Research Article

Harnessing the Power of Generative Adversarial Networks (GANs) for Novel Batik Designs: An Exploration of Lightweight GANs (LGANs) for Automatic Batik Design

Muhammad Abdul Latiff[1], Ihsan Yassin[2], Azlee Zabidi[3], Nur Qamarina Binti Mohd Noor[2], Farzad Eskandari[4], Rajeswari Raju[5], Azlinda Saadon[1], Megat Syahirul Amin Megat Ali[6]

1. College of Engineering, Universiti Teknologi Mara, Malaysia; 2. Microwave Research Institute, Universiti Teknologi Mara, Malaysia; 3. College of Computing & Applied Sciences, University Malaysia Pahang, Malaysia; 4. Department of Statistics, Allameh Tabataba'i University, Tehran, Iran; 5. UiTM Cawangan Terengganu Kampus Dungun, Universiti Teknologi Mara, Malaysia; 6. Universiti Teknologi Mara, Malaysia

This study proposes the use of Generative Adversarial Networks (GANs), specifically Lightweight GANs (LGANs), as a novel approach to revitalize the batik industry in Malaysia and Indonesia, which is currently experiencing a decline in interest among young artists. By automating the generation of innovative batik designs, this technology aims to bridge the gap between traditional craftsmanship and modern innovation, offering a significant opportunity for economic upliftment and skill development for the economically underprivileged B40 community. LGANs are chosen for their efficiency in training and their capability to produce high-quality outputs, making them particularly suited for creating intricate batik patterns. The research evaluates LGANs' effectiveness in generating novel batik designs, comparing the results with those of traditional manual methods. Findings suggest that LGANs are not only capable of producing distinctive and complex designs but also do so with greater efficiency and accuracy, demonstrating the potential of this technology to attract young artists and provide sustainable income opportunities for the B40 community. This study highlights the synergy between artificial intelligence and traditional artistry as a promising direction for revitalizing the batik industry, expanding its global reach, and preserving cultural heritage while fostering innovation and inclusivity.

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Corresponding author: Ihsan Yassin, ihsan_yassin@uitm.edu.my

Introduction

Batik, an ancient form of wax-resistant dyed cloth, has been a part of the cultures of Malaysia and Indonesia for centuries [1]. This art form has been used to tell stories, express identity, and convey spiritual beliefs. The history of Batik art can be traced back to the 8th century when it was first practiced in India [2] and later adopted by Hindu Java islanders in Indonesia [3]. The designs were initially used for ceremonial purposes as an expression of religious devotion. Over time, the art form spread throughout Indonesia and Malaysia and became increasingly popular among all classes of people as a form of personal adornment. Batik is highly valued in both Indonesia and Malaysia as a representation of culture heritage and identity [4]. The timeless design has also been used in contemporary fashion items like clothing or accessories [5], and decoration for interior design [6], [7].

To highlight the importance of the batik industry, the economics of the industry in Malaysia and Indonesia are explored here, focusing on its current market size and structure, its potential for growth, and its implications for economic development in both countries. The industry is an important contributor to the economies of both Malaysia and Indonesia primarily through its small-scale producers [8]. For example, the Indonesian Batik industry experienced rapid export growth from USD 22 million in 2010 to USD 340 million in 2014, and this trend is expected to continue to 1.5 billion in 2021 [8]. Similarly, the current state of Malaysian batik remains strong despite competition from foreign markets due primarily to their superior quality compared with other international brands. In addition, the artform has been recognized by United Nations Educational, Scientific and Cultural Organization (UNESCO) as an intangible cultural heritage, increasing its international popularity. Realizing the potential growth of the Malaysian batik industry, there has been an increasing focus on promoting local production through government initiatives such as tax incentives [9] and dedicated funds for research and development [10]. Additionally, government initiatives have also helped bolster demand by promoting local designs through international trade with worldwide audience. In Indonesia, there has been a similar trend towards greater investment in local production with particular focus on modernizing manufacturing techniques and to improve production efficiency [11].

