

Experimental Optimization of Camera Placement for a Raspberry Pi-Based ANPR Smart Gate System

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ABSTRACT

Camera geometry directly affects the responsiveness of embedded automatic number plate recognition systems, yet installation parameters are often selected without controlled evaluation. This study investigates the effects of camera distance, horizontal angle, and mounting height on a Raspberry Pi 5-based smart gate prototype. The system combines a Razer Kiyo X webcam, OpenCV preprocessing, Tesseract optical character recognition, whitelist classification, and an SG90 servo motor for gate actuation. Three one-factor experiments were conducted under adequate outdoor lighting using a standard Malaysian license plate. Five distances from 1.0 to 3.0 m, five angles from 0 to 40 degrees, and six heights from 70 to 120 cm were evaluated with ten trials per setting. Mean detection time increased from 1.34 s at 1.0 m to 3.55 s at 3.0 m, although all distance trials were classified accurately. Increasing the angle had the largest effect: mean time rose from 1.38 s at 0 degrees to 6.84 s at 40 degrees, where all ten classifications were unsuccessful. Increasing camera height improved mean time from 1.83 s at 70 cm to 1.44 s at 120 cm, with successful classification throughout. Considering response, visibility, and installation practicality, the recommended configuration is 1.5-2.0 m distance, 0-degree alignment, and 120 cm mounting height. The findings provide experimental guidance for deploying low-cost ANPR access control.

Keywords: automatic number plate recognition, camera placement, embedded vision, Raspberry Pi, smart gate

INTRODUCTION

Automatic number plate recognition (ANPR) provides contactless vehicle identification for parking, gated communities, and controlled premises [1], [6], [14]. Compared with remote controls, keypads, or transferable cards, a plate-based system can link access decisions to the approaching vehicle and create an image record of each event. Affordable embedded computers further allow image acquisition, recognition, decision-making, and actuator control to be integrated within a compact installation.

ANPR performance nevertheless depends on the quality and geometry of the captured plate. Classical pipelines rely on preprocessing, edge or contour detection, region isolation, and optical character recognition [3], [5], [10]. Deep-learning detectors can increase robustness [2], [4], [8], [11], [13], [15], but camera placement remains important because distance reduces plate pixel density and oblique angles distort character shapes. Large shooting angles have been specifically identified as a challenge for plate recognition [9].

The source thesis developed a Raspberry Pi-based automatic gate and tested its response under changes in distance, angle, and height. This paper reorganizes those results as a focused installation study. Its objective is to quantify how the three placement variables affect detection time and observed classification success, then derive a practical camera configuration for a low-cost residential smart gate. The contribution is an experimentally grounded placement guideline based on 160 timed trials rather than a general description of the prototype.

System Architecture

Hardware configuration

The system comprises a Razer Kiyo X USB webcam, a Raspberry Pi 5, and an SG90 servo motor. The webcam supplies the real-time video stream; the Raspberry Pi executes image processing, OCR, classification, logging, and control logic; and the servo represents the gate actuator. A 3D-printed enclosure houses the processing and camera assembly, while a small mechanical gate prototype demonstrates the open-close sequence.

