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AR Training for Automotive Repair Paint Inspection: Development and Evaluation

Yuka Takai *, Shigeru Ikemoto †

Abstract

This study presents the development and evaluation of an augmented reality (AR) training application (app) aimed at improving skills in automotive paint inspection. Although the accurate assessment of paint finish quality is essential in automotive repair, opportunities for conventional training are often limited. To address this gap, we developed a prototype AR app that simulates visual inspection tasks. The prototype AR app was subsequently evaluated by two experts and one novice, with a focus on usability and perceived effectiveness. Although participants experienced minor difficulties with camera handling, they recognized the potential of the app to support skill development. Experts' feedback emphasized the need for enhanced realism in the representation of paint textures. Overall, preliminary findings indicate that the AR app is a promising supplementary tool that can be used in conventional training methods during automotive-repair paint inspection.

Keywords: Automobile repair painting, Metallic paint, AR training application, Paint inspection

1 Introduction

Automotive-repair painting involves reapplying paint to vehicle bodies damaged in accidents or other incidents, with the goal of restoring the original finish. Automobile paints often contain aluminum, mica, and other reflective components. This study focuses on metallic paints that contain aluminum particles (flakes). A key characteristic of metallic paint is its angle-dependent brightness, whereby its appearance changes depending on the viewing angle, as illustrated in Figure 1 [1]. This phenomenon becomes particularly complex in repair painting. When the orientation of aluminum

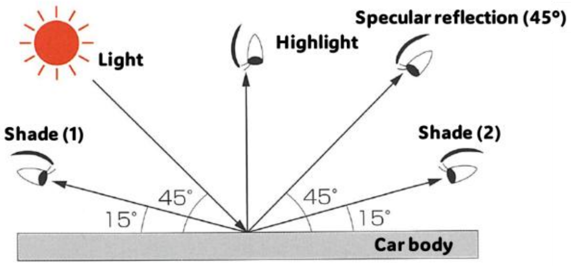


Figure 1: Schematic of the angle-dependent appearance of metallic paint on a car body surface.

* Osaka Sangyo University, Osaka, Japan
† Body Garage Ikemoto, Shiga, Japan

flakes in the newly applied paint film differs from that in the original surrounding paint, subtle color variations known as "paint mottling" may occur. Paint mottling is generally absent when technicians possess strong spray gun operation skills and an understanding of paint properties and often occurs with novice technicians. Although a repaired area may appear to match the original color when viewed directly (that is, head-on), it may look significantly lighter or darker when observed from an oblique angle.

Visual inspection for paint mottling requires careful consideration of both the light source direction and observation angle [2]. Identifying mottling poses a significant challenge for novices and typically requires extensive experience. Furthermore, because the visibility of mottling strongly depends on the type of light source, incident angle, and viewing angle, accurately capturing it in photographs or videos is challenging. Consequently, direct visual inspection remains the most effective method for detection.

Augmented reality (AR) technology, which overlays digital information onto real-world views, offers promising solutions for technical training. Previous studies have reported that AR can: (1) provide safe and cost-effective environments for practicing operations that are hazardous or expensive [3], and (2) display procedural guidance and highlight critical steps in real-time during tasks [4]. These capabilities suggest that AR can enhance skill acquisition while addressing issues such as workforce shortages and the challenge of transferring expert knowledge.

The conventional method for practicing paint-finish inspection involves observing several real-world repair cases. However, acquiring sufficient experience across a wide range of successful and unsuccessful repairs is time-intensive.

Prior research on automotive-repair-painting techniques has identified behavioral differences between skilled and unskilled workers [5]. Skilled technicians inspect the repair from both close and distant perspectives, simulating a customer's viewpoint by examining the area from various angles and distances. This allows them to visually assess how well the repaired section blends with the adjacent original paint in terms of gloss and color uniformity, including the detection of mottling.

By leveraging AR technology and a 3D model of a vehicle, it is possible to simulate paint mottling intentionally and flexibly. We hypothesized that an AR application (app) incorporating such a simulation could provide an accessible platform for users to practice paint inspection techniques regardless of time or location. Therefore, the primary objective of this study is to develop an AR app for automotive-repair paint-finish inspection and evaluate its effectiveness in improving users' ability to identify paint mottling.