Artificial Intelligence (AI) approaches offer contemporary solutions to this issue. One such approach, the Generative Adversarial Networks (GANs), are deep learning algorithms consisting of two

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competing neural networks, a generator and a discriminator that work together to generate new, synthetic data that resembles the original training data in a zero-sum game [12]. The generator works by taking random noise as input, which is then processed through a series of layers to produce an output that resembles real data, such as images or sounds [13]. This output is then fed into the discriminator, which attempts to classify whether it was generated or real. The two networks compete against one another in a process called adversarial training until the generator produces results that cannot be distinguished from real data by the discriminator. As both networks gradually perform better, the synthesized outputs begin to resemble the actual samples. This discovery has significantly advanced research in AI in several ways due to their ability to learn representations quickly and accurately while also allowing for creative applications such as generating images based on text descriptions or audio clips as sophisticated generative models to generate samples from noise without a priori knowledge about the data distribution. GANs have been used successfully for image generation tasks such as face generation [14], image super-resolution [15], [16], style transfer [17], [18], [19], and many other applications.

Batik fabric is traditionally highly detailed, featuring intricate patterns and motifs that require immense creativity, as they must develop the overall design, color palette, and individual motifs. Dwindling youth interest, coupled with the advancing age of batik artisans could cause this beautiful traditional art to be lost forever. Until recently, art is difficult for computers to understand, let alone replicate as computers do not have the ability to understand the emotions, subtleties, and context of a piece of artwork like humans. Additionally, computers lack the creativity and imagination that humans have, which is essential in the creative process.

Despite its recognition by UNESCO and incorporation into contemporary fashion and interior design, the batik industry faces challenges such as dwindling interest from youth and competition from foreign markets. These challenges are exacerbated for Malaysia's B40 community, the lower income bracket comprising 40% of households, who encounter barriers in entering the batik industry due to financial, educational, and infrastructural limitations.

Assisting B40s through Batik

In Malaysia, the term B40 identifies the bottom 40% of households by income, indicating the segment with the lowest income levels. This classification, part of a broader socio-economic framework by the Malaysian government, aims to guide economic planning, policy making, and targeted assistance programs, dividing the population into B40, M40 (middle-income), and T20 (top income earners) categories. The government's focus on the B40 category seeks to address income disparity through policies designed to enhance living standards by providing education, healthcare, housing, financial aid, and opportunities for economic mobility, thereby promoting equitable growth, and improving social welfare nationwide. However, the B40 community faces significant challenges in entering industries like batik, including financial constraints, skill and education gaps, competitive market access, insufficient infrastructure, and cultural barriers. These obstacles highlight the need for comprehensive support systems and initiatives to foster inclusivity and diversity within the batik industry, ensuring full participation and benefit for the B40 community from this culturally and economically important sector.

Batik offers a vital pathway for uplifting the B40 community, the lowest 40% income earners. This is because the integration of batik with contemporary development strategies presents a model for leveraging traditional arts to advance societal progress, highlighting its role in the economic and cultural upliftment of Malaysia's B40 community. This craft, notable for its wax-resistant dyeing technique, not only fosters economic empowerment and cultural preservation but also enhances social inclusion and community development among underprivileged groups. Through skill development, employment opportunities, and entrepreneurship, batik empowers the B40 community, particularly enabling women to improve their family incomes and social status. Additionally, batik contributes to cultural continuity and boosts tourism by attracting visitors interested in authentic experiences, thereby increasing income through workshops and sales.

Moreover, batik's potential could be amplified as a platform for educational programs that cover business management, marketing, and digital literacy, preparing the B40 community for the modern economy. Innovative strategies to access markets, such as using online platforms and partnerships with designers, extend batik's reach both nationally and internationally. These benefits necessitate a collaborative effort from the government, NGOs, and the private sector, with support mechanisms like financial aid and marketing assistance crucial for the batik enterprises' growth among the B40.

Problem Statement

Batik fabric, known for its highly detailed and intricate patterns, embodies a traditional art form that requires immense creativity and skill. The process of developing the overall design, color palette, and individual motifs demands a deep understanding of the art, making it a precious cultural heritage.

