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AN IMPROVE AUGMENTED REALITY APPROACH FOR STEM IN EARLY CHILDHOOD LEARNING VIA IMAGE PROCESSING

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Abstract

This study aims to improve Augmented Reality marker detection by using a combination of several techniques of digital image processing. The first objective is to improve the marker used by removing noise from the marker by using bilateral filtering, the second objective is to improve the contrast on the marker by using the Histogram Equalization technique, and the third objective is to develop a marker-based Augmented Reality that has a good quality with a combination of Bilateral filtering and Histogram Equalization. Five experiments were carried out: the MSE test, the PSNR test, the FAST corner detection test, the marker distance test with the camera, and lighting test. The results of the MSE and PSNR tests show that the improved marker has a higher quality compared to the original marker. For the FAST corner detection test, the improved marker has more points compared to the original marker, and the results for the marker distance test and the camera show that the improved marker can be detected up to 70 cm and 80 cm compared to the original marker. For the lighting test also shows that the improved marker can be detected in all different lighting compared to the original marker.

Keywords: Augmented Reality, Marker-Based AR, Image Enhancements, Image Denoising, Image Restoration, bilateral, histogram equalization

INTRODUCTION

STEM education is praised for promoting collaboration and knowledge-sharing among educators and students, thereby enriching their educational experiences. The statement also stresses the relevance of STEM skills, such as critical thinking, creativity, and collaboration, in today's job market. These skills complement 21st-century competencies like communication and literacy, empowering students to tackle real-world challenges and innovate solutions, thus enhancing their adaptability and competitiveness.

The statement advocates for a teaching approach that integrates Science, Technology, Engineering, and Math through hands-on activities, aiming to spark greater interest in STEM subjects among learners. It enumerates the benefits of STEM education for students, including enhanced critical thinking skills, preparation for future careers, improved technological literacy, promotion of innovation and creativity, emphasis on teamwork and collaboration, and enhancement of career readiness. As the demand for STEM education continues to rise, there is an increasing need for highly qualified STEM educators who can proficiently teach these subjects.

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Empowering more young individuals to pursue technology and related fields can contribute significantly to fulfilling this demand. Decades of research indicate that access to high-quality early learning and is associated with superior academic achievement throughout the lifespan. Despite the broadening role of technology in early childhood, there are limited resources available to ensure the technology is being used to its optimal benefit.

The technology of Augmented Reality has been widely applied in a variety of industries, particularly the sector of education. Technology is paying more and more attention to the usage of applications in the field of education to make the learning process simpler to grasp, more exciting, and participatory by fusing the virtual and real worlds. Because Augmented Reality technology is less expensive, simpler to produce, and has several characteristics that can deliver a distinct learning experience than traditional learning, it has an advantage over VR in the education sector. Users can move virtual things and view them from different perspectives, simulating how they would see and hold a real object [1]. Also, this technology aids pupils' cognitive function, particularly when it comes to navigating spatial perception problems [2]. This Augmented Reality application is a technique that combines the virtual world and reality by using interesting rendering techniques because it will display objects such as 3D, animation, audio, and video by simply scanning the smartphone camera towards a specific image that has been designed [3]. This application is also often used in the construction of a gamification to provide a good experience to users.

Through the use of digital data, Augmented Reality technology seeks to alter how real-world images are seen. By using new methods, the real world can be enhanced with information in real time. Real-time data can be added to the physical world. Real-time computer-generated material is displayed in a variety of industries, including education, medical, robotics, manufacturing, and entertainment. Their article emphasized that digital technology has various applications in the digital era. They recommend that there are basic requirements for understanding Augmented Reality, such as the nature of the technology, architecture, required devices, types of Augmented Reality, benefits, and limitations of its use [4].

The very small field of view of the smartphone camera is the cause of the common problem for users when detecting markers. Camera parameters need to be accurate during detection [5]. The user cannot move to let the object be in the camera's view. If movement occurs, the displayed image will disappear. The use of single marker detection limits the movement of the user to maintain image results.

Once the image is detected, another problem that users face is noise on the image that can interfere with the quality of the time the image is produced. This is due to Augmented Reality based on conventional markers that are easy to be disturbed by noise. So, a marker with a bilateral filter can be used to overcome the problem of noise in the image.