2 App Development and Deployment

An AR app, called "Repair Paint Checker," was developed to simulate the inspection of automotive-repair paint finishes. The application takes the form of a game in which users must identify paint mottling randomly placed in one of the four corners of a car door panel displayed within an AR environment.

The app was developed for the iOS platform, considering the devices most commonly used by young automotive-repair technicians in Japan. Leveraging data from prior research [5], the app dynamically alters the paint color appearance based on the user's viewing angle and distance from the virtual panel. Lighting conditions within the app were configured to simulate outdoor daylight under clear skies.

Figure 2 shows the title screen of the AR app. Upon launching the app and selecting a difficulty level (EASY or HARD), users proceed to the plane detection screen (Figure 3), where the device's camera captures the surrounding environment. Once a suitable horizontal surface (such as the floor) is detected, the virtual vehicle body is rendered in the AR view, initially positioned to be seen from the left side (Figure 4). In the gameplay interface shown in Figure 4, tapping the gear icon in the top-left corner of opens the options menu, while tapping the time icon in the top-right corner opens the results interface. Buttons in the bottom-left corner allow users to slide the camera position by sliding up/down or left/right, while the bottom-right button lets users rotate the camera orientation.

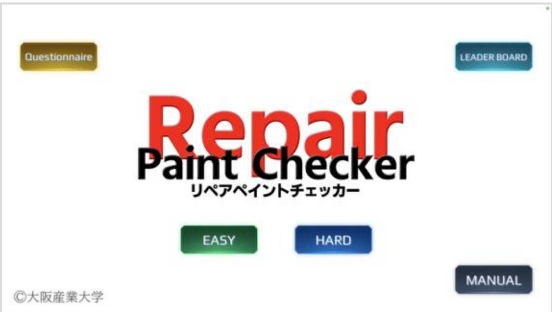


Figure 2: Title screen of the AR app

Figure 3: Plane detection screen

Figure 4: Gameplay interface displaying the virtual vehicle within the AR environment, with paint mottling defects (example: green sphere indicates correct identification, red sphere indicates user selection), timer, and viewpoint adjustment controls

Users can adjust the viewpoint in all directions—horizontally, vertically, and front/back—using on-screen controls. Alternatively, users can physically move around to change their viewpoint if sufficient space is available. The movement buttons also allow users to rotate the vehicle itself.

Once the vehicle body appears, a countdown timer of 3-min begins in the top-right corner of the screen. If the timer reaches zero before the task is completed, a "Time Out" screen is displayed (Figure 5). Each door of the vehicle (front and rear, left and right) features randomly positioned paint mottling in one of its four corners, as illustrated in Figure. 6.

Figure 5: "Timeout" notification displayed when the user fails to identify all defects within the 3-min time limit

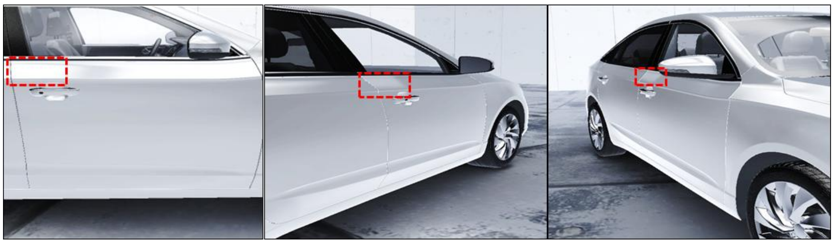


Figure 6: Example of one paint mottling from three directions

To mark a suspected mottling location, users tap the area on the door panel. A red sphere appears at the selected point as a marker (Figure 4). If the user wishes to revise a selection, the sphere can be removed by tapping it again. Users can check their accuracy at any time by tapping the timer icon, which opens the results interface. Incorrect selections remain red, whereas correct locations change to green, and the gameplay resumes (Figure 4).

When all mottling spots are correctly identified, a "Round Clear" screen appears (Figure 7), showing the number of incorrect attempts, the time remaining, and the score for the round before proceeding to the next game.

