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Application of the Fractal Geometry in Development Surya Majapahit Batik Motif

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ABSTRACT

The Mandelbrot and Julia sets are generated through iterative mathematical functions applied to points in the complex plane. These operations enable the detailed and intricate patterns characteristic of these fractals, allowing for modifications and zooming to explore different regions of the sets. The Mojokerto Surya Majapahit batik motif is a motif that has eight corners. One way to develop a Mojokerto batik motif that is similar to Surya Majapahit is by applying the science of fractal geometry. Fractal geometry studies a fractal pattern that can change shape according to input parameters and the number of iterations carried out. This research was conducted to determine the application of Mandelbrot and Julia's fractal geometry using geometric transformations to obtain batik motif variants that is similar to Surya Majapahit. There are three steps in forming this motif variant. First, generating Mandelbrot fractals and Julia fractals. Second, the patterns generated by Mandelbrot and Julia are applied using geometric transformations. The geometric transformations that will be used are rotation, dilation, and translation. Finally, these patterns will be modified by combining patterns implementing logic operations using Python computer applications. The results of this research obtained four variants of batik motif that is similar to Surya Majapahit. The difference in each variant lies in the order of transformation. Variant 1 and variant 3 can be carried out by changing the sequence of geometric transformations, namely rotation, translation and dilation. Meanwhile variants 2 and 4 apply different rotations, dilation scales, namely 0.451 and 0.318, and translation to the Mandelbrot pattern.

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A. INTRODUCTION

Batik is one of Indonesia's cultural heritages which has high artistic value and is full of philosophical meaning (Lifindra, dkk., 2023) and (Budiman, 2016). Each batik motif often reflects the history, beliefs and cultural identity of the region it comes from (Djulius, 2017). One of the famous batik motifs is Batik Surya Majapahit, which comes from Mojokerto, East Java. This motif is inspired by the symbol of the Majapahit kingdom, one of the largest kingdoms in Indonesian history. Batik Surya Majapahit has motifs consisting of very complex geometric and repetitive patterns. The order and beauty of this pattern is reminiscent of fractal patterns (Isnanto, dkk., 2020). Research and development in the field of digital art shows that the fractal concept can be used to create aesthetic and meaningful designs, including batik designs (Febrianti, 2019). However, the continued growth in the number of craftsmen has resulted in the selling power and selling price of these objects in the domestic and export markets becoming weaker. The main problem is that generally the patterns of the products they produce are still the same, not yet balanced with improvements in artistic quality and diversification/innovation of batik pattern forms required by customers both in terms of the level of symmetry, harmony and variety of models as well as in terms of the variety of sizes of goods offered.

Based on sources from the Ministry of Industry Perindustrian (2020), data was obtained that in 2018 batik exports were recorded at a value of US$ 803.3 million, in 2019 at US$ 776.2 million, in 2020 at US$ 532.7 million, and in the first quarter of 2021 batik exports reached a value of US$ 157.84 million. This shows that from 2018 to 2021 batik exports to foreign countries have decreased significantly. Factors causing the decline due to market demand for batik with diverse motifs, such as the American population is more interested in batik motifs that show the impression of luxury, while the European population is more interested in ethnic motifs or motifs typical of the region in Indonesia, but some countries in the Asian region such as China are more interested in batik motifs that present different and unique motifs.

Explained the concept of fractal geometry on Tanimbar woven fabric (Ngilawajan, 2015). Developed Labako Batik's design by combining Dragon curve fractal geometry and tobacco leaf pattern (Wulandari, dkk., 2017). Explained about the Julia fractal generation by analyzing the function of the Julia set to produce a new pattern, from which the pattern will be developed using geometric transformations with the help of Maple computer applications to produce varied batik motifs (Juhari, 2019). Focusing the problem on developing fractal batik motif by combining Sierpinski Triangle, Hilbert curve, and Koch Snowflake with Bandeng Lele Motif using Matlab computer application so as to produce new fractal batik motif which has similar meaning to the original batik motif (Sunaryo, dkk., 2020), while developing batik motif using L-System (Sholeha, dkk., 2020). Poblems in the development of Julia sets by determining certain parameters and the results of the pattern will be combined with nusantara batik motifs using the Photo Studio application (Solar, *et al.* 2021). Discussed about generating fractal Koch Snowflake and Koch Anti-Snowflake the using Desmos application with 4 iterations, from the results of the pattern will be modified to form Jlamprang batik motif (Febrianti, dkk., 2022). Based on the exposure of several studies that have been mentioned, this writing will focus on the application of fractal geometry in the development of the Mojokerto batik motifs that ris similar to Surya Majapahit.