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However, this beautiful tradition faces the threat of being lost forever, with dwindling interest from the youth and the advancing age of batik artisans highlighting a concerning trend. The challenge is compounded by the inherent difficulty computers face in replicating such art, as they lack the ability to grasp the emotions, subtleties, and context that human artists imbue into their work, not to mention the essential creativity and imagination.

Furthermore, despite the recognition of batik by UNESCO and its integration into contemporary fashion and interior design, the industry confronts significant challenges. Among these are the dwindling interest from younger generations and stiff competition from foreign markets. These issues are particularly acute for Malaysia's B40 community, which represents the bottom 40% of households by income. This segment of the population faces numerous barriers when attempting to enter the batik industry, including financial constraints, lack of educational opportunities, and infrastructural limitations. These factors collectively exacerbate the challenges faced by the batik industry, threatening its sustainability and the preservation of its rich cultural heritage.

Proposed Solution

To address these challenges, the integration of Generative Adversarial Networks (GANs) into the batik design process is proposed. This solution leverages the power of AI to generate novel batik patterns that are both innovative and reflective of traditional batik artistry. By training GANs on a diverse dataset of existing batik designs, including geometric, floral, faunal, and nature-inspired motifs, the technology can produce a wide array of new designs that maintain the essence of traditional batik while introducing fresh, contemporary elements.

The proposed solution aims to significantly reduce the time and effort required to create unique batik designs, thereby increasing the efficiency and productivity of designers and artisans. This approach also opens opportunities for experimentation with patterns, enabling the batik industry to adapt more rapidly to changing fashion trends and consumer demands. Furthermore, the digitization of traditional motifs through this process aids in the preservation of cultural heritage, ensuring that these designs are not lost to future generations.

To address these issues and revitalize the batik industry, this paper proposes the use of Generative Adversarial Networks (GANs), specifically Lightweight GANs (LGANs), for batik design. LGANs, known for their efficient training and ability to generate high-quality images with limited samples, offer a novel approach to creating diverse and intricate batik patterns. This integration of AI with traditional craftsmanship aims to democratize design creativity, reduce production costs, and preserve cultural motifs, thereby providing economic upliftment and skill development opportunities for the B40 community. By enhancing design productivity and market responsiveness, LGANs present a viable solution for preserving the cultural heritage of batik while fostering economic development and inclusivity within the industry.

The LGAN was presented in [20] as a computationally efficient method to generate high-quality images from samples was presented. The so-called Lightweight GAN (LGAN) architecture achieved excellent results, capable of generating 1,024x1,024 resolution images with incredible speed and limited samples. It does this by increasing the number of training data by performing a series of augmentations on the samples, as well as introduction of the skip-layer channel-wise excitation module to the network structure and a self-supervised discriminator trained as a feature-encoder. This combination of speed and limited samples was previously unheard of in GAN research circles as GANs typically require astoundingly long training times on an incredible number of samples to generate convincing synthetic samples. The authors described that the LGAN was capable of being trained on a single RTX-2080 Graphics Processing Unit (GPU) (relatively low-end hardware) for only a few hours of training while maintaining consistent performance even with fewer than 100 training samples. The network was successfully tested on thirteen datasets covering a variety of image domains, showing its robustness under different settings. Realizing the potential of this new architecture, this paper presents a method for Batik design using LGAN.

Organization of this Paper

The methodology for training the LGAN is presented in Section 2, followed by the results and discussion in Section 3. Finally, concluding remarks are presented in Section 4.

Materials & Methods

The hardware and software specifications of the computer used for training the model is shown in Table 1. The system configuration includes a Central Processing Unit (CPU) from AMD™, specifically the Threadripper 3990x. Training the LGAN was performed using a NVIDIA RTX 3090 Ti graphics card with 10,752 Compute Unified Device Architecture (CUDA) cores. CUDA is primarily used for developing high-performance applications that require large amounts of computational power, such as scientific simulations, data analytics, and machine learning by executing simultaneous instructions on multiple Graphics Processing Unit (GPU) cores, providing significant performance improvements.

