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Implications of the Method of Construction of UK Number Plates for Infrared Reflectance and Camera Settings on ANPR Systems

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***Abstract*— This paper considers the implications of two aspects of number plates firstly the varied manufacturing process in the physical construction of vehicle number plates that might affect the reflectance characteristics and secondly the ANPR camera settings that affect the night time capture performance. These parameters have an effect on the overall performance of an Automatic Number Plate Recognition system. A set of controlled experiments on number plates is carried out to establish variation in the retroreflective response to illumination as well as field analysis on real world number plates.**

Keywords—ANPR, retroreflection, capture rates, capture zones

I. INTRODUCTION

ANPR is a powerful tool that has been used by police for the prevention and detection of crime as well as for safeguarding purposes. ANPR data can be linked to other data sets such as vehicle detail lists that contain all UK registration marks, make model and colour, mobile phone data, and mapping software. When this is done it is possible to derive a registration mark relating to specific criteria such as vehicles in common to particular locations, link a mobile phone to a particular vehicle or to find a vehicle when only scant details are known such as a silver van. When ANPR data is used in this way data accuracy is essential and this research contributes to that requirement.

The work is carried out as part of the UK Home Office requirement to assess the performance of ANPR systems. A specific exercise is related to the quality of number plates manufactured and their effect on the overall performance of ANPR systems. This requires a full understanding of how number plates are manufactured, the composition of superstrates that constitute the plate, a measurement of the reflectance properties of the finished product and the response of ANPR cameras when they capture the registration marks on the plate. In addition, the correct installation of ANPR cameras in regards to the correct height, angle of focus, capture zone, including the number plate quality are key performance factors in determining capture rates. In this work, we consider some of these aspects in detail.

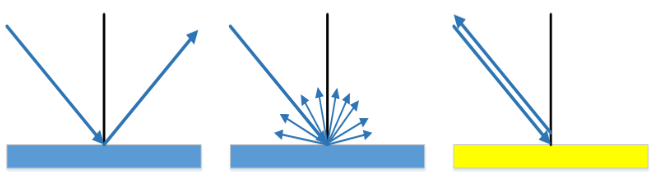
The rest of the paper is organised as follows: In Section II, the concept of retroreflective number plates and the UK legislative requirements is introduced. In Section III, an experimental set up is described that enables reflectivity response characteristics of a set of number plates. From this experiment, we can infer the quality of plates manufactured. In Section IV, the effect of camera settings on the ANPR capture rates along with guidelines for optimal settings for effective capture is suggested. Section V provides a conclusion to the work and suggestions for further work.

II. BACKGROUND

a) Retroreflective Number Plates

Retroreflective number plates were introduced in the UK at the end of 1972. Retroreflection causes the retroreflective layer to appear brighter than surrounding objects and thus easier to see when the illuminating source and receiver are close together.

Retroreflection is caused by special materials whereby the surface is covered in hundreds of tiny glass hemispheres which cause light to be reflected back to the source. For normal plane surfaces the reflected angle equals the angle of incidence [1]. Fig. 1 indicates the difference in reflective properties between specular, diffuse and retroreflective surfaces.



(a) Specular *(b) Diffuse* *(c) Retroreflective*

Fig. 1 Types of Reflectance

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Retroreflective materials stand out and are almost always easier to see in almost all lighting conditions where the source of light and the observer are close together. Under normal circumstances a number plate is much easier to read because of the contrast between the black lettering and the white (or yellow) number plate sheet. In daylight at normal camera angles the retroreflectivity of a number plate will not be such an important factor as the illumination will be a combination of all direct and indirect sunlight as well as diffuse sky radiation. At night time or in poorly lit conditions the retroreflective properties of the number plate become more significant. The point source illumination from the ANPR camera and the properties of the retroreflective number plate will reflect a proportion of the incident beam back along the incident path back to the camera. Illuminators are usually co-located with the camera such that the source of illumination and the observer (camera) are close together.

