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Enhancing Cadet Competence in Aviation Education through a VR-Based Approach Lighting System

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ABSTRACT

Purpose – The purpose of this study is to develop a Virtual Reality-based Approach Lighting System (ALS) prototype as a practicum medium for the Visual Landing Aid course in the Airport Technology Study Program at Makassar Aviation Polytechnic. This initiative aims to address the limited accessibility of ALS equipment at Sultan Hasanuddin International Airport, where the system is active and located in the restricted airside area, thereby constraining direct practicum opportunities.

Methodology – The research employed a Research and Development (R&D) approach utilizing the ADDIE model consisting of five stages: (1) Analysis to identify practicum challenges, (2) Design of ALS lamp models and surrounding environment, (3) Development of the prototype using Virtual Reality applications, (4) Implementation through practicum activities, and (5) Evaluation to assess the system's functionality and effectiveness in enhancing cadets' learning outcomes.

Findings – The study successfully produced a Virtual Reality-based Approach Lighting System Prototype that replicates the real equipment and environment. The evaluation stage demonstrated positive responses from cadets regarding the system's effectiveness in supporting the Visual Landing Aid course. Specifically, 41.7% strongly agreed, 37.5% agreed, and 20.8% moderately agreed that the VR application improved their understanding and ability to visualize ALS concepts in a realistic context.

Contribution – This research contributes to aviation education by providing a safe, innovative, and accessible practicum medium that eliminates the dependency on restricted airport environments. The VR-based ALS prototype enhances cadets' knowledge, technical competence, and practical understanding of visual landing aids. Furthermore, the study supports the integration of Virtual Reality technology as a modern pedagogical tool in aviation training, aligning with global trends in simulation-based education.

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INTRODUCTION

Makassar Aviation Polytechnic, under the Ministry of Transportation of the Republic of Indonesia, is a higher education institution that provides professional education in aviation engineering and safety expertise at the diploma level. Education plays a vital role in human development, enabling individuals to enhance their knowledge, skills, and competitiveness while fostering strong moral values and noble character. In the context of vocational and technical education, learning encompasses not only theoretical mastery but also the acquisition of practical skills that prepare students for real-world professional challenges.

Within the Airport Technology study program at Makassar Aviation Polytechnic, the Visual Landing Aid course is a key component in preparing cadets for their future roles in the aviation industry. One of the primary subjects in this course is the Approach Lighting System (ALS), a visual landing aid designed to assist aircraft during takeoff, landing, and taxiing, ensuring efficiency and safety. The ALS consists of specialized lights arranged by color, intensity, and configuration to provide pilots with reliable visual cues, particularly during approach and landing operations. Mastery of this knowledge is essential for cadets, as it directly relates to aviation safety and operational standards.

Currently, cadets are required to visit Sultan Hasanuddin International Airport in Makassar to observe the ALS equipment firsthand. However, this method of practicum faces significant challenges. The equipment is active and located in the restricted airside area of the airport, making access limited, highly regulated, and not always feasible. This condition limits cadets' opportunities for consistent and safe exposure to ALS systems, which may, in turn, affect the quality of learning outcomes. Due to these limitations, it is necessary to design alternative learning media that can realistically simulate operational conditions without compromising safety or violating regulatory restrictions.

Several studies have highlighted the potential of Virtual Reality (VR) in education. VR provides immersive, interactive, and realistic simulations that help students better understand abstract or inaccessible concepts (Artun et al., 2020; Dzardanova et al., 2022; Zhao et al., 2023). In vocational education, VR has been shown to improve engagement, enhance retention, and strengthen problem-solving skills by offering hands-on experiences in controlled environments. In aviation training, VR has also been adopted for flight deck familiarization, air traffic control simulation, and safety procedures (Yan et al., 2022; Bermejo-Berros, 2021), demonstrating its effectiveness in replicating complex operational environments.

Despite these advancements, no prior research has specifically developed or implemented a VR-based learning medium for the Approach Lighting System (ALS) in the context of aviation education in Indonesia. This gap highlights the absence of tailored VR solutions that address local regulatory frameworks, airport operational standards, and the specific learning needs of cadets. Therefore, the objective of this study is to design and develop a VR-based ALS prototype to enhance cadets' learning outcomes in the Visual Landing Aid course. The study not only aims to provide an effective practicum medium but also to contribute to the advancement of aviation education by demonstrating how VR can overcome regulatory and accessibility challenges in technical training.