Item	Specification
CPU	AMD Threadripper 3990x
Random Access Memory (RAM)	64 GB DDR4
GPU	RTX 3090 Ti

Table 1. Specifications of computer used for the experiment.

Four main activities were performed in this research, as described in Figure 1. The dataset consisted of 5,403 images of batik patterns collected from various stock photograph websites such as pexels.com, istockphoto.com, kaggle.com and pixabay.com. These images were used as the original data to train the GANs software and produce the generated samples. To ensure that the LGAN can discover and recognize the unique motifs and patterns, the samples were selected such that the resolution (width and length) must be at least 500 pixels. The samples were then rescaled using an AI-based image scaling software (Topaz Gigapixel AI) to remove artefacts and improve the samples' details. To maximize the number of samples and assist the LGAN to generalize better, several types of augmentations were performed on the original samples, including random adjustment of brightness, saturation, contrast; the movement of pictures along the x- and y-axes; and the generation of random black boxes to hide certain sections of the image samples.

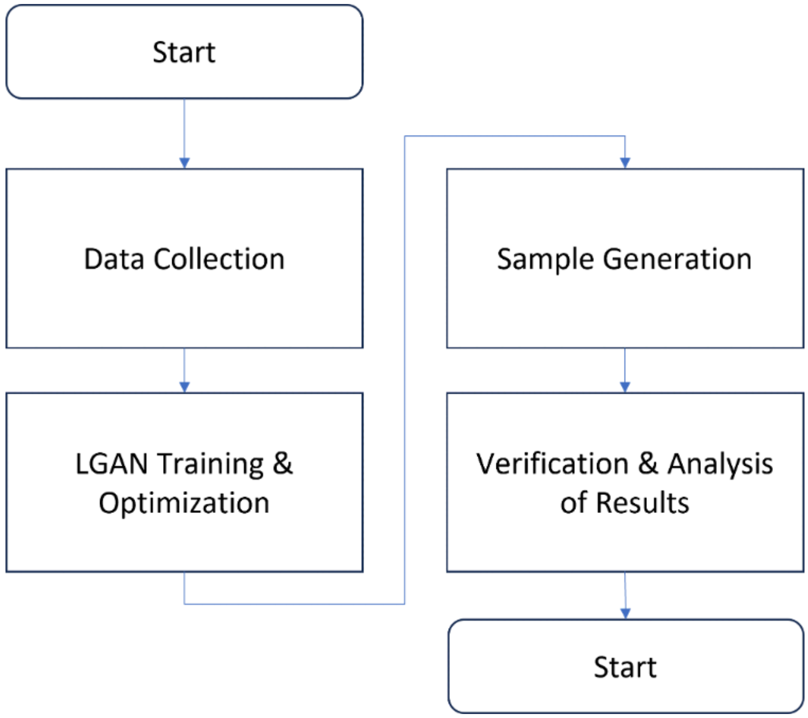

Figure 1. Research methodology

Training the LGAN models requires careful optimization of non-convex objectives with many local minima, making the process difficult and time-consuming. To address this challenge, researchers have proposed various gradient-based optimization algorithms such as Stochastic Gradient Descent (SGD), Adaptive Gradient Algorithm (Adagrad) and Root Mean Square Propagation (RMSProp), which attempt to find optimal parameters for deep learning models. Adaptive Moment Estimation (ADAM), the algorithm used to train the LGAN, is an algorithm that combines ideas from both momentum and RMSProp methods into a single unified framework with several advantages over existing approaches. Adam is an optimization algorithm for training deep learning proposed by Kingma and Ba [21]. It combines the advantages of AdaGrad and RMSProp. ADAM is simple to implement, computationally efficient, requires little memory and works well with large data/parameters. Additionally, it is appropriate for non-stationary objectives and noisy/sparse gradients. The hyper-parameters have an intuitive interpretation and require little tuning. The algorithm has been proven to converge relatively quickly in comparison to other optimization algorithms such as SGD, while providing more robust performance across many training cases.