The most important part of an Augmented Reality system is estimating camera poses, whether for virtual or real. This process is called tracking, because the position and orientation of the camera is tracked, while observing a scene that does not contain visual markers. The detection process is done in two stages. From another point of view, the advantage of Augmented Reality

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is often reported to be that it promotes increased learning achievement [6]. Nevertheless, they emphasize that some of the challenges in Augmented Reality as imposed by Augmented Reality are usability issues and frequent technical problems.

Types of Augmented Reality

There have been two types of AR applications reported: marker-based AR and marker-free AR According to [8] there are four kinds of augmented reality: marker-based AR, marker-free AR, projection-based AR, and superimposition-based AR. This study employs marker-based AR because it is appropriate for children, as they must scan the marker to generate a 3D image based on the marker provided.

A picture or marker is used as a marker for the camera to detect objects that are required for the application to transmit the generated image when using marker-based AR applications. When using AR-based applications without markers, the application will use the user's actual location as a reference or marker for the purpose of transmitting computer-generated images. Images are aligned according to the position specified in the application.

Marker-based AR

Marker-based Augmented Reality, also known as image recognition, employs paper-based or physical visual markers found in the real world. Cameras are required to locate specific markers in the real-world environment and serve as reference points for where virtual reality locations will be placed on the scene. The AR application will generate virtual elements and display them on the device screen after detecting AR markers via webcam or mobile camera footage. Color can also be used, according to [9] if the contrast in the image is appropriate. One type of paper-based visual marker is QR codes. In their intervention study, [10] used AR techniques (marker-based, marker-based, or location-based). The findings of the [10] study revealed a positive effect on achievement.

The resulting additional image can be seen on the device screen in real time, with virtual objects adding reality to the marker contact position. The most basic type of augmented reality marker is a black and white image with a 2D barcode [9].

Table 1: Comparison between Marker-Based AR and Marker-Free AR [12]

Comparison Aspects		Marker-Based AR	Marker-Free AR
Method	Angle relative position	Depends on marker	Depends on technology localization and gyroscope
	AR Software Development Kit (SDK)	Commonly used	Rarely used
Determination Position	High/low	Relatively higher	Relatively lower
	Influence factor	Brightness	Technology localization
Stability	High/low	Relatively lower	Higher
	Influence factor	Marker and SDK	Technology localization and gyroscope
Support Hardware	Desktop	Supported	Usually, unsupported
	portability	Supported	Supported

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METHODOLOGY

System Architecture

The system architecture for this project is divided into three parts namely input, process and output. The system for this project starts with image processing where the image will go through several techniques to improve image quality, marker generation using Vuforia SDK to generate in the system, marker detection using SURF techniques to detect key points in the image, marker tracking using homograph techniques to estimating the pose matrix, and finally rendering the 3D object.