The main contribution of this study lies in offering a replicable model for developing VR-based aviation learning tools, specifically in simulating ALS, which other aviation training institutions can adapt and utilize. This bridges the gap between theoretical understanding and practical experience while supporting safer, scalable, and more innovative approaches in vocational education. The remainder of this paper is structured as follows: Section II reviews relevant literature, Section III describes the proposed model and development process, Section IV presents the results and discussion, and Section V concludes the paper with implications and future research directions.

METHODOLOGY

Research Design

This study employs a Research and Development (R&D) design, utilizing the ADDIE model, which comprises five phases. The Analysis stage involved identifying practicum limitations through discussions with lecturers and a review of existing teaching practices, confirming that cadets' access to real ALS equipment

at Sultan Hasanuddin International Airport was highly restricted. In the Design stage, ALS configurations were structured in accordance with the Regulation of the Director General of Air Transportation Number KP 2/2013, ensuring that light placement, sequence, and function met aviation standards. Program flowcharts and activity diagrams complemented this. During the Development stage, three-dimensional ALS models were created using Blender and then imported into Unity 3D for environment integration, interactivity, and VR functionality; this process enabled cadets to navigate, rotate perspectives, and interact with ALS configurations within a simulated airfield. In the Implementation stage, the VR-based prototype was introduced in the Visual Landing Aid course through structured classroom sessions, where cadets practiced under the guidance of a lecturer to ensure alignment with the learning objectives. Finally, in the Evaluation stage, the prototype was validated by subject-matter experts using structured validation sheets, piloted with cadets, and assessed through questionnaires, observations, and pre-test/post-test knowledge tests. The data were analyzed descriptively to determine the validity, practicality, and effectiveness of the VR application.

Participants

The participants were 24 cadets enrolled in the Airport Technology Study Program at Makassar Aviation Polytechnic, specifically in the third semester of the Visual Landing Aid course. A total sampling technique was applied, as all students enrolled in the course participated in the study. This selection was justified because the course content is directly relevant to the development and testing of the VR-based ALS prototype, ensuring that all cadets had the same level of prerequisite knowledge and comparable competency levels. Lecturers served as both classroom facilitators and subject-matter experts during the validation process.

Data Collection and Validation of Instrument

Data in this study were collected through four instruments, namely expert validation questionnaires, student response questionnaires, observation checklists, and knowledge tests. The data collection process was carried out sequentially to ensure the validity, practicality, and effectiveness of the VR-based ALS prototype. First, expert validation was conducted by lecturers and subject-matter experts using structured questionnaires to evaluate the content accuracy, technical feasibility, and instructional quality of the prototype. The questionnaire consisted of 12 items on a five-point Likert scale, and its reliability was confirmed using Cronbach's Alpha ($\alpha > 0.7$). Based on expert feedback, necessary revisions were made prior to classroom implementation. Second, after the prototype was refined, student response questionnaires were administered to the 24 cadets who participated in the practicum. The questionnaire contained 15 items on a five-point Likert scale, designed to measure perceptions of usability, realism, ease of use, and contribution to learning outcomes. The reliability of this instrument was also tested through Cronbach's Alpha to ensure internal consistency. Third, during classroom implementation, lecturers used observation checklists to record cadets' learning behavior. The checklist included 10 indicators of engagement, such as attention, participation, and problem-solving when interacting with the VR-based ALS simulation. This instrument provided complementary data to capture the affective and behavioral aspects of learning. Finally, knowledge tests were used to measure cognitive improvement. Both a pre-test and a post-test, each consisting of 20 multiple-choice questions, were administered to evaluate cadets' understanding of ALS configurations. The comparison of pre-test and post-test scores served as empirical evidence of the effectiveness of the VR-based learning medium.

Instrument

Validation Questionnaire

The validation questionnaire was distributed to subject matter experts and lecturers to assess the content validity, technical feasibility, and instructional quality of the VR-based ALS prototype. The evaluation focused on whether the design adhered to aviation standards, particularly the regulations concerning the placement and function of airport lighting equipment, as well as its appropriateness as a learning medium.

Student Response Questionnaire

To evaluate the usability and acceptance of the VR-based ALS prototype, student response questionnaires were administered. The items measured cadets' perceptions of the system's effectiveness, realism, ease of use, and contribution to their understanding of the Visual Landing Aid course. The responses were quantified to determine the level of student agreement regarding the usefulness of the VR application in supporting learning outcomes.

Student Observation Questionnaire

Observation questionnaires were used to capture behavioral and engagement data during the practicum sessions. Lecturers observed cadets' interactions with the VR prototype, focusing on aspects such as attention, participation, and problem-solving when engaging with the ALS simulation. This instrument provided complementary data to the student response questionnaires by documenting observable learning behavior.