For practical purposes, it is assumed the day time illumination in the ANPR capture zone is constant (Fig. 2); however for night time, the illumination is much less intense and will depend on the distance of the vehicle from the camera and its co-located illuminator (Fig. 3).

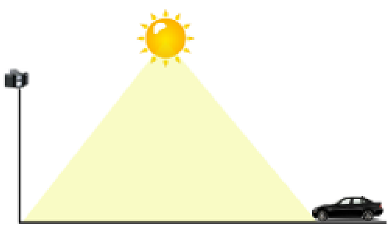


Fig. 2 Daytime Illumination Surrounding ANPR Zone

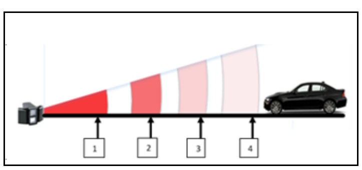


Fig. 3 Night time Point Source Illumination

b) Reflective Properties of a Manufactured Plate

UK number plates have black lettering on a white or yellow retroreflective layer. The retroreflective properties are achieved by depositing a layer of tiny refractive spheres (or small pyramid like structures) onto the number plate sheet. In both cases, internal reflection causes the light to be reflected back towards the point of origin. Perfect retroreflection is not desired as the light would be directed back into the headlights of an oncoming vehicle rather than towards the driver's eyes.

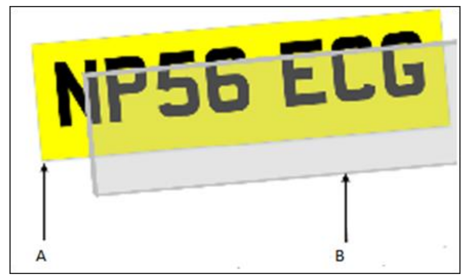
c) Number Plate Construction

UK number plates are normally made from composite layers and then pressed together to form a fabricated item. There are two broad types of construction [2] as shown in Fig. 4 **Two Types of Composite Plates (a) Thick Film (b) Thin Film**

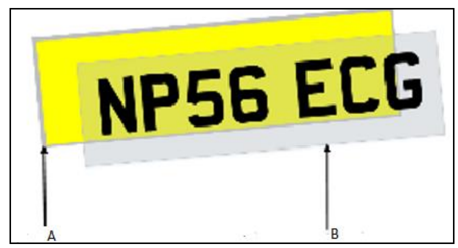
. One method is where the registration mark is behind a rigid transparent 3.2mm acrylic or perspex sheet, as indicated in Fig. **4 Two Types of Composite Plates (a) Thick Film (b) Thin Film**

4a. The other method is where the registration mark is behind a thin plastic film and then attached on top of a rear rigid plastic layer as indicated in Fig. 4 **Two Types of Composite Plates (a) Thick Film (b) Thin Film**

4b. In these cases, the thick film is made up of a 3.2mm acrylic or perspex sheet whilst the thin film is composed of polyethylene terephthalate (PET) sheet.



(a) Thick Film Number Plate Construction. A indicates characters printed on retroreflective film. B is a transparent self adhesive 3.2mm acrylic/perspex sheet



(b) Thin Film Based Number Plate Construction. A is a self adhesive retroreflective film attached to rigid plastic sheet. B indictes Registration marks printed on rest of the film

Fig. 4 Two Types of Composite Plates (a) Thick Film (b) Thin Film

d) Legislative Requirements

The requirement for UK vehicles to display registration marks (number plates) became compulsory on 1 January 1904 following the introduction of the Motor Car Act 1903. The Act was introduced such that vehicles could be traced in the event of an accident or contravention of the law. Current UK legislation, *The Road Vehicles Regulations 2001* (Display of Registration Marks), which incorporates the British Standard BS AU 145d (currently being revised) defines all aspects of a UK number plate.

e) Number Plate Reflectance Conformance

The manufacturing process is required to conform to the maximum and minimum reflectance properties set by the British Standard. For instance, the white number plates need to maintain consistent contrast levels between the characters and background layer in the range 380nm–1,000nm. Yellow number plates need to maintain consistent contrast levels between the characters and background layer in the range 550nm-1,000nm. There is no significant contrast between 380nm-550nm for black characters and the yellow backing layer. However, in the real world, number plates may not

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necessarily conform to the standard due to the variation in the manufacturing process.

