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# INTEGRATION OF MACHINE LEARNING AND AUGMENTED REALITY FOR MALAY CULTURAL HERITAGE

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***ABSTRACT***

*Cultural heritage digitization has become an essential strategy for preserving local heritage through the adoption of emerging digital technologies. This study aims to investigate the integration of Machine Learning and Augmented Reality (AR) for preserving and promoting Malay cultural heritage. A descriptive research approach was employed through literature review, field observations, image acquisition, and cultural object documentation. The research data consisted of digital images and descriptive information of Malay cultural heritage objects collected from five cultural sites: Maimun Palace, North Sumatra State Museum, Deli Serdang Museum, Tebing Tinggi Museum, and Batubara Museum. The collected cultural objects were curated and classified according to their visual characteristics and historical significance to establish a structured dataset suitable for Machine Learning-based object recognition and AR integration. The results demonstrate that the proposed data collection and classification process successfully produced a well-organized cultural heritage dataset capable of supporting automatic object recognition and interactive visualization in an AR environment. The integration of Machine Learning and Augmented Reality provides an effective foundation for developing intelligent digital cultural applications that enhance public engagement while supporting the preservation, promotion, and accessibility of Malay cultural heritage.*

# INTRODUCTION

Advances in digital technology have shifted the paradigm of cultural heritage preservation from conventional approaches toward digital systems that are more interactive, immersive, and accessible to the general public (Revianur, 2020; Boboc et al., 2022). This transformation has made the digitization of culture one of the key strategies for ensuring the sustainability of historical values and cultural identity in the modern era (Nugroho et al., 2024).

Augmented Reality (AR) has become an increasingly relevant digital approach in cultural heritage preservation because it can combine virtual elements with the real environment in real time, thereby providing a more interactive, immersive, and contextual experience for users (Kartini et al., 2024). In the context of education and cultural preservation, AR serves not only as a visualization tool but also as a means to enhance the public's understanding of historical objects through more vivid and accessible digital representations (Dawis et al., 2024).

On the other hand, Machine Learning (ML), as part of Artificial Intelligence, enables systems to learn patterns from visual data and automatically classify objects with a high degree of accuracy (Harisanty et al., 2024). In the field of cultural heritage, this approach has the potential to be used for identifying artifacts, classifying motifs, and grouping cultural objects based on digital images more efficiently and consistently. The combination of AR and ML is also considered strategic because it can enhance the user experience while improving the system's ability to intelligently recognize cultural objects (Rizki et al., 2022).

Nevertheless, various studies indicate that the development of AR and ML for cultural preservation is still often conducted in isolation, meaning that integration between these technologies has not yet been maximized (Bakti et al., 2023). Another prominent challenge is the scarcity of structured, well-documented, and representative cultural datasets, particularly for local cultural contexts characterized by complex visual and historical variations. This situation highlights the need for a more systematic approach to data collection, image annotation, and the development of AI-based models to support sustainable cultural preservation (Karim et al., 2025).

The Malay cultural context in the city of Medan and its surrounding areas underscores this urgency, given that many historical and cultural objects are still primarily presented through conventional media that are relatively less interactive (Laudra et al., 2021). Several buildings, artifacts, and cultural sites scattered throughout the region require digital strategies to make them more accessible to the public, particularly the younger generation who are familiar with visual media and mobile devices. Therefore, the integration of AR and ML can serve as an appropriate

approach to expand access, enhance the learning experience, and strengthen public understanding of the historical value and cultural identity of the Malay people (Nasution et al., 2019).

## RESEARCH METHODS

This study uses a descriptive approach to examine the integration of machine learning and augmented reality in the preservation of Malay cultural heritage. The research stages include data acquisition, image preprocessing, dataset labeling, training a machine learning model using MobileNetV2, cultural object recognition, and augmented reality visualization.

Research data was obtained through field observations and digital documentation at five Malay cultural heritage sites in North Sumatra: Maimun Palace, the North Sumatra Provincial Museum, the Deli Serdang Museum, the Tebing Tinggi Museum, and the Batubara Museum. Each cultural object was documented using a digital camera to capture images that were used as the research dataset.

The dataset that was successfully collected consists of 50 cultural objects with 50 digital images. The distribution of the dataset is shown in Table .