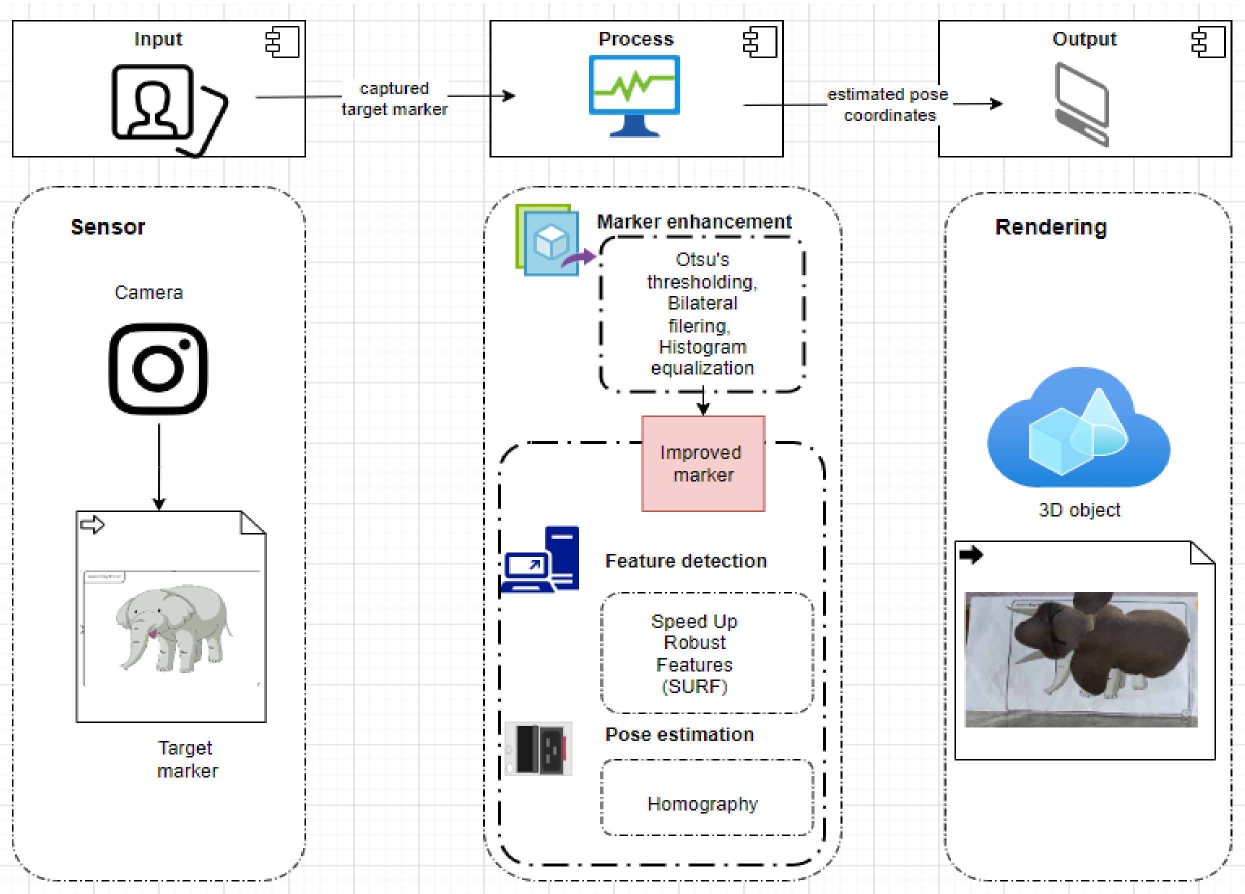

Fig 1: Input-Process-Output for marker detection improvement system

Input

A smartphone camera, native single marker, improved single marker, Unity, and Vuforia software will be used in the development of this application. This study employs the augmented reality single marker technique. Two types of input will be used: mobile device cameras and markers.

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a) Portable Device Camera

The OPPO Reno 6 Pro, which has a camera for the mobile device sensor, was used in this project. Android OS is the operating system in use. Android OS is used because it is popular, and it also has good performance and processing power.

b) Markers

Marker design is critical because it determines whether an augmented reality system will run smoothly. The marker is square because it can carry a greater symbolic load of data than other shapes. A square marker is depicted in Figure 2.

