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ORIGINAL ARTICLE

EVALUATING SOUTHEAST ASIAN MILITARY CAMOUFLAGE DESIGNS USING CAMOUFLAGE SIMILARITY INDEX (CSI)

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ABSTRACT

Military camouflage plays a critical survivability component of the front-line soldiers. The purpose of this study was to evaluate the existing military camouflage effectiveness across Southeast Asian countries using Camouflage Similarity Index (CSI). CSI is a color-based image algorithm based on CIELAB color space. The value ranges from 0 to 1 and the best value 0 is achieved if the selected camouflage perfectly blends with the selected background. 10 existing military camouflage designs across Southeast Asian countries were evaluated under 7 different locations (20x50 pixels) from 1 selected woodland background. Each location had different L, a*, and b* values. Post-hoc Tukey test showed that there was no significant difference between camouflage, indicating that the existing Southeast Asian Military camouflage had equal effectiveness of concealment on the selected woodland background. This study represents the first attempt to investigate the effectiveness of Southeast Asian military camouflages. The results of this study could be very beneficial for Southeast Asian military organizations, academicians, and camouflage manufacturer in terms of finding the enhanced direction from the current design which subsequently enhances the survivability of the front-line soldiers.*

Keywords: *Military camouflage, soldier survivability, camouflage similarity index, color design.*

INTRODUCTION

Camouflage represents a critical survivability component of a military combat uniform and depicts a soldier's first line of defences [1]. It is an attempt to minimize the difference between the army combat uniform and the combat environments so that human eyes and military detection instruments struggle to detect and distinguish the target [2]. Academicians [3-5], manufacturers, and even military organizations are continuously involved in the military camouflage research, seeking to enhance the concealment of the camouflage while also considering diverse combat environments [6-8]. The camouflage of the soldier's first line could be improved by a comprehensive assessment that considers two important aspects of the military camouflage: pattern and color [9]. One of the most commonly used assessments of military camouflage is image quality algorithm [10].

Image quality algorithm is often used as a preliminary assessment during the enhancement stage of military camouflage. Previously, we developed a camouflage similarity index (CSI), which mainly focused on the color assessment of military camouflage [11]. CSI measured the color difference between selected camouflage and background pixel to pixel by applying the CIE 1976 $L^*a^*b^*$ color system [12] and NBC color difference as the basis calculation [11]. CSI has ranged from 0 to 1 and the best value 0 is achieved if the selected camouflage perfectly blends with the background [3-5,11]. Lower CSI value was proved to be correlated with longer detection time with the Pearson correlation around 0.436 ($p < 0.05$) [3,4,11]. In addition, our image quality assessment algorithm was found outperformed some common image quality assessment algorithms such as UIQI [13], MSE, PSNR, and SSIM [14-17].

Despite the availability of many studies related to image quality assessment algorithm, very limited study investigated the camouflage effectiveness of the existing military camouflage. Most military camouflages studies were mainly focused on the development of the new color or algorithm [18-21]. In fact, the most challenging aspect of different camouflage assessments is measuring the existing camouflage effectiveness instead of keeping proposing a new algorithm to extract new camouflage. Previously, we investigated the existing China military camouflage designs and the results of CSI was very effective to derive the significant difference among selected camouflages [5]. Using a similar CSI approach, this study tried to expand the CSI for evaluating other existing military camouflage designs.

The purpose of this study was to investigate the effectiveness of Southeast Asian military camouflages using Camouflage Similarity Index (CSI). Different from our previous study which mainly focused on the enhancement of the existing camouflage [3,4], the current mainly focuses on the comparison of CSI values between selected existing camouflage in Southeast Asian. The results of this study could be applicable to the enhancement of military camouflages in Southeast Asian. Besides, it could also be very beneficial to Southeast Asian countries military research organizations in terms of enhancing the current existing military camouflage which subsequently, enhances the survivability of the front-line soldiers.

METHODS

Camouflage Collection

Southeast Asian countries consist of ten countries which coded as BD, C, I, L, M, MY, P, S, T, and V. Ten different existing military camouflages from ten different Southeast Asian countries were selected in the current study. The camouflages were obtained using Google search engine by typing “(name of country) camouflage” or “(name of country) military uniform”. Therefore, this study is different from some previous some camouflage studies which generated digital camouflage from the selected background [18-21]. Similar to our previous approach [3-5], the image later was cut to 20x50 pixels using Adobe Photoshop CS6 for CSI calculation. Matlab 2018 was used to derive global L*, a*, and b* values of each camouflage by using our previous algorithm [11]. Table 1 shows the global L*, a*, and b* values of each camouflage.

Background Collection

Southeast Asian military organizations already had a standard camouflage and mostly the camouflages consist of several colors such as green, khaki green, black, and grey. Based on these colors, it could be seen that the existing camouflages mainly used for the woodland environment. Therefore, similar to our previous studies [3-5], one woodland background was selected to measure the camouflage level of concealment since the woodland background also consists of several colors such as khaki green, green, grey, black, and white. The woodland background was captured by Canon EOS 5D Mark II and the X-Rite Color Checker Color Rendition Chart was used to create an ICC profile [3].