Table 1. Distribution of the Malay Cultural Heritage Dataset

| No | Location | Number of Objects | Number of Images |
|---|---|---|---|
| 1 | Istana Maimun | 10 | 10 |
| 2 | Museum Negeri Sumatera Utara | 10 | 10 |
| 3 | Museum Deli Serdang | 10 | 10 |
| 4 | Museum Tebing Tinggi | 10 | 10 |
| 5 | Museum Batubara | 10 | 10 |
| Total | | 50 | 50 |

The dataset is represented as:

$$\boldsymbol{D = \{(x_i, y_i)\}_{i=1}^{50}} \quad \textbf{1}$$

where $\boldsymbol{x_i}$ is an image of a cultural object and $\boldsymbol{y_i}$ is the category label for that cultural object.

All images were processed through a preprocessing stage that included image resizing, normalization, and grouping by cultural object category. The normalization process was performed to improve data consistency and reduce the effects of lighting variations during image acquisition.

Image normalization was performed using the following equation:

$$X' = \frac{x - min(x)}{\max(x) - \min(x)} \quad \textbf{2}$$

where (x) is the original pixel value and (x') is the normalized pixel value.

After preprocessing, each image was labeled according to its cultural object category to form a structured dataset ready for use in the machine learning model training process.

This study used the MobileNetV2 architecture as the machine learning model to recognize Malay cultural heritage objects. MobileNetV2 was chosen because it has low computational complexity, a lightweight model size, and is still capable of delivering good classification performance on mobile devices. The dataset was divided into a training set (80%) and a testing set (20%). Of the total 50 available images, 40 were used for model training and 10 were used for testing.

Table 2. Dataset Split

| Dataset | Percentage | Number of Images |
|---|---|---|
| Training | 80% | 40 |
| Testing | 20% | 10 |
| Total | 100% | 50 |

The feature extraction process using MobileNetV2 is formulated as follows:

$$f_i = \phi(x_i) \quad \textbf{3}$$

where $x_i$ is the input image, ϕ is the MobileNetV2 feature extraction function, and $f_i$ is the resulting feature vector (Sandler et al., 2018b).

Next, the process of classifying cultural objects is described as follows:

$$\hat{y} = f(x) \quad (4)$$

where (x) is the input image and ŷ is the predicted category of the cultural object (Tharwat & Schenck, 2023).

Cultural objects successfully identified by the MobileNetV2 model are then integrated into the Augmented Reality system. The system displays digital information related to the cultural objects, such as the object's name, historical description, cultural value, and multimedia visualizations in real time.

The integration of Machine Learning and Augmented Reality can be described as:

$$\boldsymbol{AR_{\{CH\}} = f(ML(D), M)} \quad (5)$$

where $\boldsymbol{AR_{\{CH\}}}$is an augmented reality system for cultural heritage, (ML(D)) is the result of object recognition from a cultural dataset, and (M) is the cultural metadata displayed to the user (Rinaldi et al., 2022).

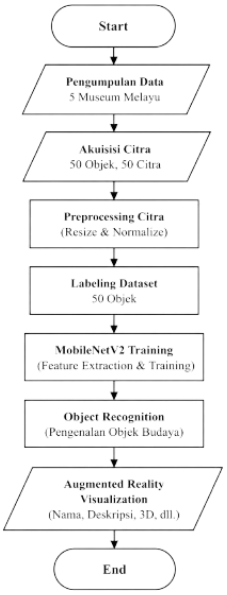



Figure 1. Overall research flowchart

Figure 1 illustrates the research framework, which consists of the following stages: data collection, image acquisition, preprocessing, dataset labeling, MobileNetV2 model training, cultural object recognition, and augmented reality visualization. This workflow is used to build a digital system capable of recognizing and presenting information about Malay cultural heritage in an interactive manner.

## RESULTS AND DISCUSSION

### A. RESULT

This study successfully collected and documented 50 objects of Malay cultural heritage from five cultural sites in North Sumatra: Maimun Palace, the North Sumatra Provincial Museum, the Deli Serdang Museum, the Tebing Tinggi Museum, and the Batubara Museum. The collected objects span various cultural categories that represent the social, cultural, and historical life of the Malay people.

The cultural objects successfully documented include traditional clothing, traditional weapons, cannons, royal thrones, chairs, traditional household items, and various other cultural artifacts. All objects were documented in the form of digital images and descriptive information to support the process of classification and digital visualization.

Table 3. Categories of Cultural Objects

| No | Object Category | Example of an Object |
|---|---|---|
| 1 | Pakaian Adat | Baju Melayu, Tengkolok |
| 2 | Senjata Tradisional | Keris, Tombak |
| 3 | Alat Perang | Meriam |
| 4 | Perlengkapan Kerajaan | Singgasana, Payung Kerajaan |
| 5 | Perabot Tradisional | Kursi, Meja |

The results of the data collection indicate that Malay cultural heritage comprises a wide variety of objects and has the potential to be developed into a digital dataset that supports technology-based cultural preservation.