B. METHODS

The stages carried out in the research is first step generating fractals. The type of fractal generated is the Mandelbrot set and Julia set by providing parameter values and iterating as much as needed to produce fractal patterns that match the batik motif. The Mandelbrot and Julia fractal generation uses the equation $f(z) = z^2 + c$, where the initial values for Mandelbrot $z_0 = 0$ and $c = x + yi$, while the initial values for Julia $z_0 = x + yi$ dan $c = -1.002 + 0i$. The parameter value c is determined by selecting the x and y values that are in the interval [-2,2] which is based on the *Escape Criterion Theorem*, namely $-2 \leq x \leq 2$ dan $-2 \leq y \leq 2$, because the value c is a pixel point, it will be used The pixel density is 1000, that is, there are 1000 rows and 1000 columns, meaning that the higher the pixel density used, the more detailed (sharp) the resulting pattern. Second step is determining fractal batik motifs using geometric transformations. Geometric transformations used are rotation, dilation, and translation.

Several geometric transformations are used on fractals to produce the appropriate fractal pattern components. The Mandelbrot pattern will be rotated at the center point $Q = (a,b)$, $0 \leq a, b \leq 540$ with angle c, $0 \leq c \leq 360^o$, while the dilation is k, $0 \leq k \leq 1$, and translation is p, $0 \leq p \leq 100$. The last step is modify fractal motifs. Modification of this Fractal motif is done by combining fractal motif components using image logic operations to form a variant of the Mojokerto batik motif that is similar to Surya Majapahit. The Mandelbrot and Julia patterns that have been obtained will be applied to the AND logic operation, with these patterns being represented in matrix form. The Mandelbrot pattern obtained has a size of $n \times n$, $0 \leq n \leq 1000$, which means the pattern has n number of rows and columns. The following is the Procedure for making Surya Majapahit batik motif, as shown in Figure 1.