c) Development Tools

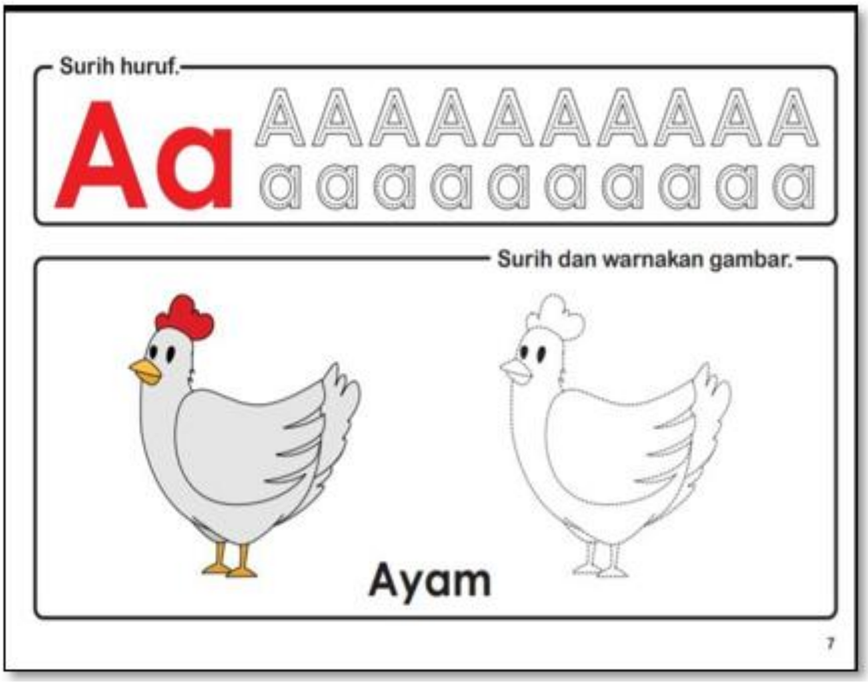

Fig 2: Squared markers example

This program employs design tools that run on the Android operating system. It is classified as follows:

i. 3D computer graphics software
ii. Software development kit (software development kit): Vuforia AR SDK
iii. 3D Engine: Unity 3D
iv. Development environment: C#

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2) Process

The process stage is divided into several sections, including image pre-processing, marker generation, marker detection, marker tracking, and 3D object display.

a) Pre-Processing

During the image processing process, the marker image is used to remove noise and add contrast to the image.

b) Markers Generation

In this project, the Vuforia Augmented Reality SDK is used to generate markers. Qualcomm's Vuforia is an Augmented Reality framework. The Vuforia platform employs superior, robust, and efficient vision-based image recognition computing. It has the most features and capabilities and allows developers to expand their vision without technical constraints.

c) Markers detection

The SURF algorithm (Speed up Robust Features) is a patented local feature detector and descriptor. It can be used for object recognition, image registration, classification, and 3D reconstruction, among other things. It draws inspiration from scale invariant feature change (SIFT) descriptors.

d) Markers Tracking

Marker tracking employs a projection (pose) matrix derived from homograph-extracted features that include virtual object coordinates for magnification. The Homographic coordinates are as follows:

$$\begin{bmatrix} x_i{}' \\ y_i{}' \\ z_i{}' \end{bmatrix} = \begin{bmatrix} h_{00} & h_{10} & h_{20} \\ h_{01} & h_{11} & h_{21} \\ h_{02} & h_{12} & h_{22} \end{bmatrix} \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} = H \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} \quad (1)$$

A homograph, h, in other words, maps coordinate x to coordinates x'. Equation (1) yields the coordinates x' and y' as follows:

$$x' = \frac{h_{00}x+h_{01}y+h_{02}}{h_{20}x+h_{21}y+h_{22}} \quad (2)$$

$$y' = \frac{h_{10}x+h_{11}y+h_{12}}{h_{20}x+h_{21}y+h_{22}} \quad (3)$$

The coordinates x' and y' can also be expressed as a linear equation:

$$x'(h_{20}x + h_{21}y + h_{22}) = h_{00}x + h_{01}y + h_{02} \quad (4)$$

$$y'(h_{20}x + h_{21}y + h_{22}) = h_{10}x + h_{11}y + h_{12} \quad (5)$$

And in matrix form:

$$\begin{pmatrix} x & y & 1 & 0 & 0 & 0 & -x'x & -x'y & -x' \\ 0 & 0 & 0 & x & y & 1 & -y'x & -y'y & -y' \end{pmatrix} h = 0$$

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Nine vector elements containing H elements.

$$\begin{bmatrix} x_0 & y_0 & 1 & 0 & 0 & 0 & -x'_0x_0 & -x'_0y_0 & -x'_0 \\ 0 & 0 & 0 & x_0 & y_0 & 1 & -y'_0x_0 & -y'_0y_0 & -y'_0 \\ x_1 & y_1 & 0 & 0 & 0 & 0 & -x'_1x_1 & -x'_0y_0 & -x'_1 \\ 0 & 0 & 0 & x_1 & y_1 & 1 & -y'_0x_0 & -y'_0y_0 & -y'_0 \\ x_2 & y_2 & 0 & 0 & 0 & 0 & -x'_2x_2 & -x'_0y_0 & -x'_2 \\ 0 & 0 & 0 & x_2 & y_2 & 1 & -y'_0x_0 & -y'_0y_0 & -y'_0 \\ x_3 & y_3 & 0 & 0 & 0 & 0 & -x'_3x_3 & -x'_0y_0 & -x'_3 \\ 0 & 0 & 0 & x_3 & y_3 & 1 & -y'_0x_0 & -y'_0y_0 & -y'_0 \end{bmatrix} h$$

$$= Ah = 0$$

e) Create 3D Objects

3) Output

This project builds and produces applications that interact with users using Application Programming Interface (API) and Graphic User Interface (GUI). API and GUI will be used in tandem to create an application. After the user completes the necessary steps, the 3D object will be displayed on the phone screen after scanning the provided marker image.