Each round comprises three games. After completing all three, a final "Results" screen appears (Figure 8), summarizing the score for each game, total score for the round, and total time taken. From this screen, users may tap "RETRY" to reset their scores and begin a new round, or tap "TITLE" to return to the title screen. Scores are automatically recorded in a Google Spreadsheet upon completing all three games; partial results are not saved.

3 Usage Investigation Methods

The app was distributed as a beta version via TestFlight [6], rather than being released publicly on the App Store. Participants were instructed to first install "TestFlight" on their iOS devices and then install the "Repair Paint Checker" app. The study protocol, which spanned two weeks, is shown in Figure 9. The two-week duration was selected to allow sufficient time for participants to become accustomed to the operation of the app and to improve their ability to detect paint mottling. Data collection comprised three components: game scores, screen recordings of app usage, and post-use survey responses.

Figure 7: "Round clear" notification displayed upon successful identification of all defects within a game, showing mistakes, remaining time, and score

Figure 8: Final results screen displayed after completing one round (three games), summarizing scores per game, total score, and total time

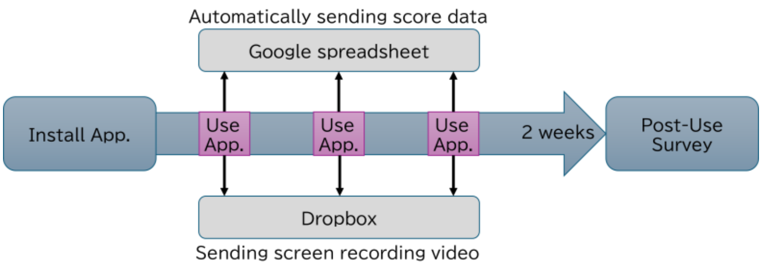


Figure 9: Flowchart illustrating the two-week study protocol, including app installation, usage periods, data collection methods (scores and screen recordings), and the post-use survey

3.1 Scores

We collected game scores to assess whether the participants' performance in detecting paint imperfections improved during the evaluation period. We also integrated a feature into the app to automatically transmit score data to a designated Google Spreadsheet upon the conclusion of each round. The collected data included the selected difficulty level, individual game scores (three per round), completion times, number of mistakes, and specific locations where color irregularities were presented. The scoring formula was as follows:

$$Score = 100(179 - A) - 100B + C$$

where A, B, and C denote the remaining time (s), number of mistakes made, and bonus points awarded for selecting the HARD difficulty level, respectively.

3.2 Screen Recordings of App Usage

To analyze potential changes over time in participants' viewing distance, angle relative to the virtual vehicle body, and simulated color irregularities, participants were asked to record their device screens during app usage and upload the videos to Dropbox.

These videos were analyzed to determine the duration of each game using the in-game timer and to measure the time required to identify each irregularity across the four door panels. Still images were extracted to document the user's visual perspective during the search and at the moment defects were identified.

3.3 Post-Use Survey

After the two-week period, participants completed a Google Forms survey that collected demographic data (gender and age) and assessed usability aspects, including installation issues, manual clarity, ease of learning, and perceived difficulty. Participants were also asked about specific features they found challenging, their perceived improvement in inspection skills, ability to grasp inspection techniques, perceived usefulness in real-world scenarios, continued interest in using the app, likelihood of recommending it to others, and insights gained through usage.

3.4 Evaluators

Three individuals participated in the evaluation:

- Expert A: The CEO of a spray gun manufacturing company, who also conducts nationwide training in spray painting techniques for automotive paint technicians using the company's products.
- Expert B: An automotive body and paint technician with 32 years of professional experience.
- Non-expert: A reporter for an automotive-repair magazine with general knowledge but no hands-on experience in paint repair.

4 Results

4.1 App Evaluation Status

Table 1 summarizes the status of data submission for each participant. Although Experts A and B used the app, no score data were submitted—likely because they did not complete a full round (three games). Expert B also did not submit any screen recordings. However, all participants completed the post-use survey.

Table 1: Data submitted by each participant.

Participant	Score submitted	Video submitted	Post-use survey submitted
Expert A	No	Yes (5)	Yes
Expert B	No	No	Yes
Non-expert	Yes (8 trials)	Yes (13)	Yes

4.2 Game Scores

Only the Non-expert submitted score data (Figure 10). This participant failed to complete a full round until the sixth trial; consequently, scores were not recorded for Trials 1–5. Scores were recorded from the sixth trial onward, and a trend of increasing scores became apparent from Trial 9.