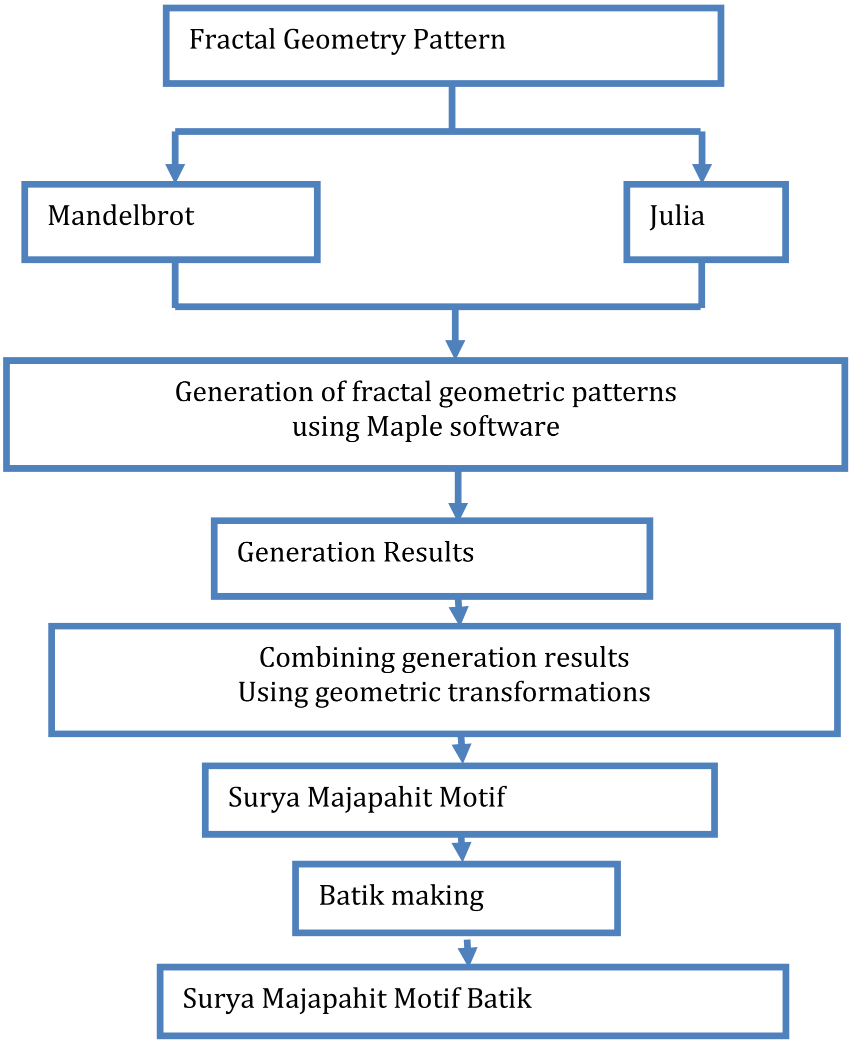


Figure 1. Procedure for making Surya Majapahit motif batik

C. RESULT AND DISCUSSION

Fractals can be developed into fractal batik using a computer program, where geometric transformations in the form of rotation, dilation and translation will be applied to the generated fractal pattern, then the resulting pattern will be modified using image processing logic operations to produce a fractal batik motif. In Chapter 3, we will provide a presentation of research results regarding the application of fractal geometry in the development of Mojokerto batik motif variants that is similar to Surya Majapahit.

1. Mandelbrot and Julia Fractal Generation

Mandelbrot and Julia patterns have the same formula, but the difference between Mandelbrot and Julia is taking the c value and z_0 value. Mandelbrot and Julia pattern generation are based on the equation iteration process

$$z_n = z_{n-1}^2 + c \tag{1}$$

where for initial value of Mandelbrot $z_0 = 0$, $c = x + yi$ with $x, y \in \mathbb{R}$, while the initial value for Julia $z_0 = x + yi$, $c = -1.002 + 0i$ with $x, y \in \mathbb{R}$, and both fractals are iterated by $n = 1, .., 100$ to show the changing shape of the Mandelbrot and Julia patterns. Parameter c value in Mandelbrot and parameter z_0 in Julia are determined by selecting x and y values in the interval $[-2,2]$, based on the *Escape Criterion theorem* (Devaney, 2018).

Theorem 1. The Escape Criterion Theorem
Given $Q_c(z)$ is complex polynomial then $Q_c^n(z)$ is iteration of $Q_c(z)$ n times. Suppose that $|z| \geq |c| > 2$ then $|Q_c^n(z)| \to \infty$ where $n \to \infty$.

Proof. This will be proved using the triangle inequality, namely

$$\begin{aligned} Q_c(z) &= z^2 + c \\ |Q_c(z)| &= |z^2 + c| \\ &\geq |z|^2 - |c| \end{aligned}$$

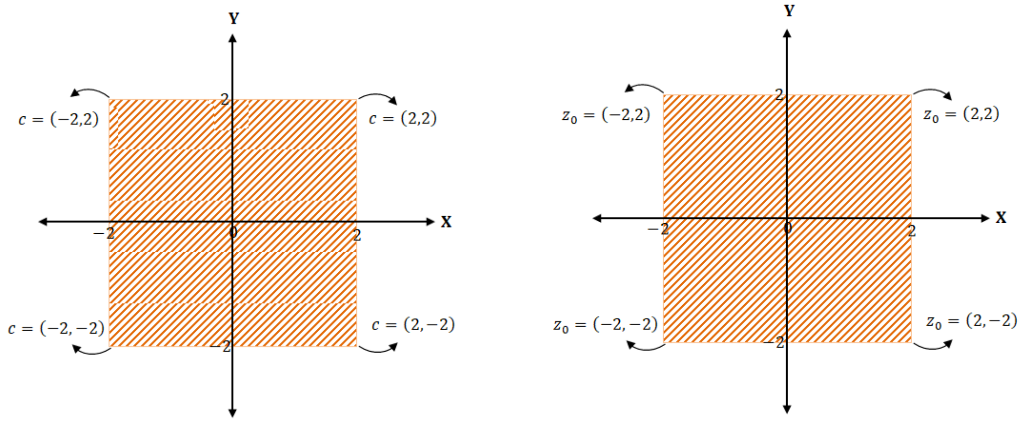
Since $|z| \geq |c|$,

$$\begin{aligned} |Q_c(z)| &\geq |z|^2 - |z| \\ &= (|z| - 1)|z| \end{aligned}$$

Since $|z| > 2$, there is $\epsilon > 0$ such that $|z| > 2 + \epsilon$ atau $|z| - 1 > 1 + \epsilon$, consequently

$$|Q_c(z)| > (1 + \epsilon)|z|$$

In particular, $|Q_c(z)| > |z|$, iterate up to n times n $(n \to \infty)$, then $|Q_c^n(z)| > (1 + \epsilon)|z|$, the orbit of z tends to infinity or the orbit of z is *escape*.