III. Experimental Analysis on Reflectance of Number Plates

In order to establish a systematic way to assess the quality of number plates, a controlled experimental set up is considered.

a) Experimental Setup

Measuring the reflectivity and optical contrast of registration plates is a straightforward task provided the instruments, optical configuration, and calibration are combined in a robust experimental design. The Applied Optics and Polarimetry Laboratory at the University of Hertfordshire uses a fibre-optic coupled spectrometer (Ocean Optics HR4000) as the basic measuring instrument for selected areas of the registration plate as shown in the schematic in Fig. 5 Optical **Bench Setup (b) Thin Film**

Note that this technique does not image the entire plate. The spectrometer acts as the light sensor coupled with a broad spectrum (UV, visible, NIR) halogen lamp source (Thorlabs OTH10). In the simplest tests the registration plate is mounted such that the light source and fibre sensor are held in a fixed geometry to illuminate and measure the light reflected from the plate. An optical bench provides a stable base to hold the plate, the light source, and the fibre sensor firmly while varying distances and angles as appropriate for the test measurements. A calibration standard Lambertian white reflector (Spectralon) is used to establish the relative reflectivity of selected areas of the plate. Conversion to absolute values of reflectivity are straightforward but relative reflectivity is the most useful measurement of the plate. Contrast between the background plate and the letters and numbers and retroreflectivity are easily measured with the same setup by simple changes in the geometry of the measurement configuration. Specialist measurements with narrow band (laser, LED) sources can examine the qualities of the plate in more detail in the same experimental setup.

b) Number Plate Reflectance Variance Analysis

A set of number plates were subjected to the spectroscopy analysis from which reflectance response curves are plotted. A vehicle's front plate has white background and 20 such plates were analysed in the spectrum of 400-1,000nm [1]. The results indicate a broad spectrum of reflectance as well some unexpected divergence in the near infrared spectrum above 850nm as shown in Fig. 6 .

c) Thick and Thin Film Reflectance Variance

In the experiment above, both thick and thin films were used to determine their reflectance characteristics. The results revealed a broad but consistent spread of reflectance between 400nm-825nm. After about 825nm the red and blue bands diverge. Thin films (blue curves) show higher reflectance compared to thick films (red curves) as shown in Fig. 7 Reflectance Categorisation **Based on Thick and Thin Films**