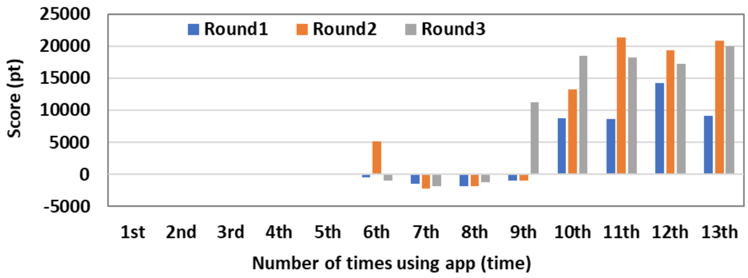
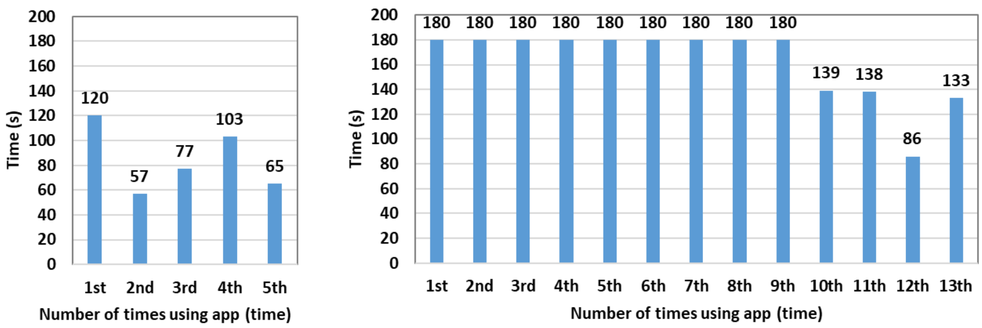


Figure 10: Scores achieved by the Non-expert from Trials 6–13, indicating a general improvement trend

4.3 Game Play Time

Figure 11 compares game completion times for Expert A and the Non-expert. Trials were considered incomplete if the participant failed to locate all paint defects within the 3-min limit, in which case the time was recorded as 180 s. Expert A's completion time was longest in the first trial and shortest in the second. The Non-expert began completing games from the ninth trial, with completion times gradually decreasing thereafter; the twelfth trial was completed the fastest.



(a) (b)

Figure 11: Comparisons of time taken (s) to complete each trial for (a) Expert A and (b) Non-expert.

Subsequent analysis focused on the time spent adjusting viewpoint orientation. Tables 2 and 3 show the orientation adjustment times for Expert A and the Non-expert. Expert A spent the longest time adjusting the orientation during the first trial. Conversely, the Non-expert made these adjustments more rapidly than Expert A during the analyzed trials. Table 4 lists the number of mistakes made by the Non-expert during Trials 10–13. At least one mistake was recorded in each trial, with the fewest occurring in the 12th trial.

Table 2: Time (s) spent by Expert A adjusting viewpoint orientation during the first five trials

Number of times using the app.	1st	2nd	3rd	4th	5th
Orientation change time (s)	45	16	27	18	17

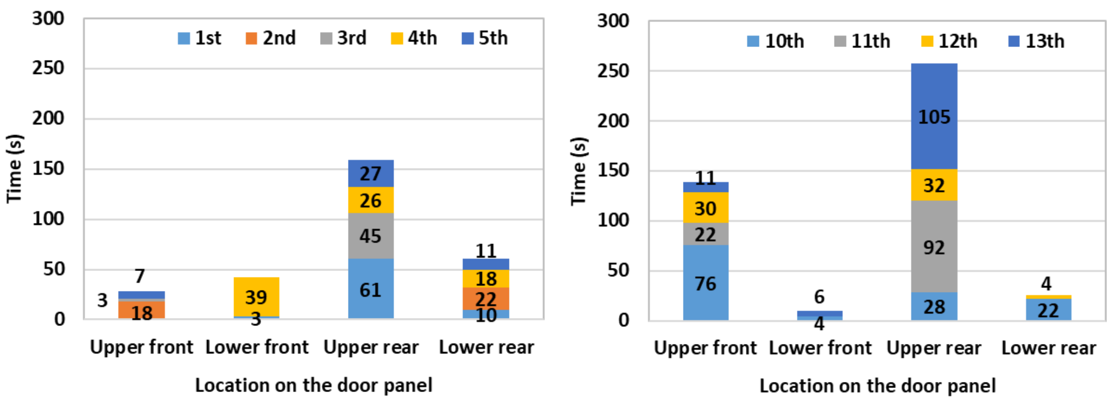
Table 3: Time (s) spent by the Non-expert adjusting viewpoint orientation during Trials 10–13