(a) (b)

Figure 2. Representation the Value of c and z_0, (a) Values of c (b) Values of z_0

Figure 2, Based on Theorem 1, the value of c in Mandelbrot and z_0 in Julia in the form of pixel dots will be used pixel density of 1000 that is, there are 1000 rows and 1000 columns, meaning that the higher the pixel density used, the more detail (sharp) the resulting pattern. Here is a representation of the values of c and z_0. It is known that for the Mandelbrot generation the value $|z|$ and $|c|$ must be less than the divergence limit which is 2. Manuals calculation in Mandelbrot pattern generation can be done by taking some arbitrary value of c to be tested 100 iterations to show the maximum value of x and y that include the Mandelbrot criteria, $c = -1.362 - 0.014i$, $c = -0.726 + 0.014i$, $c = 0.274 + 0.314i$, and $c = 0.402 - 0.402i$ with $z_0 = 0$, then

Example 1. for $c = -1.362 - 0.014i$

$z_1 = z_0^2 + c = 0^2 + (-1.362 - 0.014i) = -1.362 - 0.014i$

$z_2 = z_1^2 + c = (-1.362 - 0.014i)^2 + (-1.363 - 0.014i) = 0.492 + 0.024i$

$z_3 = z_2^2 + c = (0.492 + 0.024i)^2 + (-1.363 - 0.014i) = -1.119 + 0.009i$

$z_4 = z_3^2 + c = (-1.119 + 0.009i)^2 + (-1.363 - 0.014i) = -0.108 - 0.035i$

$z_5 = z_4^2 + c = (-0.108 - 0.035i)^2 + (-1.363 - 0.014i) = -1.351 - 0.006i$

$\vdots$

$z_{100} = z_{99}^2 + c = (-1.131 + 0.003i)^2 + (-1.363 - 0.014i) = -0.081 - 0.021i$

Example 2. for $c = -0.726 + 0.014i$

$z_1 = z_0^2 + c = 0^2 + (-0.726 + 0.014i) = -0.726 + 0.014i$

$z_2 = z_1^2 + c = (-0.726 + 0.014i)^2 + (-0.726 + 0.014i) = -0.199 - 0.006i$

$z_3 = z_2^2 + c = (-0.199 - 0.006i)^2 + (-0.726 + 0.014i) = -0.686 + 0.016i$

$z_4 = z_3^2 + c = (-0.686 + 0.016i)^2 + (-0.726 + 0.014i) = -0.255 - 0.008i$

$z_5 = z_4^2 + c = (-0.255 - 0.008i)^2 + (-0.726 + 0.014i) = -0.660 + 0.018i$

$\vdots$

$z_{100} = z_{99}^2 + c = (-0.492 + 0.019i)^2 + (-0.726 + 0.014i) = -0.484 - 0.004i$

Example 3. for $c = 0.274 + 0.314i$

$z_1 = z_0^2 + c = 0^2 + (0.274 + 0.314i) = 0.274 + 0.314i$

$z_2 = z_1^2 + c = (0.274 + 0.314i)^2 + (0.274 + 0.314i) = 0.250 + 0.486i$
$z_3 = z_2^2 + c = (0.250 + 0.486i)^2 + (0.274 + 0.314i) = 0.100 + 0.557i$
$z_4 = z_3^2 + c = (0.100 + 0.557i)^2 + (0.274 + 0.314i) = -0.026 + 0.426i$
$z_5 = z_4^2 + c = (-0.026 + 0.426i)^2 + (0.274 + 0.314i) = 0.093 + 0.291i$

$$\vdots$$

$z_{100} = z_{99}^2 + c = (0.118 + 0.411i)^2 + (0.274 + 0.314i) = 0.118 + 0.411i$