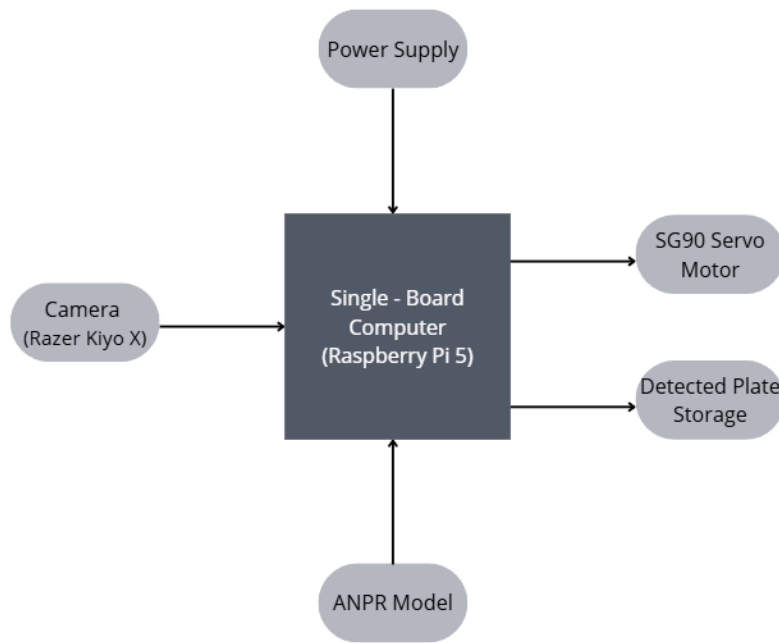


Figure 1: Block diagram of the embedded ANPR gate system.

Table 1: Core prototype components and roles.

Component	Specification in prototype	Function
Camera	Razer Kiyo X webcam with ring light	Captures the approaching vehicle and license plate.
Processor	Raspberry Pi 5	Runs OpenCV, OCR, authorization logic, logging, and control.
Actuator	SG90 servo motor, 180-degree PWM control	Simulates gate opening and closing.
Software	Python, OpenCV, Pytesseract, gpiozero, NumPy	Implements vision processing and hardware control.

Recognition and gate-control pipeline

At startup, the program verifies camera availability and attempts to initialize the servo. The live stream is then sampled by processing every third frame to reduce computational load. Each selected frame is converted to grayscale, filtered for noise, and processed for strong edges. Quadrilateral contours are treated as candidate plates; the selected region is cropped and enhanced before Tesseract OCR is applied.

The OCR output is restricted to uppercase letters and digits, cleaned, and accepted only when its length falls within the expected range of six to eight characters. The resulting string is compared against a predefined authorized list. A matching plate is labelled Staff and triggers the servo; a non-matching plate is labelled Outsider and leaves the gate closed. In both cases, the cropped plate image is saved with the plate string, classification, and timestamp. A cooldown period prevents a stationary vehicle from repeatedly triggering the gate.

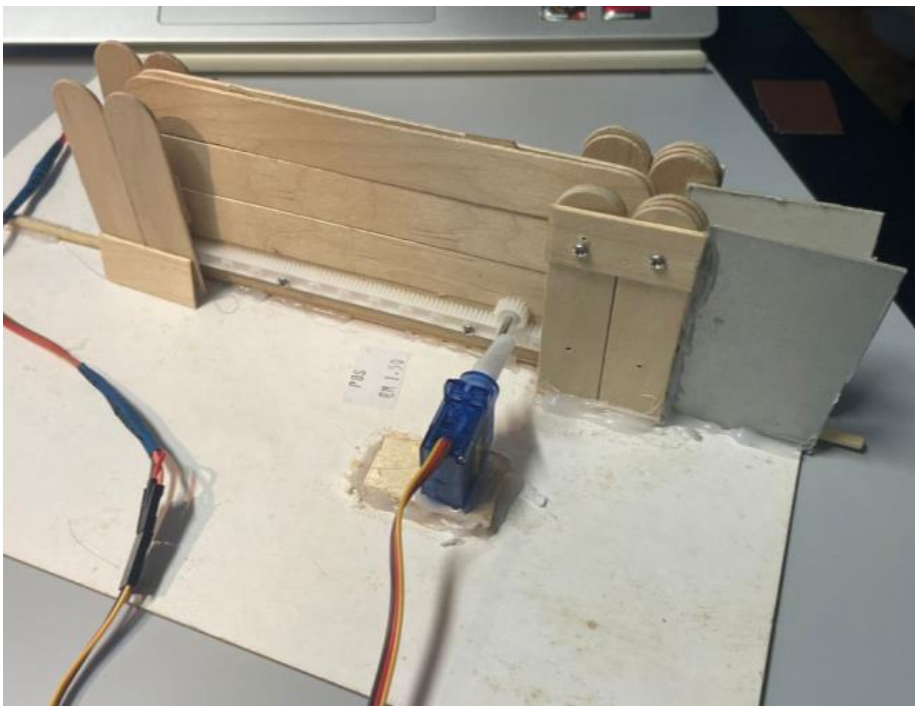


Figure 2: Mechanical gate prototype driven by the SG90 servo motor.