Fig. 7 Reflectance Categorisation Based on Thick and Thin Films

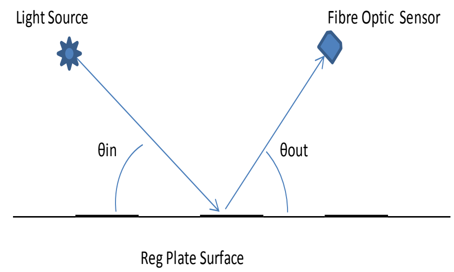

Fig. 5 Optical Bench Setup (b) Thin Film

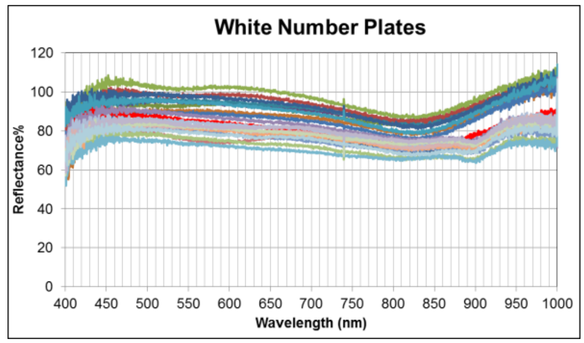

Fig. 6 Reflectance Response of 20 Front Number Plates

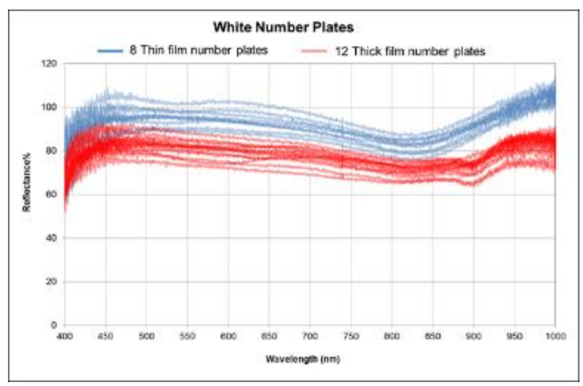

Fig. 7 Reflectance Categorisation Based on Thick and Thin Films

Acrylic, Perspex and polyethylene terephthalate have different physical and optical properties [6], [7]. Key properties that vary within and across these plastics include refractive index, turbidity, transmissivity, absorbance and resonance at wavelengths between 380 – 1,000nm. Near infrared (NIR) can used to differentiate different plastics [8].

The results shown in Fig. 7 Reflectance Categorisation Based on Thick and Thin Films

All contrast ratios for thick and thin film number plates demonstrated the same general form or shape but had variable contrast ratios when comparing different number plates. Thick film plates gave variable contrast ratios whereas thin film plates gave significantly variable contrast ratios. This is an

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aspect where we hope to conduct further research such that number plates with consistent optical properties can be defined,

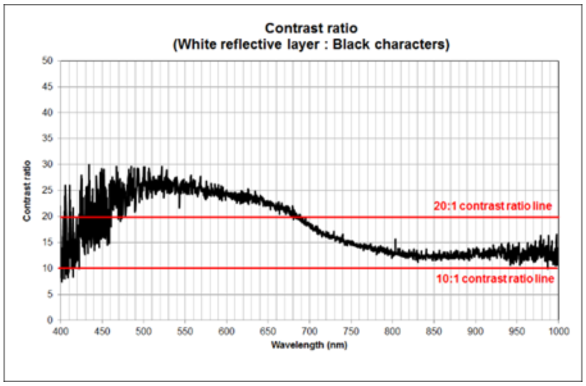

Fig. 8 Contrast ratio of the reflectance of the white layer with respect to the black characters

d) Field Trial Analysis

Reflectance results demonstrated that thick and thin film number plates have different but distinguishing reflectance profiles. There can be up to 30% variance in reflectance. A review of single lane captures for the same ANPR camera over a 15 minute period on the same day and under the same conditions indicated a range of brightness and contrast for the 250 number plate images examined.

e) Camera Setup: A Possible Issue

One issue related to the NP reflectance in the real world could emanate from the camera setup. For example, for cameras set up in the near infrared range, the reflectance could be attenuated Fig. 6 and Fig. 7. The image in this case would be too dark to be captured, therefore resulting in a failed capture or missed reads. Hence the authors set to analyse this aspect through an experimental set up described in Section IV which considers aspects of camera settings including the height of the camera, the performance of the camera's illuminator, and number plate properties.

IV. Influence of Camera Settings on ANPR Performance

In this section, the influence of some of the settings of an ANPR camera are considered to understand how they affect the system performance. The impact of the optical properties of a number plate as a vehicle approaches the camera is considered. The impact of the optical properties typically do not change significantly during the day time because of the increased intensity of natural sunlight. However, this situation varies significantly for night time captures where infrared intensity is very much reduced.

a) Approaching Vehicle and Illumination Incidence Angle

As a vehicle approaches an ANPR camera the illuminator's light incident angle increases. For an ANPR camera's collocated IR illuminator a smaller proportion of the incident energy will be returned towards the source. There is a significant difference between daylight and point source IR illumination. In broad terms, illumination can be considered much more powerful and constant during the day. That is, as a vehicle approaches the camera the illuminating energy remains constant. Fig.2 demonstrates uniform powerful illumination. The greatest retroreflectance is when the incident beam is perpendicular to the number plate. As the incident (entrance) angle of the beam increases the energy reflected decreases.

b) The British Standard for Number Plates and Reflectance Conformance

The British Standard[10] CiE retroreflectivity [10] are incorporated in the Statutory Instrument for number plates[12] which specifies the physical and optical properties of a number plate with respect to the retroreflective layer as shown in Table 1.