Example 4. for $c = 0.402 - 0.402i$

$z_1 = z_0^2 + c = 0^2 + (0.402 - 0.402i) = 0.402 - 0.402i$
$z_2 = z_1^2 + c = (0.402 - 0.402i)^2 + (0.402 - 0.402i) = 0.402 - 0.725i$
$z_3 = z_2^2 + c = (0.402 - 0.725i)^2 + (0.402 - 0.402i) = 0.037 - 0.985i$
$z_4 = z_3^2 + c = (0.037 - 0.985i)^2 + (0.402 - 0.402i) = -0.566 - 0.476i$
$z_5 = z_4^2 + c = (-0.566 - 0.476i)^2 + (0.402 - 0.402i) = 0.496 + 0.137i$

$$\vdots$$

$z_{10} = z_9^2 + c = (-1.615 - 1.555i)^2 + (0.402 - 0.402i) = 0.596 + 4.621i$

$$\vdots$$

$$Infinity$$

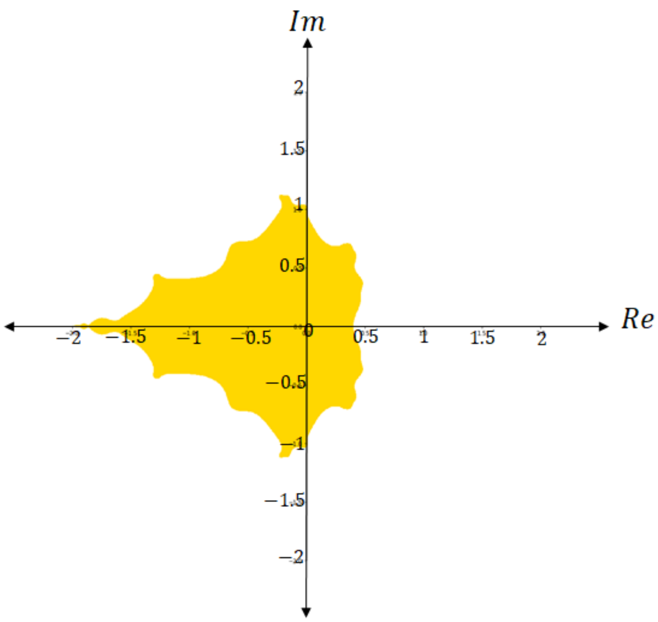


Figure 3. Mandelbrot 7th Iteration

Figure 3, Based on Theorem 1, any value of c (in Example 1 until Example 4) taken to be tested is known that for the value of $c = -1.362 - 0.014i$, $c = -0.726 + 0.014i$, and $c = 0.274 + 0.314i$ does not tend to infinity or $|z_n| \leq 2$, then the value of c is in the Mandelbrot or it can be said that the point is $c = 0.402 - 0.402i$ tend to infinity or $|z_n| > 2$, so the point is outside Mandelbrot, which means that the value of c is not a Mandelbrot pattern-forming point for 100 iterations, because in the 10th iteration the value of $|z_n|$ has exceeded the divergence limit. Take some arbitrary point z_0 in Julia with $c = -1.002 + 0i$ to show the maximum value of x and y that include the Julia criteria, then

Example 5. For $z_0 = 0.070 + 0.066i$

$z_1 = z_0^2 + c = (0.070 + 0.066i)^2 + (-1.002 + 0i) = -1.001 + 0.009i$
$z_2 = z_1^2 + c = (-1.001 + 0.009i)^2 + (-1.002 + 0i) = 0.000 - 0.0185i$
$z_3 = z_2^2 + c = (0.000 - 0.0185i)^2 + (-1.002 + 0i) = -1.002 - 0.306e^{-4}i$
$z_4 = z_3^2 + c = (-1.002 - 0.306e^{-4}i)^2 + (-1.002 + 0i) = 0.002 + 0.614e^{-4}i$
$z_5 = z_4^2 + c = (0.002 + 0.614e^{-4}i)^2 + (-1.002 + 0i) = -1.001 + 0.330e^{-6}i$

$\vdots$

$z_{100} = z_{99}^2 + c = (-1.001 + 0.918e^{-105}i)^2 + (-1.002 + 0i) = 0.001 + 0.184e^{-105}i$

Example 6. For $z_0 = -1.074 - 0.046i$

$z_1 = z_0^2 + c = (-1.074 - 0.046i)^2 + (-1.002 + 0i) = 0.149 + 0.098i$
$z_2 = z_1^2 + c = (0.149 + 0.098i)^2 + (-1.002 + 0i) = -0.989 + 0.029i$
$z_3 = z_2^2 + c = (-0.989 + 0.029i)^2 + (-1.002 + 0i) = -0.023 - 0.058i$
$z_4 = z_3^2 + c = (-0.023 - 0.058i)^2 + (-1.002 + 0i) = -1.004 + 0.002i$
$z_5 = z_4^2 + c = (-1.004 + 0.002i)^2 + (-1.002 + 0i) = 0.007 - 0.005i$