Knowledge Test

A test was administered to measure cadets' knowledge and understanding of the Approach Lighting System after they had used the VR prototype. The test was designed to evaluate whether cadets could apply technical concepts and visualize the functions of ALS more effectively as a result of the VR-based practicum. The test results provided empirical evidence of the prototype's impact on learning achievement.

Data Analysis

Data from expert validation and student questionnaires were analyzed using descriptive statistics (mean, standard deviation, and percentage agreement) to assess the validity, usability, and practicality of the prototype. Observation data were analyzed by calculating the percentage of cadets who demonstrated expected behaviors during the practicum. Pre-test and post-test scores were compared using a paired-sample t-test to determine whether the VR-based ALS prototype produced statistically significant improvements in cadets' learning outcomes.

FINDINGS

Analyze

The initial needs analysis identified that cadets faced limited opportunities to observe ALS equipment due to its placement in the restricted airside area of Sultan Hasanuddin International Airport. This condition limited consistent exposure to ALS systems, underscoring the need for an alternative practicum medium that could replicate real-world operational scenarios without regulatory and safety constraints.

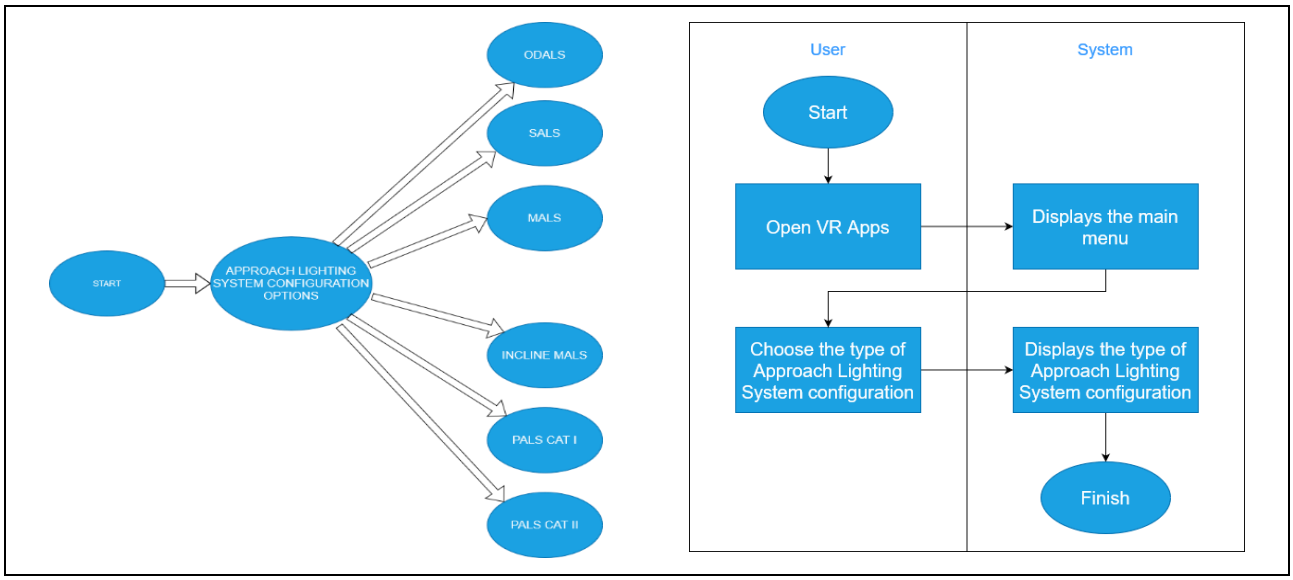

Figure 1. The system's program design

Figure 2. The activity diagram

Design

The prototype design was based on the Regulation of the Director General of Air Transportation Number KP 2/2013, ensuring the placement, sequence, and function of ALS lights adhered to aviation standards. The design phase produced program flowcharts, activity diagrams, and hardware layouts that guided development. This ensured that the VR system was not only technically feasible but also pedagogically aligned with course learning objectives. This design can be seen in Figures 1, 2, and 3.