After the data acquisition process was completed, all images underwent a preprocessing stage that included image resizing, normalization, and dataset labeling. This stage aimed to improve data quality and produce a consistent dataset for use in the object recognition process.

The total dataset consisted of 50 images, which were then divided into training and testing data using an 80:20 ratio.

Table 4. Dataset Split

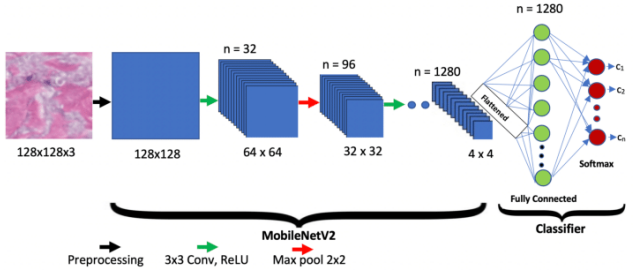
| Dataset | Number of Images | Percentage |
|---|---|---|
| Training | 40 | 80% |
| Testing | 10 | 20% |
| Total | 50 | 100% |

The labeling process is performed manually based on the names and categories of cultural objects. The labeling process produces a structured dataset that is ready for use in training machine learning models.


Figure 2. Dataset of Malay Cultural Objects

The MobileNetV2 model was used as the primary architecture in the process of feature extraction and recognition of Malay cultural objects. MobileNetV2 was chosen because of its lightweight and efficient model size, making it suitable for implementation in mobile-based applications and WebAR.

In this study, MobileNetV2 was used to analyze the visual characteristics of each cultural object in the dataset. The training process was conducted using data that had undergone preprocessing and labeling.




Gambar 3. Arsitektur MobileNetV2 untuk Pengenalan Objek Budaya

The results of cultural object recognition are integrated into the WebAR application to provide users with an interactive experience. When a cultural object is recognized by the system, the application displays digital information, including the object's name and a historical description related to it.

The WebAR implementation allows users to access cultural information directly through mobile devices without needing to install additional applications. This approach enhances accessibility and ease of use in the cultural learning process.

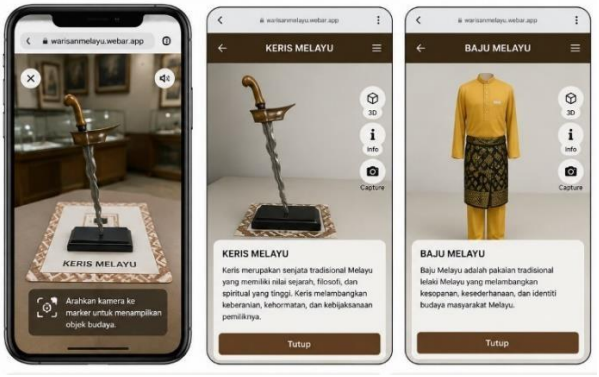



Figure 4. WebAR View of Malay Cultural Objects

The visualizations displayed include images of cultural objects, the names of the objects, and information about their history and cultural significance. As a result, users can access cultural information in a more interactive way than with conventional methods.

## B. DISCUSSION

The findings suggest that the integration of Machine Learning and WebAR offers significant potential for supporting the preservation of Malay cultural heritage. The digitization process, including dataset collection and image labeling, provides a structured foundation for developing an automated cultural object recognition system.

MobileNetV2 enables efficient and lightweight image classification, while WebAR delivers interactive cultural information that can be easily accessed through mobile devices. Together, these technologies support digital documentation and enhance user engagement in learning about Malay history and culture.

Beyond educational applications, the proposed system also has potential as a digital platform for cultural promotion and tourism. By presenting cultural information in an accessible and interactive format, it can help introduce Malay heritage to a broader audience while contributing to sustainable preservation efforts in the digital era..

## CONCLUSION

This study developed a digital framework for preserving Malay cultural heritage by integrating machine learning and Web Augmented Reality (WebAR). A total of 50 cultural artifacts from five museums in North Sumatra were documented and organized into a structured dataset, which was used to support object recognition using MobileNetV2 and interactive cultural information delivery through WebAR.

The results indicate that the integration of AI-based object recognition and AR visualization can improve access to cultural information while providing a more engaging learning experience. This approach contributes to the digital preservation, education, and promotion of Malay cultural heritage.

Although the current work focuses on dataset development and framework design, the findings demonstrate strong potential for broader implementation. Future research should expand the dataset, conduct comprehensive performance evaluations, and incorporate advanced features such as 3D models and richer interactive content to further enhance user experience and cultural engagement..

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