B. Experimental Setup

Table VI shows the characteristics and uses of the equipment that will be used for the experimental setup.

Table I: List of equipment used

Equipment	Unit	Characteristics	Use
Smart phone	1	• Phone type: OPPO Reno 6 Pro • Resolution: 1080 × 2400, 20:9 ratio (~ 402 ppi density) • OS: Android 11, upgradable to Android 12, ColorOS 12 • Chipset: Mediatech MT6893 Dimensity 1200 (6 m) • CPU: Octa-core (1 × 3.0 GHz Coretx-A78 & 3× 2.6 GHz Cortex-A78 & 4 × 2.0 GHz Cortex-A55) • GPU: Mali-G77 MC9 • Main Camera (Quad): 64 MP, f/1.7. 26mm (wide), 1/2.0”, 0.7µm, PDAF 8MP, f/2.2, 120° (ultrawide), 1/4.0”, 1.12µm 2MP, f/2.4, (macro) 2MP, f/2.4, (depth)	Capture or detect markers in real-time that will display virtual 3D objects.
Unity	1	Version: 2021.3.11f1	Designing and implementing a visualization programming environment. Develop and implement systems.
Markers	1	• Original markers and improved markers • JPG/PNG • Size less than 2MB	Acts as a marker in the detection of augmented reality.
Distance Indicator	1	20 cm, 30 cm, 40 cm, 50 cm, 60 cm, 80 cm	Distance indicator between the mobile device and the marker.

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Experimental Design (Benchmark)

Several experiments were carried out to study the efficiency and performance of the proposed system to validate it. Table II lists the different types of experiments, as well as the procedures and benchmarks used.

Table II: List of experiments with procedures and benchmarks used in the system for evaluation purposes

Experiment Type	Implementation	Benchmark
Mean square error(MSE) Test [14]	Measure the MSE value to know the quality of the image by importing the image into the system for measurement.	Assess image quality. When the MSE value approaches zero, the image quality is better.
Peak-signal-to-noise ratio (PSNR) Test [14]	Measure the PSNR value to know the quality of the image by importing the image into the system for measurement.	Assess image quality. When the PSNR value is more than 40dB it indicates good image quality. The higher the PSNR value, the higher the quality of the image.
Feature from accelerated segment test (FAST) Detection Test	Measure the key points in the image used to measure as many points as the system can detect on the enhanced marker image and the original marker image.	Evaluate the key points in the traceable marker image.
Marker Distance Test	Detect the marker using the original marker and the improved marker and make a comparison of the distance that can be detected by the original marker and the improved marker.	Evaluate the maximum distance that can be detected with the improved marker. (measured from 20cm to 80cm)

RESULTS AND DISCUSSION

Used Marker Image

Colored marker images were used as markers in this experiment. These are photographs of animals found in Southeast Asia. The images used and image file names for experimental purposes are listed in the table below.

Table III: Used Images and filenames

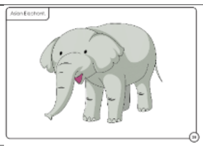
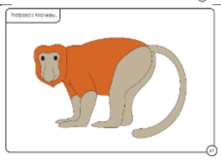
Image Marker	Image Marker Filename
	• Image 1 • Asianelephant.jpg
	• Image 2 • Proboscismonkey.jpg