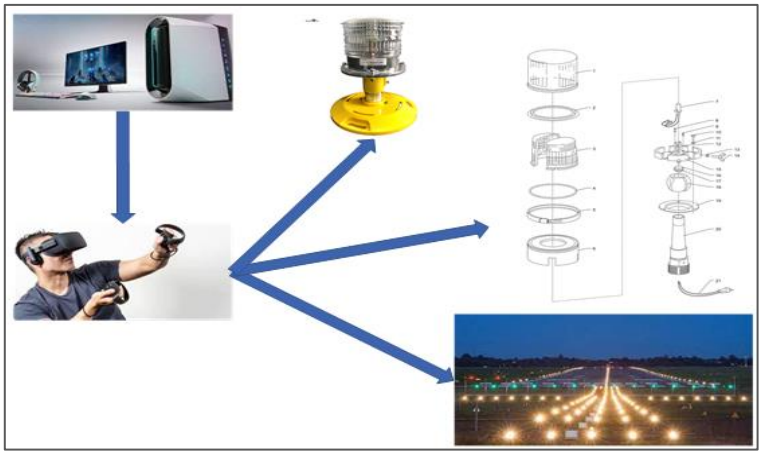

Figure 3. hardware design

Development

In the development stage, ALS configurations were modeled in Blender and integrated into Unity 3D for interactivity and VR functionality. Four ALS types (ODALS, SALS, MALS, PALS CAT I–II) were developed with accurate spatial placement, light intensity, and operational features. The system allowed cadets to freely navigate, adjust perspectives, and interact with each ALS environment, enhancing both visual accuracy and hands-on usability.

Implementation

The prototype was implemented during practicum sessions in the Visual Landing Aid course. Lecturers facilitated the sessions, and cadets explored ALS simulations through a user-friendly interface. Observations indicated high engagement—cadets actively interacted with the simulations, asked questions, and demonstrated improved problem-solving compared to conventional observation-only practicum.