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Results & Discussion

As mentioned in the previous section, the original samples were resized to 1,024 × 1,024 pixels using Topaz™ GigaPixel AI software. The software implements a novel AI-based approach to image scaling and enhancement. This software solution utilizes an adaptive upscaling ratio that analyzes the image structure and content, thereby preserving the integrity of the image and minimizing the introduction of artifacts or distortions. The resultant enlargements exhibit a high degree of accuracy and fidelity, making them suitable for a wide range of applications in photography, graphic design, and digital art. Several upscaling samples are shown in Figure 2.

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Figure 2. Intelligent upscaling results. Different from traditional methods, AI upscaling estimates and fills in visual details lost in the original low-resolution images – resulting in markedly better detail reconstruction and sharpness when resized.

AI image upscaling offers several advantages compared to standard upscaling techniques. Intelligent upscaling methods are trained on large datasets, enabling them to adapt to various types of images and scenarios, including those with complex textures and shapes. Through this intensive training process, the algorithm can learn the underlying patterns and structures within images, allowing for higher quality, more accurate and detailed enhancement of low-resolution images with less noise and artifacts. In contrast, conventional upscaling approaches often rely on interpolation or extrapolation methods, which may produce blurry or distorted output images.

The LGAN was trained for 200,000 epochs, using approximately 168 hours of computing time. The results are shown in Figure 3. During the initial part of training, the generated images had no discernible patterns, making it difficult to distinguish the batik images. However, as the generator and discriminator training progressed, the synthesized images gradually improved as the LGAN fine-tuned its learned characteristics. At approximately 75,000 epochs, some patterns began to emerge as floral patterns, a commonly used motif in the original samples. Several synthetic images contained black boxes due to the preprocessing method used by LGAN to generate more dataset samples before training.