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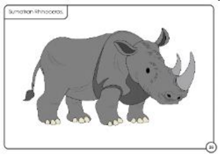
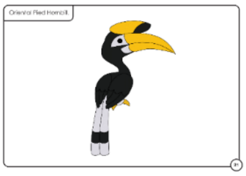
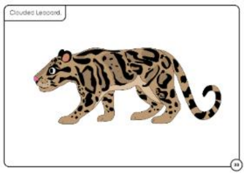
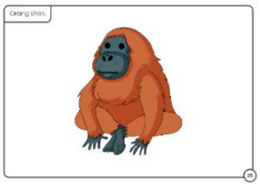
Image Marker	Image Marker Filename
	• Image 3 • SumatranRhinoceros.jpg
	• Image 4 • Slowloris.png
	• Image 5 • Orientalpiedhornbill.png
	• Image 6 • Cloudedleopard.png
	• Image 7 • Orangutan.png

C. Test Results

The image marker is measured using MSE and PSNR to compare the quality of the original and improved marker. As presented in Table IV and Figure 5, the MSE value (in bold) of the improved marker in Image 1, Image 4, and Image 5 shows a lower MSE value compared to the original marker.

Table IV: The MSE value of the original marker and the improved marker

Image Name	Image Filename	Original Marker	Improved Marker
Image 1	Asianelephant.jpeg	63.6987	**29.1749**
Image 2	Proboscismonkey.jpeg	17.6033	24.8222
Image 3	SumatranRhinoceros.jpeg	13.3935	37.6040
Image 4	Slowloris.jpeg	30.8828	**21.1318**
Image 5	Orientalpiedhornbill.png	18.0791	**14.3395**
Image 6	Cloudedleopard.jpeg	15.8544	19.6101
Image 7	Orangutan.jpeg	15.2486	19.2628

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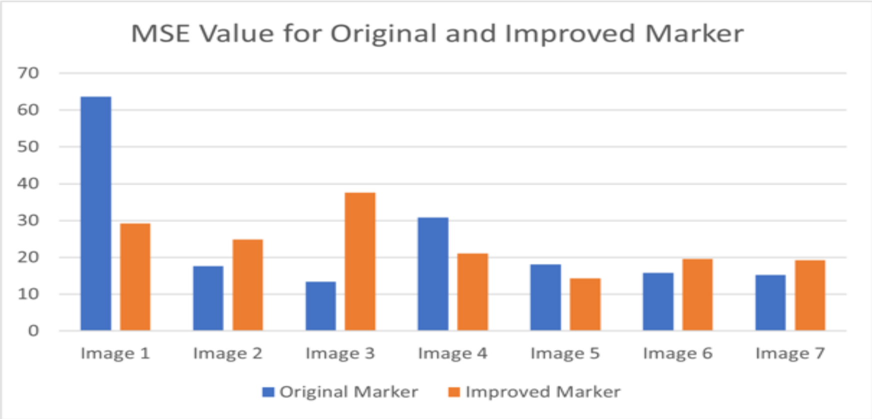

Fig 3: The graph shows the MSE value of the image for the original marker and the improved marker

Whereas the PSNR value (in bold) of the improved marker is higher in all image markers except in Image 3 as presented in Table V and visualized in Figure 6.

Table V: The PSNR value of the original marker and the improved marker

Image Name	Image Filename	Original Marker	Improved Marker
Image 1	Asianelephant.jpeg	33.4629	**33.4807**
Image 2	Proboscismonkey.jpeg	32.0120	**34.1824**
Image 3	SumatranRhinoceros.jpeg	37.4817	32.3785
Image 4	Slowloris.jpeg	34.0458	**34.8814**
Image 5	Orientalpiedhornbill.png	37.7874	**36.5655**
Image 6	Cloudedleopard.jpeg	35.1196	**35.2060**
Image 7	Orangutan.jpeg	34.1759	**35.2836**

From the obtained results, we can say that the applied filtering manages to reduce the noise in the improved image marker measured with a lower MSE and higher PSNR value.