Number of times using the app.		10th	11th	12th	13th
Orientation change time (s)	1st orientation	7	10	7	9
	2nd orientation	-	10	12	-

Table 4: Number of incorrect identifications (mistakes) made by the Non-expert during Trials 10–13.

	10th	11th	12th	13th
Number of mistakes (times)	2	3	1	3

Figure 12 shows the average time to discover paint defects at specific locations on the door panels. This analysis included all five trials for Expert A and Trials 10-13 for the Non-expert. Expert A required more time to detect defects located on the upper rear side of the door panel, whereas the Non-expert exhibited longer detection times for defects on both the upper front and upper rear sides of the panel.



(a) (b)

Figure 12: Average time (s) required to detect paint defects at specific locations on the door panel for (a) Expert A and (b) Non-expert.

4.4 Field of View During Gameplay

Figures 13 and 14 show representative frames from screen recordings of Expert A and the Non-expert gameplay, respectively. Expert A generally inspected from a full-door view, shifting to an oblique angle when defects were not readily apparent. The viewing height remained level with the door. Conversely, the Non-expert frequently approached the door more closely and searched for defects primarily from a frontal viewpoint. Over successive trials, the Non-expert increasingly adopted a broader viewing position and occasionally employed an oblique angle to search for defects.

(a) (b)

Figure 13: Representative views from Expert A's screen recording during gameplay, showing inspection from (a) a frontal perspective and (b) an oblique side angle

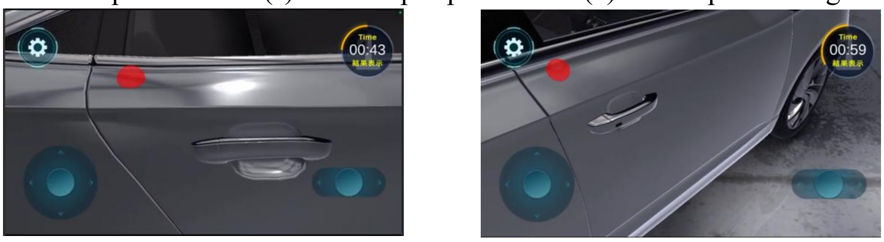


Figure 14: Representative views from the Non-expert's screen recording during gameplay, illustrating changes in inspection perspective over time.

4.5 Survey Results

Participants provided feedback via the post-use survey. When asked about installation issues ("Did you face any issues while installing the app?"), Expert A answered, "It took some time," whereas Expert B and the Non-expert reported, "It went mostly smoothly."

Regarding the clarity of the in-app manual ("Was the in-app manual easy to understand?"), Expert A selected "Neither agree nor disagree," explaining, "As I was taught how to use it, I am unsure whether the manual does so clearly." Expert B selected "Very easy to understand," stating, "It was intuitive to use." The Non-expert also answered "Neither agree nor disagree," commenting, "I prefer a more intuitive approach, similar to other apps."

Concerning the ease of learning the app's operation ("Did you quickly get used to the app's operation?"), Expert A responded, "It was quite difficult," explaining, "I don’t play games on smartphones frequently, so I had difficulty operating it." Expert B stated, "I got used to it quickly," noting, "I like games." The Non-expert reported, "It took a little time," explaining, "I didn’t read the manual thoroughly, and initially, I had no experience with the car-painting process."