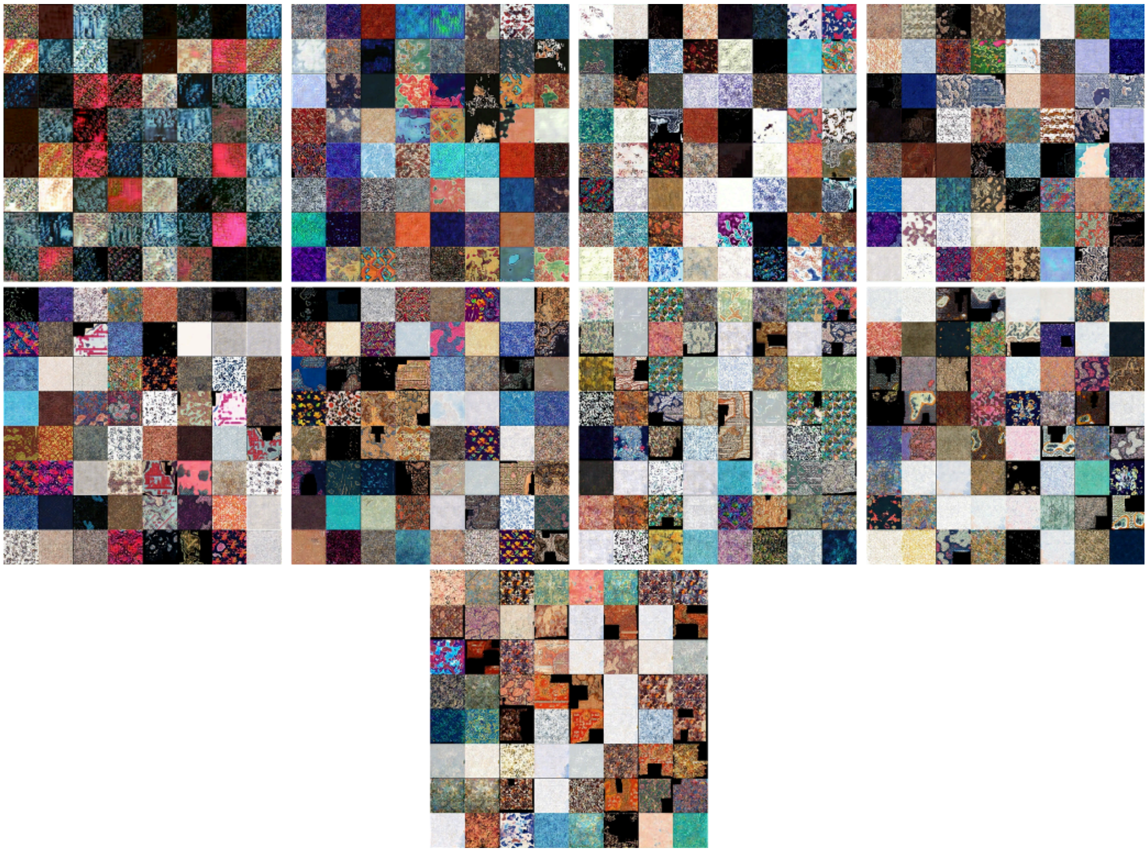

Figure 3. GAN synthesis performance (from top left, first row: 0, 25,000, 50,000, 75,000, 100,000, 125,000, 150,000, 175,000, 200,000 epochs).

To validate the post-training results, 15,000 images were generated using the LGAN. Table 2 displays the results of this analysis in the form of the distribution of the generated pictures. From the total number of samples, the LGAN produced approximately 86.74% of batik or batik-like patterns, indicating that the LGAN was able to generate a wide range of images. Several examples of successfully generated photos are shown in Figure 4. Samples from the 1,989 rejected patterns are shown in Figure 5 due to them being unclear and missing some details that makes the patterns appear defective.

Despite showing great promise in generating batik-like images, LGANs face certain challenges that need to be addressed. One limitation is the occasional appearance of "boxy" or "lined" patterns, suggesting a lack of finesse in the generation process. Additionally, rejected patterns were primarily due to random black blocks appearing at different locations, stemming from the preprocessing method employed by the LGAN. These issues can probably be resolved by further refining the LGAN parameters through additional training.

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Accepted	Rejected
13,011	1,989

Table 2. Generated image distribution. Most of the images resembled batik patterns, while others contained black box artefacts believed to be introduced during the pre-processing stage of the LGAN as part of an effort to improve the model's generalizability.

Figure 4. Synthetic batik samples generated by LGAN. There appears to be a high diversity of colors and complex patterns emerging from LGAN's design. Designs generated were predominantly floral, since the training images were predominantly of this pattern type.