EXPERIMENTAL METHODOLOGY

Test design

Three one-factor tests were performed. In the distance test, camera-to-vehicle separation varied from 1.0 to 3.0 m while the camera remained at 0 degrees and 120 cm. In the angle test, horizontal alignment varied from 0 to 40 degrees while distance and height remained at 2.0 m and 120 cm. In the height test, mounting height varied from 70 to 120 cm while distance and angle remained at 2.0 m and 0 degrees. Each setting was repeated ten times, producing 50 distance trials, 50 angle trials, and 60 height trials.

Table 2: Experimental factors and controlled conditions.

Factor	Levels	Controlled conditions	Trials
Distance	1.0, 1.5, 2.0, 2.5, 3.0 m	0 degrees; 120 cm height	10 per level

Angle	0, 10, 20, 30, 40 degrees	2.0 m distance; 120 cm height	10 per level
Height	70, 80, 90, 100, 110, 120 cm	2.0 m distance; 0 degrees	10 per level

Measurements and analysis

Detection time was recorded in seconds for each trial. The thesis also labelled each OCR result as Accurate or Not Accurate relative to the target plate. For the present paper, the raw times were used to calculate the arithmetic mean and sample standard deviation at every setting.

Classification success is reported as the number of Accurate trials divided by ten. This analysis preserves the original test observations while adding a consistent measure of trial-to-trial variation.

The tests were performed in adequate outdoor lighting with a visible, standard Malaysian plate. Consequently, the results characterize the tested prototype and placement range; they do not establish performance for night operation, rain, fog, damaged plates, non-standard fonts, multiple vehicles, or plates outside the tested field conditions.

RESULTS AND DISCUSSION

Effect of camera distance

All 50 distance trials were classified as Accurate. Mean detection time was lowest at 1.0 m (1.34 s) and rose gradually to 1.39 s at 1.5 m, 1.50 s at 2.0 m, and 1.88 s at 2.5 m. At 3.0 m, mean time increased sharply to 3.55 s. Relative to 1.0 m, the 3.0 m response was approximately 165% slower. The increase is consistent with reduced plate size and pixel density at longer range, which makes contour localization and OCR more demanding.



Figure 3: Field arrangements at the nearest and farthest tested distances.

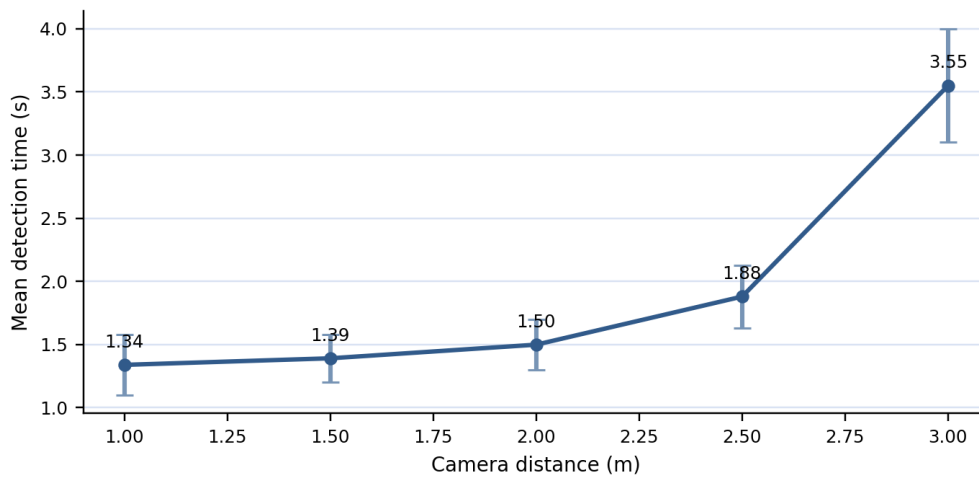


Figure 4: Mean detection time versus camera distance; error bars show sample standard deviation.