Regarding the perceived game difficulty ("How did you feel about the game's difficulty?"), Expert A answered, "It was somewhat easy," explaining, "In the EASY mode, the color differences were clear, which helped me identify the defects quickly." Expert B answered, "It was easy," again mentioning, "I like games." The Non-expert reported "It was a bit difficult," explaining, "Although I work for an automotive body and paint company, I have never actually performed any painting."

When asked about difficult-to-use features ("Which features of the app did you find difficult to use?"), Expert A responded, "Camera controls (front, back, left, right, and orientation changes), and paint-defect marking (placing the red marker on the car body)," explaining, "People who don't play games on smartphones may struggle more with the controls than with finding paint defects." Expert B answered "Camera controls (front and back), defect marking (placing the red marker on the car body)," stating, "It felt sensitive even on an iPhone Pro Max. Perhaps a tablet would be better suited." The Non-expert stated "Flat surface detection," explaining, "Sometimes the car wouldn't appear."

Regarding perceived skill improvement ("Do you think you could improve your ability to inspect automotive paint by using this app?"), Expert A was unsure, "I'm not sure," explaining, "While I might learn how to inspect in this manner, it is probably as good as an introduction. However, real-world experience is necessary to develop an experienced eye for inspection." Expert B believed improvement was possible ("I think I could improve"), commenting, "It feels close to the real thing, although it depends on the individual's imagination." The Non-expert also felt improvement was possible ("I think I could improve"), noting, "I became considerably more familiar with it toward the end."

On learning inspection techniques ("Did you learn any tricks for inspecting automotive paint from the app?"), both Expert A and Expert B stated, "I already knew the tricks before using the app." Expert A explained, "I have been taught by professionals who work in the field," whereas Expert B responded, "I rely on my experience as a painter." However, the Non-expert felt they did learn from the app, stating, "I learned some tricks by using the app," explaining, "I was able to complete the trials by the end."

Regarding the app's potential real-world usefulness ("Do you think this app would be useful in a real-world painting environment?"), Expert A was uncertain ("I'm not sure,") adding, "I don't know." Expert B found it potentially useful ("It would be useful"), suggesting, "It's great for training beginners." The Non-expert agreed ("It would be useful"), stating, "It would help those without practical painting experience grasp the concept."

Concerning future use ("Would you want to continue using this app?"), Expert A expressed low interest ("I wouldn't want to use it much"), explaining, "Because I have opportunities to inspect real cars." Expert B showed strong interest ("I would definitely want to use it"), stating, "I think it's great to teach beginners such tasks in a game-like format. It reduces the burden on trainers." However, the Non-expert was neutral ("Neither agree nor disagree"), explaining, "I don't have many opportunities to work in the painting industry."

On recommending the app ("Would you recommend this app to others?"), Expert A answered, "I'm not sure," explaining, "It might be good for newcomers, but real-world experience is important." Expert B stated, "I would recommend it," stating, "It can reduce training costs." The Non-expert was also unsure ("I'm not sure"), stating, "I would only recommend it to customers who want to learn painting."

Finally, when asked for general observations ("What did you notice after using the app?"), Expert A commented on the limitations of simulating real-world variability ("There are infinite variations in paint defects and color differences; therefore, it is difficult to teach everything through the app. If it was used on a larger screen or in a more virtual format, it could be more interesting.") Expert B noted, "It's a bit difficult to use on the iPhone. Sometimes I couldn't select the intended spot even when tapping at the desired location. Doing this on a larger tablet or with a mouse might be easier. Maybe the app is designed for tablet use; however, I believe you could aim more precisely with a mouse." However, the Non-expert answered, "I apologize for my initial unfamiliarity with the app. By the end, I learned a lot. Thank you."

5 Discussion

Expert A demonstrated a high level of proficiency from the beginning, completing all game trials without making errors in identifying paint defects. This strong performance is attributed to their considerable experience and established expertise in this domain. Conversely, the Non-expert required multiple attempts before achieving consistent success, which only began from the tenth trial onward. Notably, as the trials progressed, the Non-expert began adopting more effective viewing strategies, such as positioning themselves to view the entire door panel, which facilitated defect detection within the time limit. These observations suggest that sustained use of the app can help users develop practical inspection skills for identifying optimal viewing positions to detect paint defects.