$\vdots$

$z_{100} = z_{99}^2 + c = (0.001 + 0.587e^{-100}i)^2 + (-1.002 + 0i) = -1.001 + 0.234e^{-102}i$

Example 7. For $z_0 = 0.970 - 0.046i$

$z_1 = z_0^2 + c = (0.970 - 0.046i)^2 + (-1.002 + 0i) = -0.063 - 0.089i$
$z_2 = z_1^2 + c = (-0.063 - 0.089i)^2 + (-1.002 + 0i) = -1.005 + 0.011i$
$z_3 = z_2^2 + c = (-1.005 + 0.011i)^2 + (-1.002 + 0i) = 0.009 - 0.022i$
$z_4 = z_3^2 + c = (0.009 - 0.022i)^2 + (-1.002 + 0i) = -1.002 + 0.000i$
$z_5 = z_4^2 + c = (-1.002 + 0.000i)^2 + (-1.002 + 0i) = 0.002 + 0.000i$

$\vdots$

$z_{100} = z_{99}^2 + c = (0.001 - 0.354e^{-101}i)^2 + (-1.002 + 0i) = -1.001 - 0.141e^{-103}i$

Example 8. For $z_0 = -1.322 + 0.034i$

$z_1 = z_0^2 + c = (-1.322 + 0.034i)^2 + (-1.002 + 0i) = 0.744 - 0.089i$
$z_2 = z_1^2 + c = (0.744 - 0.089i)^2 + (-1.002 + 0i) = -0.455 - 0.133i$
$z_3 = z_2^2 + c = (-0.455 - 0.133i)^2 + (-1.002 + 0i) = -0.812 + 0.122i$
$z_4 = z_3^2 + c = (-0.812 + 0.122i)^2 + (-1.002 + 0i) = -0.357 - 0.198i$
$z_5 = z_4^2 + c = (-0.357 - 0.198i)^2 + (-1.002 + 0i) = -0.913 + 0.141i$

$\vdots$

$z_{100} = z_{99}^2 + c = (-1.001 - 0.123e^{-93}i)^2 + (-1.002 + 0i) = 0.001 + 0.248e^{-93}i$

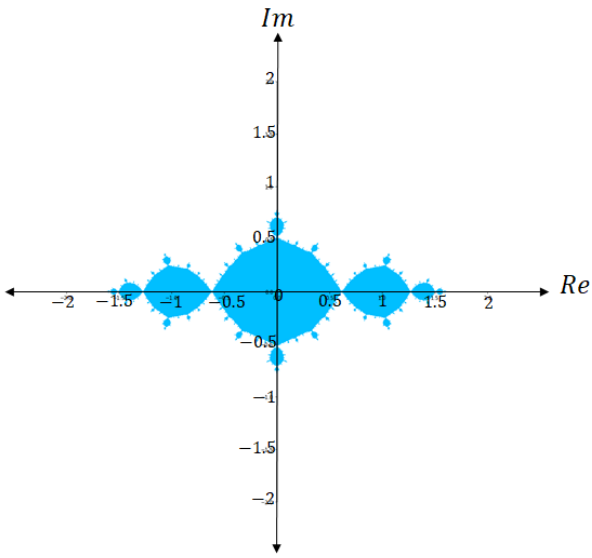


Figure 4. Julia 100th Iteration

Figure 4, Based on Theorem 1, any value of z_0 (in Example 5 until Example 8) taken is $z_0 = 0.070 + 0.066i$, $z_0 = -1.074 - 0.046i$, $z_0 = 0.970 - 0.046i$, and $z_0 = -1.322 + 0.034i$ with the value of $c = -1.002 + 0i$ it is known that after 100 iterations, the $|z_n|$ value does not tend to infinity or $|z_n| \leq 2$, then the points are inside Julia or it can be said that the points are Julia pattern generating points for 100 iterations.

2. Geometric Transformations of Mandelbrot and Julia Patterns

In 3.1 obtained Mandelbrot fractal pattern that will be applied geometric to transformations, namely in the form of rotation, dilation, and translation, as shown in Table 1.

