 12.9%
Emblem:	9.6%
Supplying outlet + BS AU 145d:	5.3%
Supplying outlet + BS AU 145e:	4.1%

74.1% of the retroreflective area can be lost to "clutter". Thick film plates [5,16] further reduce radiance by 30%.

Using our image generation technique, a series of images with varying but defined levels of clutter, blur, contrast and brightness were created and presented to ANPR software. Additional noise was not considered for the initial trials.

The influence of image standard (noise) on capture rate was the main purpose of testing. Figure 12 is a visual summary of capture rate results. Decreased image standard results in decreased capture rate.

Fig. 12. Capture rate is adversely affected by reduced reflective area and reduced image standard

B. Assessment of ANPR software that can determine make model and colour

Similarly, 100 defined artificial images were presented to such software and the results are given in Table VI.

TABLE VI. CORRECT IDENTIFICATION OF MAKE MODEL AND COLOUR

	Make	**Model**	**Colour**
Correct interpretation %	80%	42%	7%

There is more work to do to hone our image creating testing software, but the potential benefits are clear. Extensive, defined and reproducible tests can be carried out quickly and at significantly reduced cost to assess and modify ANPR software before deployment in the field. The software can also be used to augment registration plate design.

VI. CONCLUSION AND FURTHER WORK

This paper demonstrates the need for a simple process of synthetic image data generation that could be used for benchmarking ANPR engines especially used for LEAs. The process has considered data sets that are noise free, number plate representations with specific types of noise including reflectance characteristics and external noise namely grime, snow and rain. Such noise is shown to be amplified with the speed of the vehicle. Their usefulness has been demonstrated by demonstrating the performance of an OCR engine that is part of an ANPR system.

Further work will involve more controlled environments that are detailed, closely defined and reproducible. This in turn will test the capability of receiver operating characteristics for specific systems. This would help to formulate an operation manual for benchmarking ANPR systems and enhance the National Police Chief's Council (NPCC) functional requirements of ANPR.

The NPCC [22] states that "ANPR is a critical law enforcement capability used to detect, deter and disrupt criminality at a local, regional and national level, including Organised Crime Groups, people traffickers, serious sexual offenders and terrorists. ANPR is also used to protect vulnerable people from harm". It is a vital tool for National Security and our technique can help to develop and improve ANPR performance.

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