Table 3: Distance-test summary.

Distance (m)	Mean time (s)	SD (s)	Accurate trials
1.0	1.34	0.24	10/10 (100%)
1.5	1.39	0.19	10/10 (100%)
2.0	1.50	0.20	10/10 (100%)
2.5	1.88	0.25	10/10 (100%)
3.0	3.55	0.45	10/10 (100%)

Although 1.0 m produced the fastest numerical mean, the thesis recommends 1.5-2.0 m as the practical range. This range retains a short 1.39-1.50 s response while providing more clearance between the vehicle and fixed gate hardware. The 2.5-3.0 m region remains functional in the tested lighting but introduces progressively longer response time.

Effect of camera angle

Angle produced the strongest performance change. Mean detection time increased from 1.38 s at 0 degrees to 1.70 s at 10 degrees, 3.05 s at 20 degrees, and 4.22 s at 30 degrees. All ten trials at each of these four settings were labelled Accurate. At 40 degrees, mean time reached 6.84 s and all ten trials were labelled Not Accurate. Compared with perpendicular alignment, the 40-degree condition increased mean processing time by approximately 396% and eliminated successful classification in this test.



Figure 5: Camera alignment at 0 degrees and 40 degrees.

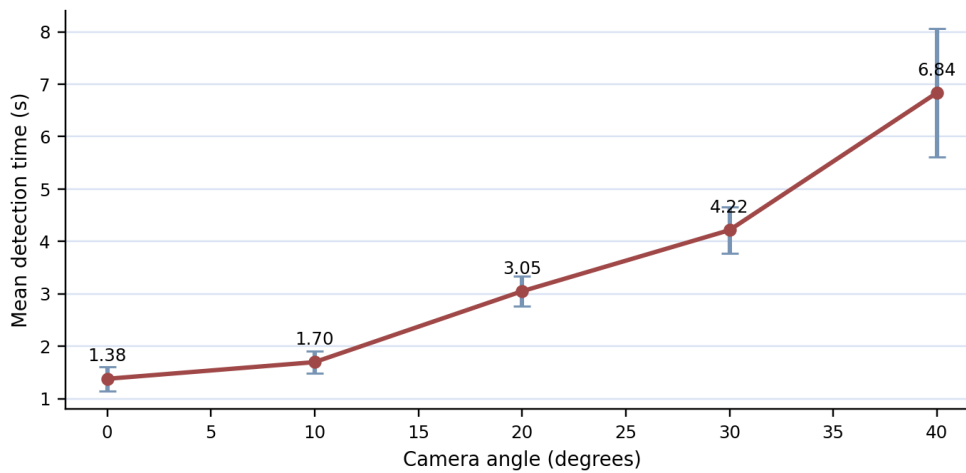


Figure 6: Mean detection time versus camera angle; error bars show sample standard deviation.

Table 4: Angle-test summary.

Angle (degrees)	Mean time (s)	SD (s)	Accurate trials
0	1.38	0.23	10/10 (100%)
10	1.70	0.21	10/10 (100%)
20	3.05	0.28	10/10 (100%)
30	4.22	0.45	10/10 (100%)
40	6.84	1.22	0/10 (0%)

The trend is attributable to perspective distortion: an oblique rectangular plate becomes trapezoidal, characters narrow unevenly, and reflections or partial occlusion become more influential. These effects complicate both contour filtering and OCR [9]. The results therefore support mounting the camera as close to perpendicular to the plate as the gate layout permits.

Effect of camera height

All 60 height trials were labelled Accurate. Mean time decreased from 1.83 s at 70 cm to 1.78 s at 80 cm, 1.66 s at 90 cm, 1.64 s at 100 cm, 1.53 s at 110 cm, and 1.44 s at 120 cm. The 120 cm setting was approximately 21% faster than the 70 cm setting. Higher placement provided a clearer view of the plate and reduced the upward viewing angle, shadowing, and interference from ground-level objects in the test arrangement.