Table 1. Geometric Transformation Mandelbrot Pattern

Patterns Name	Patterns	Geometric Transformation
Mandelbrot (MT)		Mandelbrot Patterns
$MR_{-1}T$		Rotation -45°
MR_1T		Rotation 45°
$MR_{-2}T$		Rotation -90°
MR_2T		Rotation 90°
$MR_{-3}T$		Rotation -135°
MR_3T		Rotation 135°
MR_4T		Rotation 180°
Mandelbrot Dilatation (MDT)		Dilatation $\frac{239}{1000}$

Julia pattern that has been obtained in 3.1 will be rotated and then will be dilated by scale $\frac{706}{1000}$, further applied translation, as shown in Table 2.

Table 2. Geometric Transformation Julia Pattern

Patterns Name	Patterns	Geometric Transformation
Julia (JDT)		Julia Pattern
$JR_{-1}DT$		Rotation -45°
JR_1DT		Rotation 45°
JR_2DT		Rotation 90°

Description: M is Mandelbrot Pattern; J is Julia Pattern; T is Patterns that have been translated; D is Patterns that have been dilated; R_i is Patterns that have been rotated $\left(\frac{360}{8}i\right)^{\circ}$; and $-i$ is The negative sign of index i indicates the pattern is rotated clockwise.

3. Modification of Surya Majapahit Motif

Modification of Mandelbrot and Julia patterns to combine the patterns that have been obtained to form a Mojokerto batik motif that is similar to Surya Majapahit using logic operations AND in Python computer applications, as shown in Table 3 and Table 4.

Table 3. Logical Operations AND of Mandelbrot Patterns

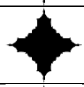
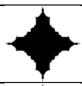
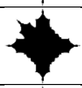
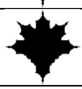
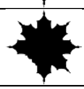
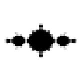
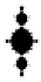
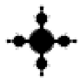
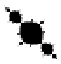
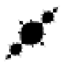
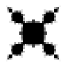
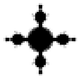
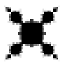
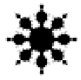
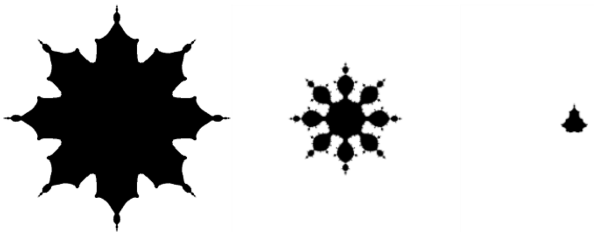
Patterns 1	Patterns 2	Result
		
		
		
		
		
		
		

Table 4. Logical Operations AND of Julia Patterns

Patterns 1	Patterns 2	Result
		
		
		

Based on the Table 3 obtained several components pattern forming Mojokerto batik motifs that is similar to Surya Majapahit, as shown in Figure 5.



(a) **(b)** **(c)**

Figure 5. Components of Batik Motifs, (a) Pattern 1 (b) Pattern 2 (c) Pattern 3

Pattern 1 in Figure 5 will form a circle with a center point (310,310) with a radius of 160. Next, perform logical operations *AND* with pattern 2. The next step is the looping of the circle making the center point (310,310) with radius 50 and performed the logic operation back with Pattern 3. So the process as shown in Figure 6.

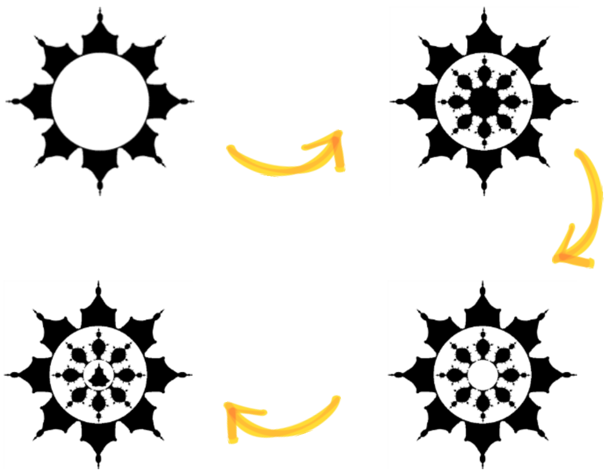


Figure 6. Variant 1 of Surya Majapahit Motif

Based on this, using the steps described, 4 variants of Mojokerto batik motifs that is similar to Surya Majapahit were obtained, as shown in Figure 7.