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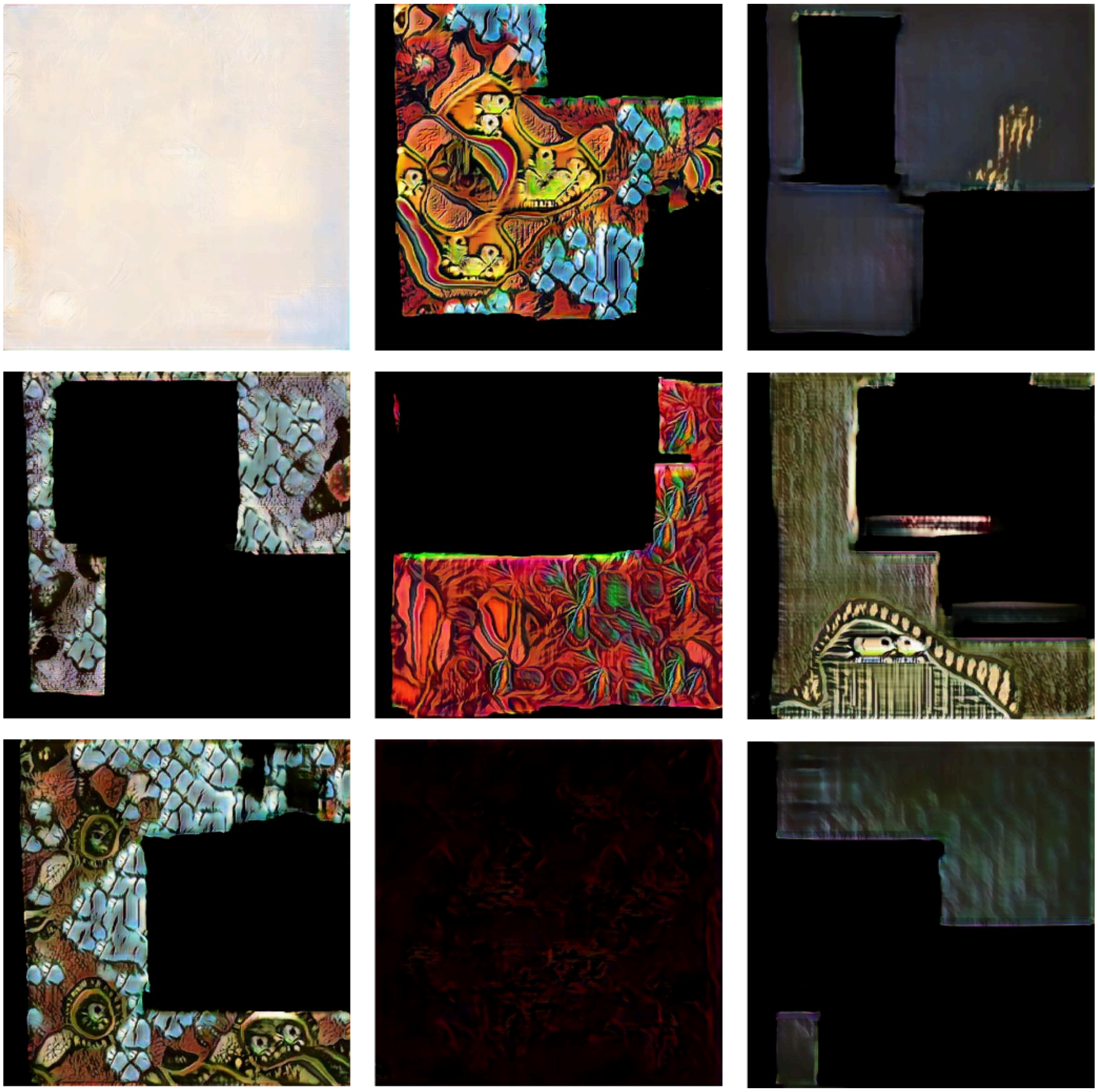

Figure 5. Sample of rejected batik pattern. Notice the random black boxes appearing throughout some synthesized patterns. This results from the preprocessing approach used prior to LGAN training.

Figure 6 and Figure 7 show data disparity results after one-to-many comparison between a synthesized image with other samples. The analysis is based on differentiating the picture's pixels, with the y-axis representing the degree of difference and the x-axis displaying the number of samples. A 'y' value close to zero indicates a high similarity with generated samples. In Figure 6, 50 samples were analyzed, revealing significant differences between each sample. Meanwhile, Figure 7 displays the results of analyzing 1,000 samples, showing no matching samples, further solidifying the proof of data disparity.