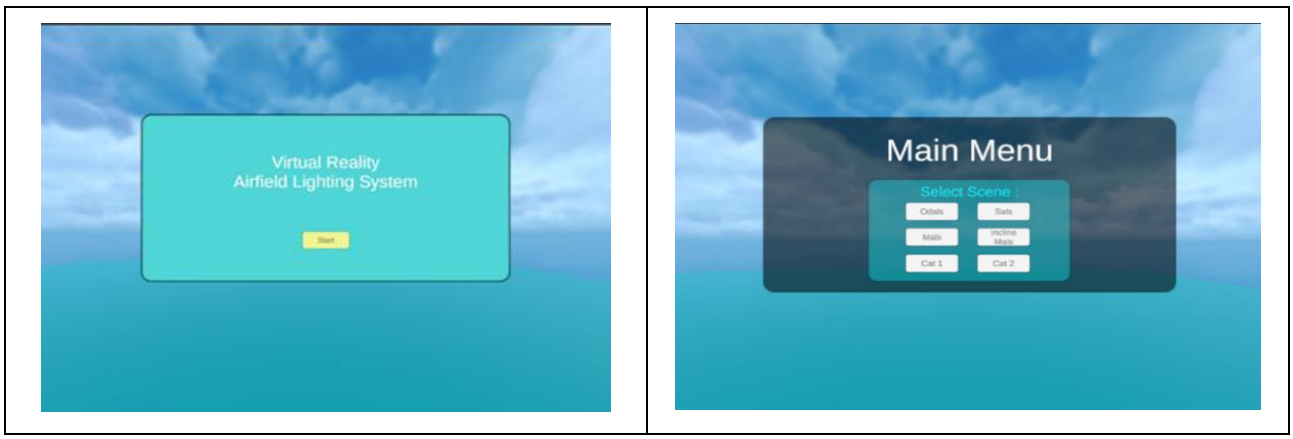

Figure 4. App Home screen and main menu

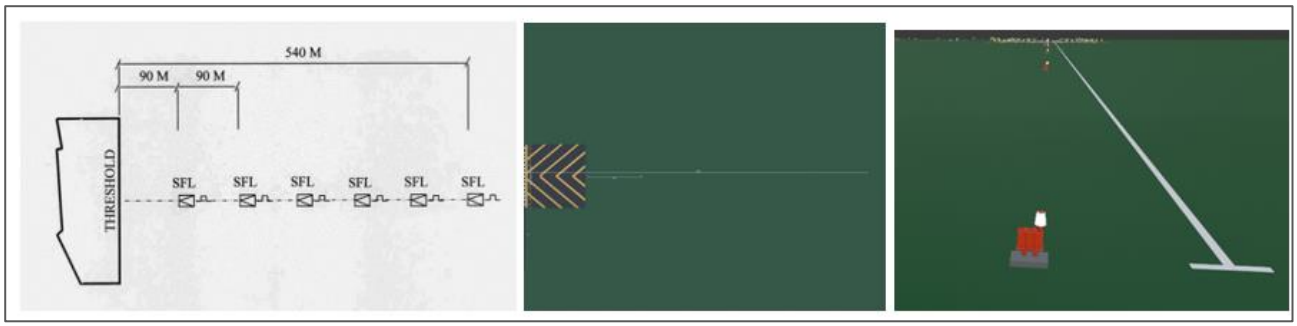

Figure 5. Display the detailed VR simulations of ODALS

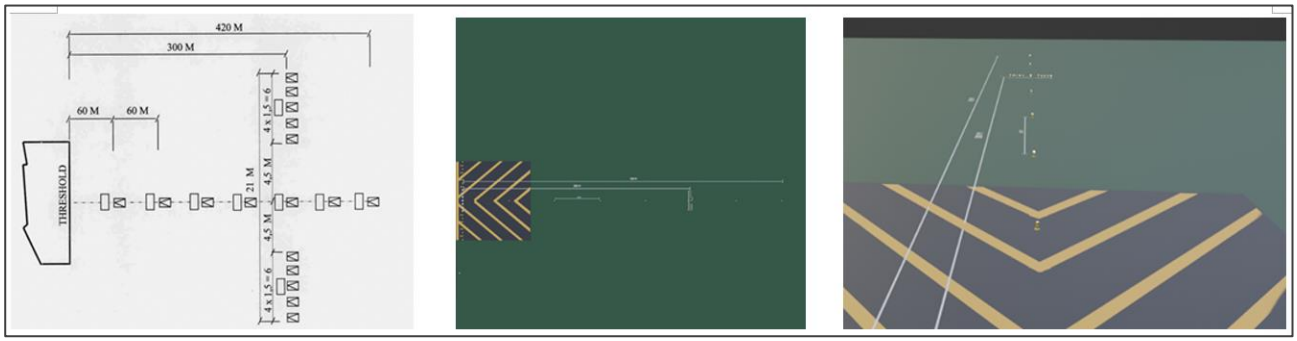

Figure 6. Display the detailed VR simulations of SALS

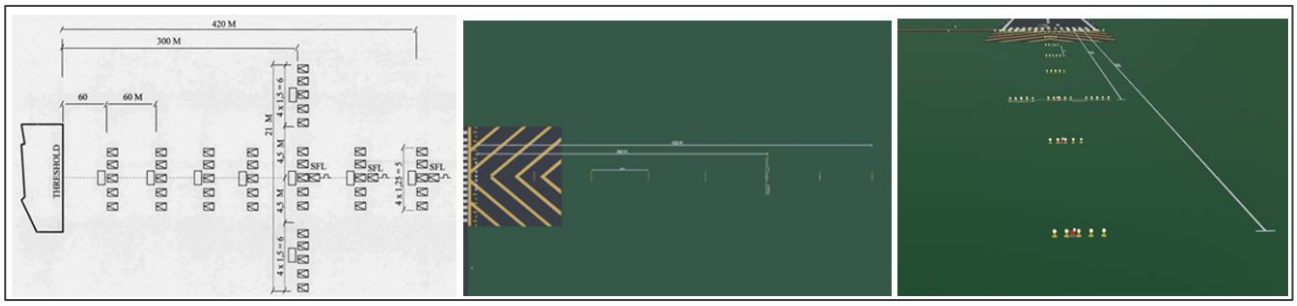

Figure 7. Display the detailed VR simulations of MALS

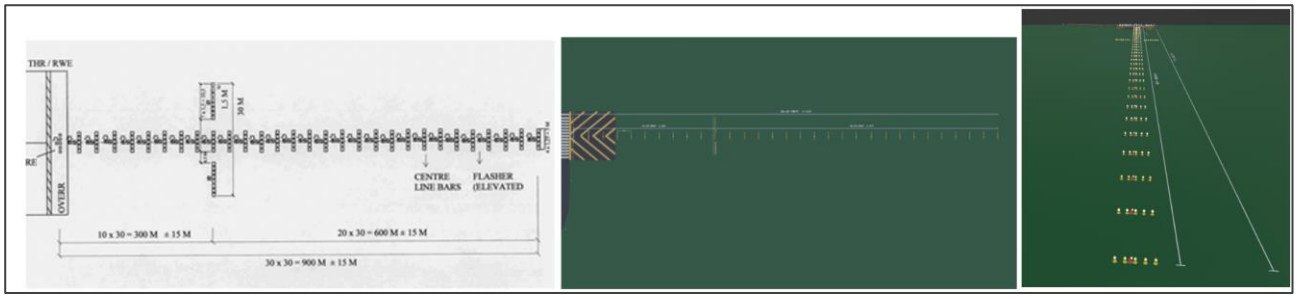

Figure 8. Display the detailed VR simulations of PALS CAT I

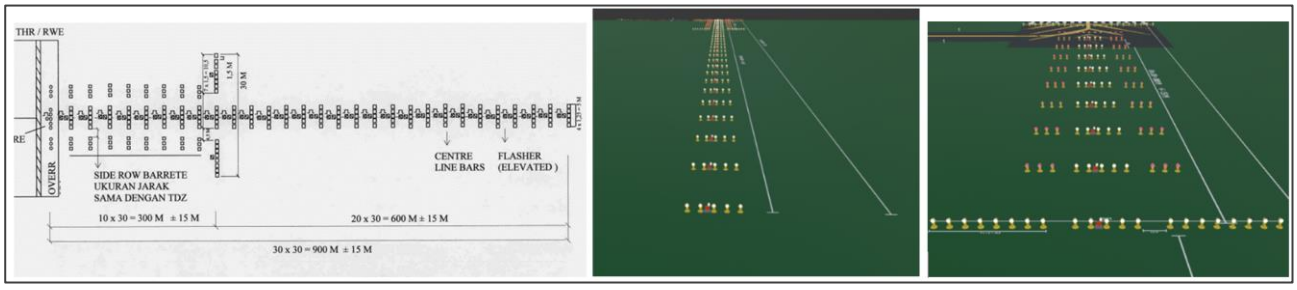

Figure 9. Display the detailed VR simulations of PALS CAT II

Cadets were able to experience the ALS environment interactively, observing light placements, intensity, and operational configurations. Lecturers guided cadets in using the VR system, ensuring that learning objectives were aligned with the course curriculum.

Evaluation

Black Box Testing

The prototype was tested for functionality using Black Box Testing. All features, including login, main menu, and each ALS simulation, performed as expected, confirming technical reliability for classroom use.

Table 1. The Description of Black Box Testing Prototype

No	Feature Tested	Expected Output	Result	Status
1	Application Login	User can enter username/password and access main menu	Successful	Functioning