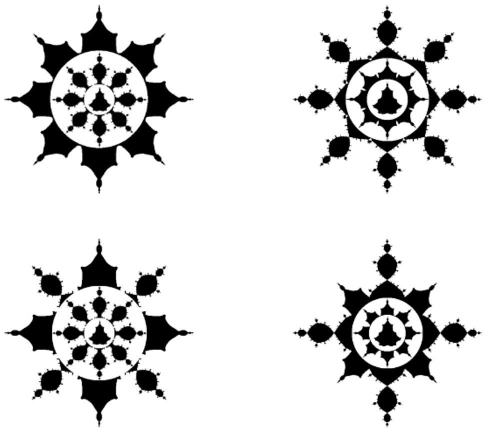


Figure 7. Variant of Surya Majapahit Motif

Figure 7, The development of Surya Majapahit batik motif can be done by applying Mandelbrot and Julia fractal geometry, where each fractal will be generated with a different number of iterations. Once obtained fractal pattern, the next step is to apply the transformation of geometry, in this research used a sequence of geometric transformations, namely rotation, dilation, and translation. Other geometric transformation sequences can also be performed such as starting from rotation, translation, then dilated. However, because the pattern-forming component of the motif has eight angles that form the cardinal directions, the first step that needs to be done is to rotate the pattern. Variant 1 and Variant 3 can be done by changing the order of geometric transformations, namely rotation, translation, and dilation, using the same input values. The development of other Majapahit solar motifs such as Variants 2 and 4 do not apply the same geometric transformation to both fractal patterns, for example Variant 2 is applied rotation, two different dilation scales, and translation to the Mandelbrot pattern, but the Julia pattern is not applied dilation, while Variant 4 is applied rotation, dilation with 3 different scales, and translation, while the Julia pattern is only applied rotation and translation or by providing color and other pattern combinations, as shown in Figure 8.

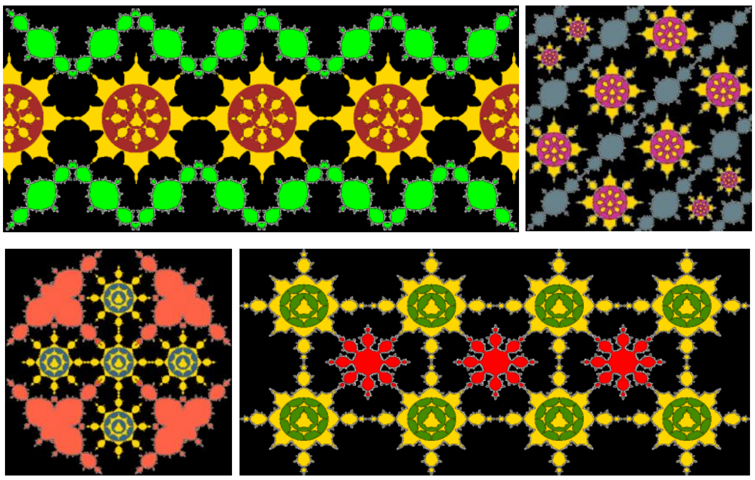


Figure 8. Variant of Batik Surya Majapahit Colored Motif

D. CONCLUSION AND SUGGESTIONS

The development of Mojokerto batik motifs that resemble Surya Majapahit can be done by applying fractal geometry using geometric transformation with the help of the Python program, namely by using the results of generating the 7th iteration of Mandelbrot fractals and the 100th iteration of Julia fractals to obtain 4 variants of developing Mojokerto batik motifs that resemble Surya Majapahit. Variants 1 and 3 were obtained by applying a sequence of geometric transformations starting from rotation, dilation and translation to the Mandelbrot and Julia patterns, then combining the transformed images using the AND logical operator. Variant 2 is obtained by applying a sequence of geometric transformations to the Mandelbrot pattern starting from rotation, dilation with two different scales, and translation, whereas in the Julia pattern only transformations in the form of rotation and translation are applied. Variant 4 is obtained by applying a sequence of transformations of rotation, dilation with three different scales, and translation to the Mandelbrot pattern, whereas in the Julia pattern only transformations are rotation and translation. This research highlights how fractal patterns, especially Mandelbrot and Julia, can be applied in Batik Surya Majapahit Mojokerto designs to produce aesthetic and meaningful motifs. The implications of this research extend to various fields, including innovation in batik art, education, and technological development. By utilizing fractal geometry, we can preserve and develop Indonesia's cultural heritage in an innovative way, ensuring its sustainability in the future.

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