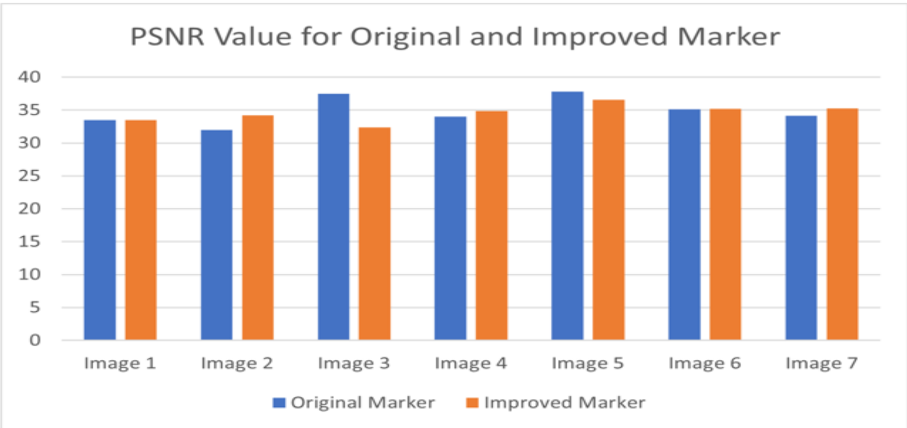

Fig. 4. The graph shows the PSNR value of the image for the original marker and the improved marker.

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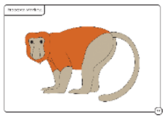
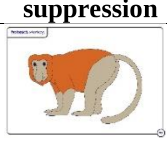
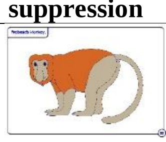
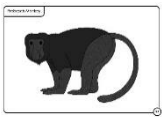
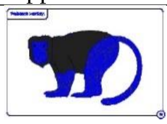
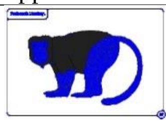
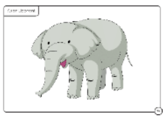
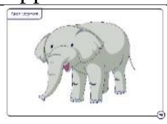
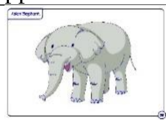
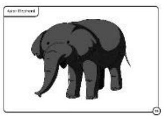
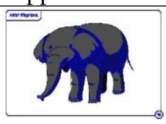
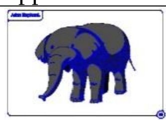
D. FAST Corner Detection Test Results

Results from FAST interest points detection are recorded and presented in Table VI. Generally, more points indicate that the marker is more likely to be detected.

Table VI: Results of the FAST Corner Detection test for the original and improved marker

Marker	Marker Type	With non-maximum suppression	Without non-maximum suppression
	Original Marker	 Total key points with non Suppression: 618	 Total key points without non Suppression: 2636
	Enhanced Marker	 Total key points with non Suppression: 5110	 Total key points without non Suppression: 8166
	Original Marker	 Total key points with non Suppression: 1211	 Total key points without non Suppression: 3682
	Enhanced Marker	 Total key points with non max Suppression: 2135	 Total key points without non max Suppression: 3682

To prove the improved marker is more detectable, star rating of target image marker 1 and 2 in Vuforia are also presented and compared. Figure 7 shows star rating between the original marker and the marker that has been improved rated through feature extraction in Vuforia. The star rating ranges between 1 (low rating) and 5 (highest rating).

Fig 5: Characteristics Detection in Vuforia

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Based on Table VI, it can be concluded that the improved marker has more detectable points compared to the original marker. Meanwhile, Figure 7 shows a comparison of the star rating between the original marker and the improved marker.

E. Distance Test Results between Marker and Camera

The table below shows the results of the marker image distance test with the mobile device camera.

Table VII: Distance Test Results between Marker and Camera

Distance (cm)	Marker Type	
	Original Marker	Improved Marker
20	Detectable	Detectable
30	Detectable	Detectable
40	Detectable	Detectable
50	Detectable	Detectable
60	Detectable	Detectable
70	Undetectable	Detectable
80	Undetectable	Detectable

Table VIII shows the output of the distance test results between the marker image and the mobile device camera in image form.

Table VIII: Rendered object of the distance test results

Distance (in cm)	Output		Discussion	
	Original marker	Improved marker	Original marker	Improved marker
20			Able to detect and render a 3D object	Able to detect and render a 3D object
30			Able to detect and render a 3D object	Able to detect and render a 3D object

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Distance (in cm)	Output		Discussion	
	Original marker	Improved marker	Original marker	Improved marker
40			Able to detect and render a 3D object	Able to detect and render a 3D object
50			Able to detect and render a 3D object	Able to detect and render a 3D object
60			Able to detect and render a 3D object	Able to detect and render a 3D object
70			Not able to detect and render a 3D object as indicated in red circle	**Able to detect and render a 3D object**
80			Not able to detect and render a 3D object as indicated in red circle	**Able to detect and render a 3D object**

Based on the tables and figures in Table VIII, the improved marker can be detected by the mobile device camera at 20 cm, 30 cm, 40 cm, 50 cm, 60 cm, 70 cm, and 80 cm. While the camera failed to detect the original marker at 70 cm and 80 cm. This limitation is contributed by the interest point visibility and the smaller size of the marker at that range. This test has proven that the improved marker image can be detected by the mobile device camera at a greater distance compared to the original marker image.