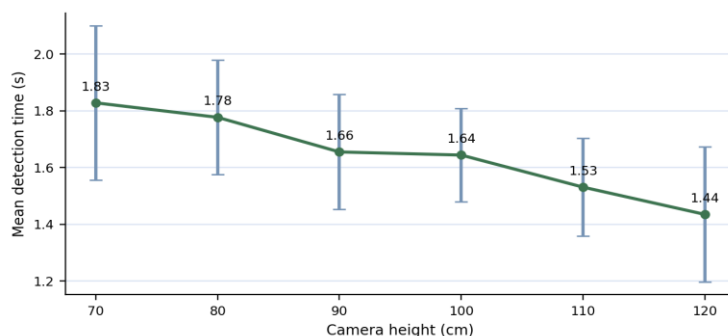


Figure 7: Mean detection time versus camera height; error bars show sample standard deviation.

Table 5: Height-test summary.

Height (cm)	Mean time (s)	SD (s)	Accurate trials
70	1.83	0.27	10/10 (100%)
80	1.78	0.20	10/10 (100%)
90	1.66	0.20	10/10 (100%)
100	1.64	0.17	10/10 (100%)
110	1.53	0.17	10/10 (100%)
120	1.44	0.24	10/10 (100%)

Recommended installation configuration

Taken together, the experiments indicate that angular alignment is the most critical placement variable within the evaluated range. Distance becomes a major response-time penalty at 3.0 m, while increasing height produces a smaller but consistent improvement. The recommended field configuration is therefore a camera distance of 1.5-2.0 m, a 0-degree horizontal angle, and a mounting height of 120 cm. Under the corresponding tested settings, mean detection times were approximately 1.39-1.50 s for the preferred distance range, 1.38 s at 0 degrees, and 1.44 s at 120 cm, with all associated trials labelled Accurate.

This recommendation is an installation guideline rather than a globally optimized operating point because the variables were tested independently, not as a full factorial experiment. The exact combination of 1.5 or 2.0 m, 0 degrees, and 120 cm was not repeated as a separate joint validation series. A future factorial design should measure interactions among distance, angle, height, illumination, vehicle speed, and plate type.

Operational Reliability and Limitations

The software includes several defensive responses needed for unattended operation. If the camera is unavailable, the program reports the fault and exits instead of operating without visual input. If the servo cannot initialize, plate detection continues in a detection-only mode. Frames with no plate contour are skipped without interrupting the preview. Unrecognized plates are saved with an Outsider label, repeated detections are suppressed during the cooldown interval, and the Q command releases the camera and closes the display cleanly.

Table 6: Implemented responses to common runtime conditions.

Condition	System response	Outcome
Camera unavailable	Display error and exit safely	No uncontrolled operation
Servo unavailable	Warn and continue detection	Detection-only mode
No plate contour	Skip OCR and process next frame	Stable preview
Unknown plate	Save image with Outsider label	Gate remains closed

Repeated plate	Suppress gate action during cooldown	Duplicate trigger avoided
Manual Q command	Release camera and close windows	Clean shutdown

The principal limitations are inherited from the thesis scope. The experiments used adequate lighting and a clear standard plate; performance may decline at night, in adverse weather, or with damaged, obscured, custom, or highly reflective plates. Tesseract and contour-based localization are sensitive to skew and contrast. The authorization list is manually maintained, the prototype does not address simultaneous vehicles, and its access log stores plate information that should be governed by appropriate retention and privacy controls in a real deployment.