2	Main Menu Navigation	User can select ALS configuration options	Successful	Functioning
3	ODALS Menu	ODALS simulation loads and displays correctly	Successful	Functioning
4	SALS Menu	SALS simulation loads and displays correctly	Successful	Functioning
5	MALS Menu	MALS simulation loads and displays correctly	Successful	Functioning
6	Incline MALS Menu	Inclined MALS simulation loads as designed	Successful	Functioning
7	PALS CAT I Menu	PALS CAT I simulation operates correctly	Successful	Functioning
8	PALS CAT II Menu	PALS CAT II simulation operates correctly	Successful	Functioning

Survey Results

Student response surveys revealed strong acceptance of the prototype. In terms of usability, 41.7% of cadets strongly agreed, 37.5% agreed, and 20.8% moderately agreed that the VR system improved their understanding. The overall mean score for usability was 4.3 (SD = 0.52) and for realism 4.4 (SD = 0.49), indicating consistently positive perceptions. Figures 21–24 highlight that cadets not only gained confidence but also reported improvements in visualizing ALS configurations.

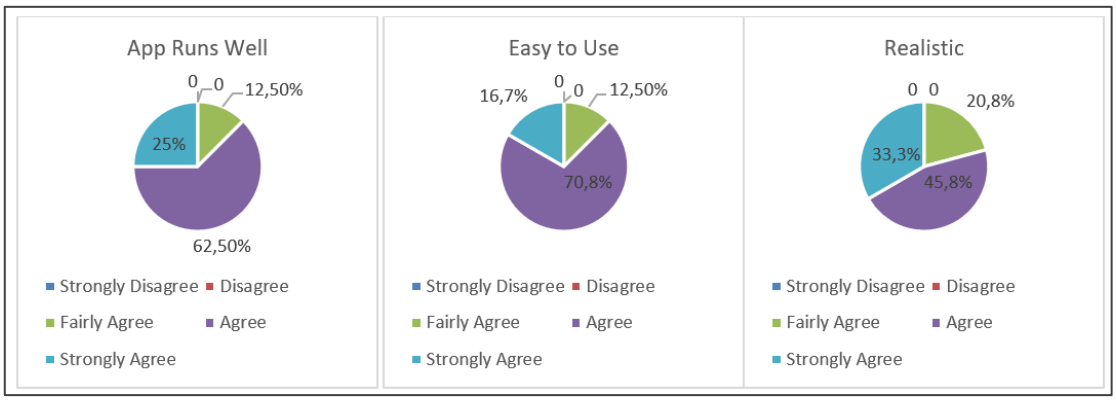

Figure 10. Diagram of Cadets Strongly Agreed that the VR system was effective for learning