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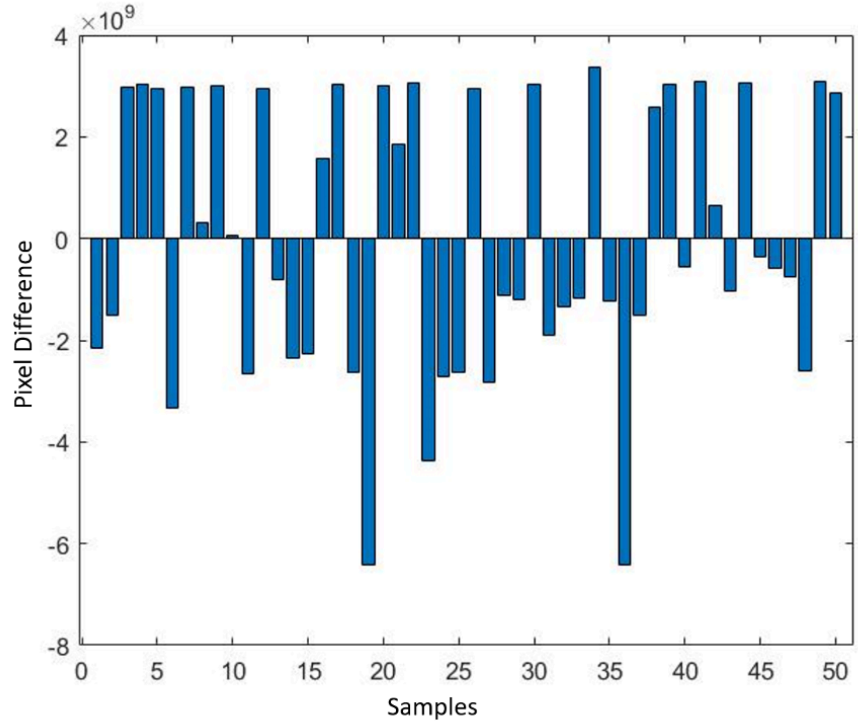

Figure 6. One-to-many inter-sample comparison (50 samples)

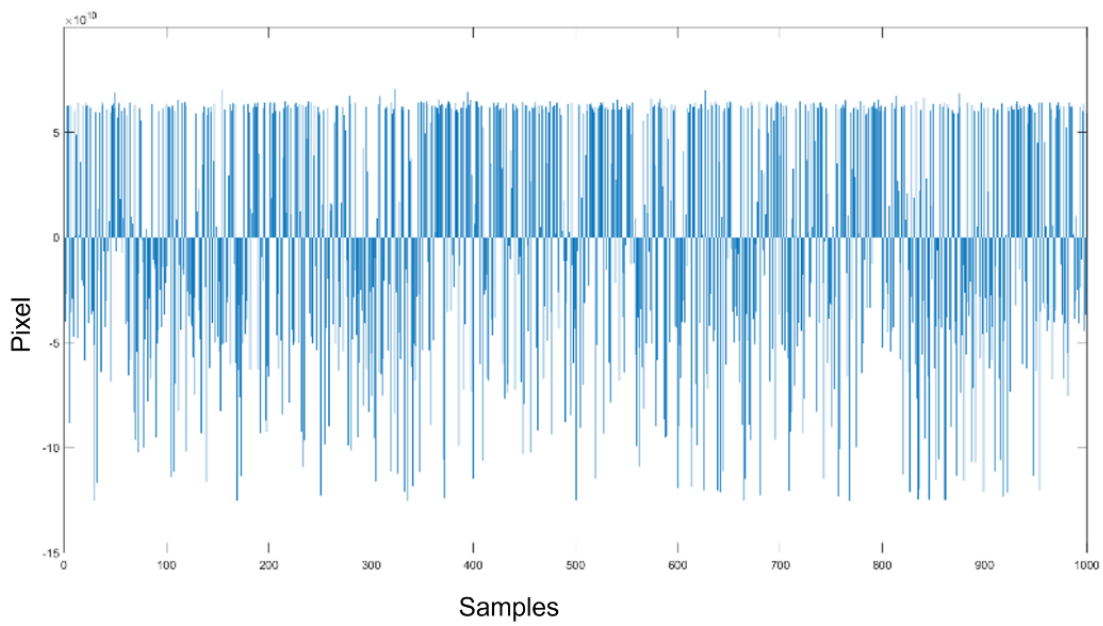

Figure 7. One-to-many inter-sample comparison (1,000 samples)

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Conclusions

Our findings indicate that GANs have demonstrated impressive generalization abilities, recognizing essential features of batik art like edges, color contrast, and distinctive shape combinations. By continuing to develop and fine-tune GANs, they could eventually become a valuable tool for producing high-quality batik-inspired designs that mirror the intricate details and beauty of their handcrafted counterparts.

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Declarations

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