CONCLUSION

This paper evaluated camera placement for an embedded ANPR smart gate using 160 timed trials. Distance testing showed that mean response increased from 1.34 s at 1.0 m to 3.55 s at 3.0 m. Angle testing produced the most severe degradation, increasing from 1.38 s at 0 degrees to 6.84 s at 40 degrees; the 40-degree trials were all unsuccessful. Height testing improved from 1.83 s at 70 cm to 1.44 s at 120 cm. Based on performance and installation practicality, a 1.5-2.0 m distance, perpendicular camera alignment, and 120 cm mounting height are recommended for the tested prototype. The conclusion is limited to the reported plate, hardware, lighting, and stationary test conditions. Future work should validate the combined configuration, add low-light illumination, compare modern recognition models, and evaluate moving vehicles and diverse Malaysian plates.

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REFERENCES

1. M. Y. Aalsalem, W. Z. Khan, and K. M. Dhabbah, "An automated vehicle parking monitoring and management system using ANPR cameras," 2015.
2. R. Al-Batat, A. Angelopoulou, S. Premkumar, J. Hemanth, and E. Kapetanios, "An end-to-end automated license plate recognition system using YOLO based vehicle and license plate detection with vehicle classification," *Sensors*, vol. 22, no. 23, p. 9477, 2022.
3. I. Astawa, I. G. N. B. Caturbawa, I. M. Sajayasa, and I. M. A. D. S. Atmaja, "Detection of license plate using sliding window, histogram of oriented gradient, and support vector machines method," *Journal of Physics: Conference Series*, vol. 953, p. 012062, 2018.
4. N. Awalganekar, P. Bartakke, and R. Chaugule, "Automatic license plate recognition system using SSD," in *2021 International Symposium of Asian Control Association on Intelligent Robotics and Industrial Automation*, 2021, pp. 394-399.
5. T. D. Duan, T. L. H. Du, T. V. Phuoc, and N. V. Hoang, "Building an automatic vehicle license-plate recognition system," in *International Conference in Computer Science - RIVF*, 2005, pp. 59-60.
6. I. S. Eltoum and Z. Xue, "Automatic gate control system based on vehicle license plate recognition," *International Journal of Engineering Research & Technology*, vol. 3, no. 8, 2014.
7. "Implementation of intelligent automated gate system with QR code - an IoT system to help gate management," *International Journal of Advanced Computer Science and Applications*, vol. 9, no. 10, pp. 359-360, 2018.
8. T. Islam and R. I. Rasel, "Real-time Bangla license plate recognition system using Faster R-CNN and SSD: A deep learning application," in *2019 IEEE International Conference on Robotics, Automation, Artificial-intelligence and Internet-of-Things*, 2019, p. 108.
9. H. Kuchuk, A. Podorozhniak, N. Liubchenko, and D. Onischenko, "System of license plate recognition considering large camera shooting angles," *Radioelectronic and Computer Systems*, no. 4, pp. 82-91, 2021.

10. A. Puranic, D. K. T., and U. V., "Vehicle number plate recognition system: A literature review and implementation using template matching," *International Journal of Computer Applications*, vol. 134, no. 1, pp. 12-13, 2016.
11. P. S. Puri and P. P. Bartakke, "SSD based vehicle number plate detection and recognition," in *2023 International Conference on Network, Multimedia and Information Technology*, 2023, pp. 1-6.
12. H. Saghaei, "Proposal for automatic license and number plate recognition system for vehicle identification," in *2016 1st International Conference on New Research Achievements in Electrical and Computer Engineering*, 2016.
13. R. Shashidhar, A. S. Manjunath, R. S. Kumar, M. Roopa, and S. B. Puneeth, "Vehicle number plate detection and recognition using YOLO-V3 and OCR method," in *2021 IEEE International Conference on Mobile Networks and Wireless Communications*, 2021, pp. 1-5.
14. N. L. Yaacob, A. A. Alkahtani, F. M. Noman, A. W. M. Zuhdi, and D. Habeeb, "License plate recognition for campus auto-gate system," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 21, no. 1, p. 128, 2021.
15. Z. Yang, F. Du, Y. Xia, C. Zheng, and J. Zhang, "Automatic license plate recognition based on faster R-CNN algorithm," in *Lecture Notes in Computer Science*, 2018, pp. 319-326.