These findings resonate with prior research [7], which utilized eye-tracking to measure gaze patterns during partial automative painting tasks.. Gaze video frames from an automotive-repair paint technician with 41 years of experience (Figure 15) reveal that skilled practitioners frequently inspect the door surface from oblique angles and, in some instances, from below and above the panel. Conversely, early gameplay recordings showed the Non-expert approaching the panel head-on, often missing subtler defects—a behavior that improved over time. Expert A, however, employed a broader field of view and dynamic angle adjustments, closely mirroring the techniques observed in the expert from the previous study [7]. Since paint defects are often less visible when viewed directly from the front, the Non-expert's initial reliance on this perspective likely contributed to more mistakes than Expert A. Furthermore, Expert A and the Non-expert experienced greater difficulty (longer detection times) with defects located on the upper portion of the door panel. This likely occurred because they did not adopt the vertical viewing angles observed in the real-world painting inspection behavior captured in the previous research [7].

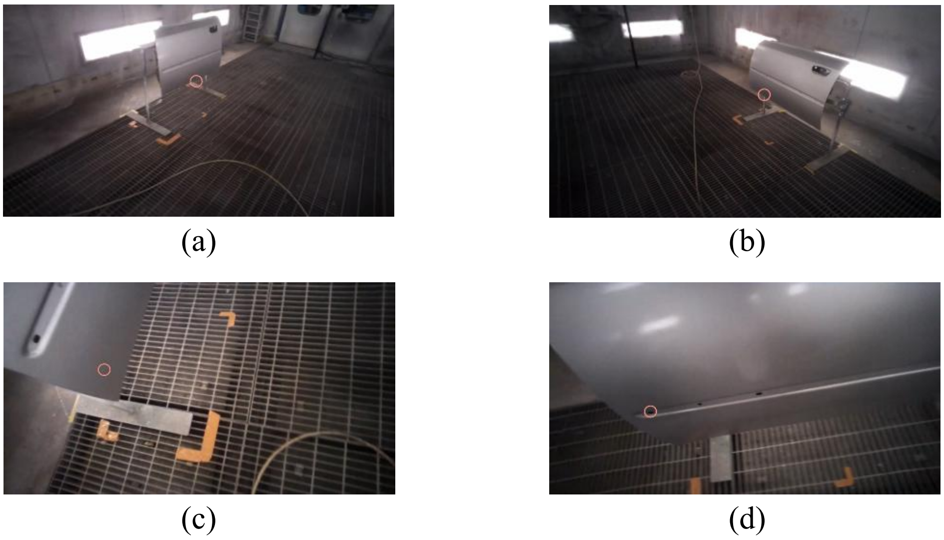


Figure 15: Examples of inspection viewpoints adopted by an experienced technician during real-world automotive-repair painting, illustrating inspection from (a), (b) oblique side angles, (c) below side, and (d) above the panel.

6 Conclusions

In this study, we developed an AR application aimed at training users in automotive-repair paint inspection. We evaluated its feasibility and potential benefits through gameplay performance and user feedback. The results revealed clear distinctions based on user experience. Expert A, leveraging extensive prior experience, accurately identified all paint defects and completed the game trials on the first attempt. Conversely, the Non-expert demonstrated gradual improvement, with performance gains becoming evident from the tenth trial onward. Screen recordings highlighted behavioral differences: Expert A consistently viewed the entire door panel and systematically changed viewing angles to locate challenging defects, whereas the Non-expert initially relied more on close-up, frontal inspection before gradually adopting a broader viewpoint. Additionally, feedback from the post-use survey further contextualized these findings, indicating that Expert B, an experienced practitioner, affirmed the app's potential as a training tool for novices, emphasizing its educational value in reducing instructor burden. Similarly, the Non-expert found the app helpful in becoming familiar with paint inspection tasks. Collectively, these results suggest that the AR app developed in this study shows potential as an educational tool for training novice technicians in identifying automotive paint defects. Although the app showed promise, recruitment was hindered by the use of TestFlight, which posed barriers for participants unaccustomed to digital tools. This highlights the need to develop a platform that is both more user-friendly and easier to install in the future. Overall, the results indicate that the AR app has meaningful potential as an introductory training tool for developing paint inspection skills in novice automotive technicians.

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