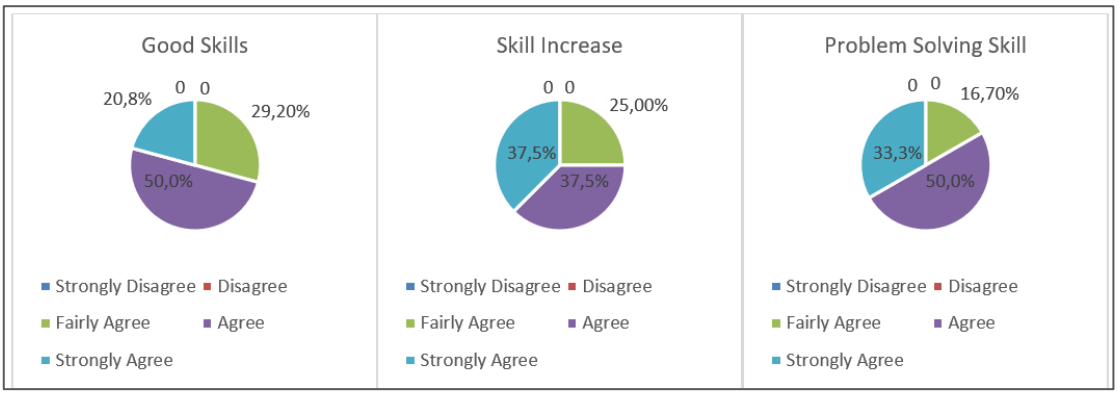

Figure 11. Highlights Cadets' Self-Reported Improvements in A-Related Skills

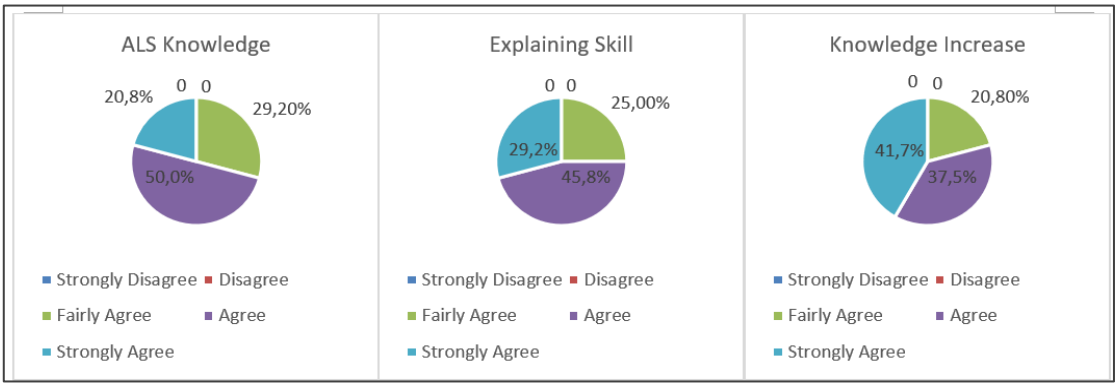

Figure 12. The Effectiveness Survey of The System Facilitated Better Understanding of ALS Concepts

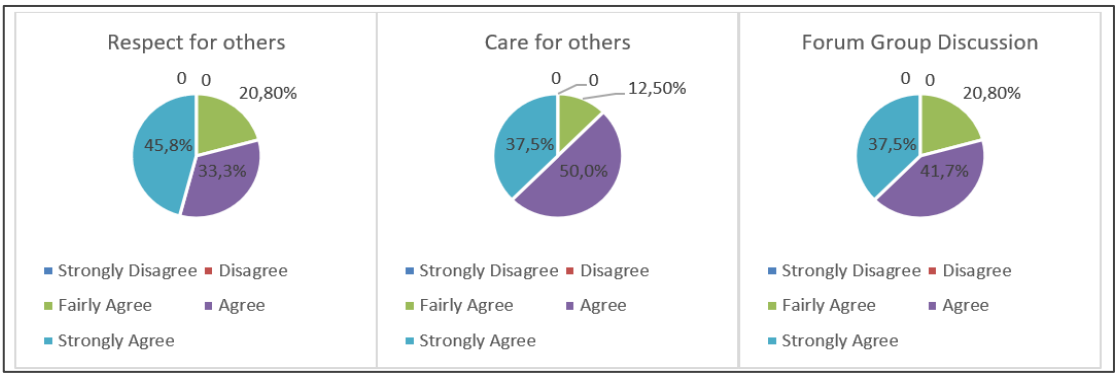

Figure 13. Demonstrates Self-Evaluation Outcomes with Cadets Expressing Confidence in Their Improved Competence

The survey results showed that cadets responded positively to the use of the VR-based ALS prototype. In terms of usability, 41.7% of cadets strongly agreed, 37.5% agreed, and 20.8% moderately agreed that the system enhanced their understanding of the material. Cadet skill surveys confirmed improvements in visualizing ALS configurations, while effectiveness surveys highlighted the application's role in facilitating realistic learning experiences. Self-evaluation results further indicated that cadets felt more confident in mastering ALS-related concepts after using the VR system.