Table 1 British Standard Specification for Minimum Reflectance Requirement

Minimum coefficient of retroreflection, ρ				
Colour	Observation angle	Entrance angle		
		5°	30°	45°
		cd/lx per square metre		
White	0° 12'	60	25	6
	0° 20'	40	14	3
	1° 30'	4	2	0.7
Yellow	0° 12'	40	18	4
	0° 20'	30	10	2
	1° 30'	3.5	1.5	0.5

c) Optimum Distance Capture

A vital factor in setting up an ANPR system which performs well is ensuring that the capture zone i.e. the optimum distance from the camera to the target vehicle for the infrared illumination used, is properly calculated. The factors that must be taken into consideration are camera height and infra-red power/range of the camera. One must also consider that the start of a capture zone will be an arc from the camera rather than a straight line across the road from the pavement. A standard set up for a camera is as shown in Fig. 9. The start of capture is triggered at 23m from the camera which is the same distance from the IR illuminator on the camera. This is a sufficiency capture zone. The overall capture zone lies between 18-23 m away from the camera.

If there is a need to increase the position of the camera (height), then capture zone distances will need to be adjusted proportionately. A camera may need to be raised to reduce the impact of vehicle size on obscuration of other vehicles (tailgating).

Several field trials on ANPR camera settings were carried out [15], [15] by the same authors to establish that incorrect camera installations led to poor capture rates ranging from 5%-60% for the cameras tested. These were worse during the rush hour in dark October evenings than they were during bright June evenings.

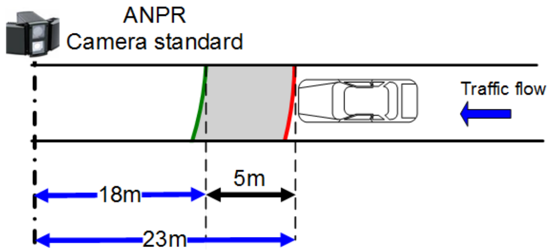

Fig. 9 Standard Camera Set Up

In the real world, camera installers can fail to understand the relation between the camera height and the capture zone fully. The ANPR camera is simply set up visually. It's a common misunderstanding that an ANPR camera can see as well at night as it can during the day because it has an IR illuminator.

d) Camera Set up Guidelines

Based on several iterations of the camera set up experiment, a set of guidelines have been drawn. A brief set of steps is provided here.

1) Decide on the capture zone (d_1, d_2)
2) Mark the road to indicate capture zone (red d_1 and green for d_2) with arcs in Fig.9.
3) Adjust camera position p_1 and alignment (pitch, θ and yaw, Ψ); verify if it captures in the marked zone. This ensures correct illumination level when solely reliant on camera's IR illuminator.
4) Ensure correct incidence angle α at the position p_1 set up in step 3.
5) Repeat until optimal.
6) Review 300 consecutive vehicles passing the camera to determine capture rate.

V. CONCLUSION

In this paper, we consider the two main criteria that influence the real world performance of ANPR systems, particulalry for law enforcement applications. These relate to the quality of the manufactured number plates and the set up of camera parameters for improved capture rates. Fundamental analysis through lab experiments have been used to demonstrate the concept which have also been verified through extensive Police field trials. A basic set of guidelines have been proposed that are easy to adopt by manufacturers and installers.

In the future, rigorous mathematical formulation is proposed to establish the various physical properties of number plates and their effect on ANPR performance metrics.

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