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CONCLUSION

Four tests have been performed, analyzed, and discussed. All of the tests have shown that the markers have been improved using image processing techniques such as the Bilateral filter and Histogram Equalization are suitable, as demonstrated by the study conducted by [14] and [10], yielding better results than the original markers. The combination of bilateral techniques and histogram equalization applied to the marker image can improve its quality. Based on the results of the tests, the results show that the image quality improves, and the detection of markers improves as well. However, further research is required to improve marker-based augmented reality systems, as studies show that augmented reality systems have a very high potential today.

References

1) Billinghurst, M. (2003). Augmented reality in education. New Horizons for Learning, pp. 12.
2) Scheiter, K., Wiebe, E. & Holsanove, J. (2009). Theoritical and instructional aspects of learning with visualizations. Dlm. R. Zheng (pnyt.). Cognitive effects on multimedia learning, pp. 67-88. USA: Information Science Reference (an imprint of IGI Global)
3) Ramli, R., Nordin, F, N. & Ahmad Sokri, N, E. (2018). Teknologi Realiti Luasan: Satu Kajian Lepas. e-Journal Penyelidikan dan Inovasi, 5(1), pp. 17-27.
4) Dargan, S, N., Bansal, S. & Kumar, M. (2022). Augmented Reality: A Comprehensive Review. Archives of Computational Methods in Engineering. https://doi.org/10.1007/s11831-022-09831-7.
5) Siltanen, S. (2012). Theory and Application of Marker-Based Augmented Reality.
6) Akçayır, M. & Akçayır. G. (2017). Advantages and Challenges Associated with Augmented Reality for Education: A Systematic Review of the Literature. Educational Research Review, 20, pp. 1-11. https://doi.org/10.1016/j/edurev.2016.11.002.
7) Azuma, R, T. (1997). A survey of augmented reality. International Journal of Presence: Teleoperators and Virtual Environment, 6(4), pp. 355-385. https://doi.org/.1162/pres.1997.6.4.355.
8) Edwards-Stewart, A., Hoyt, T., & Reger, G. (2016). Classifying different types of augmented reality technology. Annual Review of CyberTherapy and Telemedicine, 14, 199-202.
9) Katiyar, A., Kalra, K. & Garg, C. (2015). Maker Based Augmented Reality. Advance in Computer Science and Information Technology, 2(5), pp. 441-445.
10) Xu, WW., Su, CY., Hu, Y. et al. Exploring the Effectiveness and Moderators of Augmented Reality on Science Learning: A Meta-analysis. J Sci Educ Technol 31, 621–637 (2022). https://doi.org/10.1007/s10956-022-09982-z
11) Cheng, J. C., Chen, K., & Chen, W. (2017). Comparison of marker-based AR and marker-less AR: a case study on indoor decoration system. In Lean and Computing in Construction Congress (LC3): Proceedings of the Joint Conference on Computing in Construction (JC3) (pp. 483-490).
12) Amin, D. & Govilkar, S. (2015). Comparative Study of Augmented Reality Sdk's. International Journal on Computational Science & Applications. 5(1), pp. 11-26. https://doi.org/10.5121/ijcsa.2015.5102.
13) Fernandes, S., Vashi, H., Shetty, A. & Kelkar, V. (2019). Adaptive Contrast Enhancement using Fuzzy Logic. 2019 International Conference on Advances in Computing, Communication and Control (ICAC3), 20-21 December 2019, Mumbai, India, ms. 1-6.
14) Li, C., Liu, J., Zhu, J., Zhang, W., & Bi, L. (2022). Mine image enhancement using adaptive bilateral gamma adjustment and double plateaus histogram equalization. Multimedia Tools and Applications, 81(9), 12643-12660.