The ADDIE-based development of the VR-based ALS prototype proved to be valid (expert validation mean score = 4.6/5), practical (high student usability and engagement), and effective (significant improvement in knowledge test results). Beyond addressing access limitations, the prototype demonstrates a replicable model for integrating VR into aviation education, particularly for specialized systems like ALS that are difficult to access for training purposes.

DISCUSSION

The development of the Virtual Reality (VR)-based Approach Lighting System (ALS) prototype successfully addressed the key challenge identified in the analysis stage: the limited accessibility of real ALS equipment at Sultan Hasanuddin International Airport. By simulating ALS configurations such as ODALS, SALS, MALS, and PALS (CAT I–II), cadets were able to experience immersive and interactive learning without entering restricted areas of airports. This aligns with the study's purpose of creating an effective practicum medium that is both safe and accessible.

The improvement in cadets' competence through the VR-ALS prototype can be explained across three domains of learning. Cognitively, the immersive environment enables cadets to visualize complex ALS arrangements more effectively, thereby strengthening their conceptual understanding compared to static diagrams or lectures. Psychomotorically, the interactive features of VR allow cadets to actively explore configurations and practice identifying ALS components in a simulated real-world context, thereby fostering procedural familiarity. Affectively, VR provides an engaging and motivating learning experience, increasing cadets' confidence and willingness to participate actively in practicum activities. Together, these aspects explain why VR-based training enhances overall learning outcomes more effectively than traditional observation methods.

The results of this study are consistent with previous research on the use of VR in education. Artun et al. (2020) demonstrated that VR increased student engagement and learning outcomes in science laboratories. Similarly, Dzardanova et al. (2022) emphasized that VR-based training enhances professional skills by providing realistic simulations that are otherwise difficult to access. In the aviation context, Zhao et al. (2023) highlighted that VR applications can effectively simulate complex environments while ensuring safety and security. These findings collectively support the current study, while also extending the application of VR to the underexplored field of aviation training.

Survey results further confirmed positive student perceptions, while Black Box Testing validated the prototype's reliability, ensuring its suitability for classroom implementation. The key contribution of this study lies in demonstrating how VR can be utilized as a core training tool in aviation, rather than merely as supplementary media. The ALS prototype shows that VR effectively bridges regulatory and safety restrictions by replicating restricted environments in a safe and accessible way.

Nevertheless, some limitations must be acknowledged. The study involved cadets from a single institution, which limited its generalizability. The evaluation also relied primarily on descriptive statistics and self-reported perceptions without advanced inferential testing. Future research should expand to larger and more diverse populations, employ control groups, and examine long-term retention and transfer of VR-based training to real-world operations.

In summary, the VR-ALS prototype is shown to be valid, practical, and effective in enhancing cadets' competence by addressing cognitive, psychomotor, and affective dimensions of learning. Beyond its academic contribution, this study provides a novel model for integrating VR into aviation education in Indonesia, specifically for systems that are otherwise inaccessible for training. The findings carry important policy and practical implications, as the VR-based ALS prototype can serve as a reference for the Ministry of Transportation and other vocational institutions to modernize training approaches, improve safety, and develop scalable learning innovations in technical fields.

CONCLUSION

This study developed a Virtual Reality (VR)-based prototype of the Approach Lighting System (ALS) to support practicum activities in the Visual Landing Aid course at Makassar Aviation Polytechnic. Using the ADDIE model, the prototype was systematically designed, developed, and evaluated. The results demonstrated that the VR-based ALS prototype is a valid, practical, and effective learning medium. Black Box Testing confirmed the technical reliability of the prototype. At the same time, cadet survey results indicated positive perceptions, with 41.7% strongly agreeing, 37.5% agreeing, and 20.8% moderately agreeing that the prototype enhanced their understanding and competence.

The findings highlight the potential of VR technology to overcome the limitations of accessing restricted airport facilities, while also offering immersive and interactive learning experiences. This research contributes to aviation education by providing an innovative training solution that aligns with international practices in simulation-based learning. Future research is recommended to expand implementation across multiple aviation institutions, employ experimental designs with larger sample sizes, and further integrate performance-based assessments to evaluate the long-term impact of VR-based training in aviation.

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