In the current study, 7 different locations (20x50

$$CSI = \frac{\Delta E_{\mathrm{bc}}}{\Delta E_{\max}} \quad (5)$$

$$\Delta E_{\mathrm{bc}} = \frac{1}{n}\sum_{\mathrm{i}=1}^{\mathrm{n}} \left\{ \left(L^*_{\mathrm{bi}} - L^*_{\mathrm{ci}}\right)^2 + \left(a^*_{\mathrm{bi}} - a^*_{\mathrm{ci}}\right)^2 + \left(b^*_{\mathrm{bi}} - b^*_{\mathrm{ci}}\right)^2 \right\}^{1/2} \quad (6)$$

$$\Delta L' = \frac{1}{n}\sum_{\mathrm{i}=1}^{\mathrm{n}} \left(L^*_{\mathrm{bi}} - L^*_{\mathrm{ci}}\right)$$
$$\Delta a = \frac{1}{n}\sum_{\mathrm{i}=1}^{\mathrm{n}} \left(a^*_{\mathrm{bi}} - a^*_{\mathrm{ci}}\right) \quad (7)$$
$$\Delta b = \frac{1}{n}\sum_{\mathrm{i}=1}^{\mathrm{n}} \left(b^*_{\mathrm{bi}} - b^*_{\mathrm{ci}}\right)$$

$$\Delta C' = \left(\Delta a^2 + \Delta b^2\right)^{1/2} \quad (8)$$

pixels) from the woodland background were

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0{\cdot}6067 & 0{\cdot}1736 & 0{\cdot}2001 \\ 0{\cdot}2988 & 0{\cdot}5868 & 0{\cdot}1143 \\ 0{\cdot}0000 & 0{\cdot}0661 & 1{\cdot}1149 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (1)$$

$$L^* = 116\left(\frac{Y}{Y_0}\right)^{1/3} - 16 \quad (2)$$

$$a^* = 500\left\{\left(\frac{X}{X_0}\right)^{1/3} - \left(\frac{Y}{Y_0}\right)^{1/3}\right\} \quad (3)$$

$$b^* = 200\left\{\left(\frac{Y}{Y_0}\right)^{1/3} - \left(\frac{Z}{Z_0}\right)^{1/3}\right\} \quad (4)$$

selected as a demonstration of evaluation in different woodland environments. Each location had had different L*, a*, and b* values [3-5], therefore it would enrich the evaluation since there were many background scenarios in a woodland environment. Similar to the camouflage, the image location was cut to 20x50 pixels using Adobe Photoshop CS6 for CSI calculation [3-5]. Matlab 2018 was also utilized to calculate global L*, a*, and b* values of each camouflage. Table 2 shows the global L*, a*, and b* values of each camouflage.

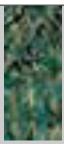
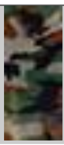
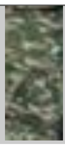
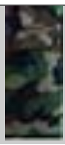
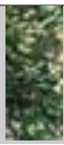
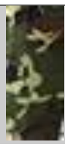
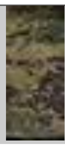
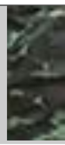
Camouflage Similarity Index (CSI)

Our CSI was mainly based on CIELAB color space [22-24]. The CIELAB color space is a color-appearance model that incorporates chromatic adaptation and compressive nonlinearities to predict hue, chromaticity, and lightness [22-24]. L* is a perceived lightness ranging from 0 for black to 100 for a diffuse white [22-24]. a* is a perceived dimension correlate with red-green (-120 to 120) and b* is a perceived dimension correlate with yellow-blue (-120-120) [22-24]. The CIELAB formula takes the XYZ tristimulus values of a stimulus and the reference white as input and produces correlates to lightness, L*; chroma, C*; and hue, h, as output [11]. Our CSI first step is to use a linear transformation to get the CIE XYZ color space from the RGB color space as in equation (1) below [11]. The CIE L*a*b* color space was obtained through non-linear transformation, as in equations (2) - (4) [11].

X_0, Y_0, and Z_0 were three of the stimuli of reference white, and Y_0=100 [11]. Color changes were calculated with the use of the CIE L*a*b* uniform scale. A three-dimensional color space having components of luminance (L*), red (+a*), green (-a*), yellow (+b*), and blue (-b*) is presented in this system [11].

Similar to our previous study [3-5], the camouflage effectiveness of selected Southeast Asian military camouflages on selected locations were accessed by our CSI algorithm. The CSI is calculated in equations (5) – (8) [11]:
In this equation, L_{bi}, a_{bi}, and b_{bi} are the CIELAB value of the ith point of the background image, while L_{ci}, a_{ci}, and b_{ci} are the CIELAB value of the ith point of the camouflage image [11]. The $\triangle E_{max}$ for CSI is 18, thus making the dynamic of CSI to be [0,1] [3-5]. Figure 3 shows the flow to calculate CSI value [3-5].

Table 1. L, a*, and b* values of each camouflage.*

	BD	C	I	L	M	MY	P	S	T	V
										
L*	64.4710	54.3530	68.5957	49.8999	74.9602	56.8905	61.4336	68.0698	55.8390	56.9086
a*	-12.5019	-0.0309	-3.9931	-3.0817	-4.7491	-2.8646	-0.9755	-10.2618	-3.2557	-16.670
b*	4.7068	5.2066	6.4255	0.7823	3.6128	11.5594	10.6875	6.8621	3.9321	8.4066

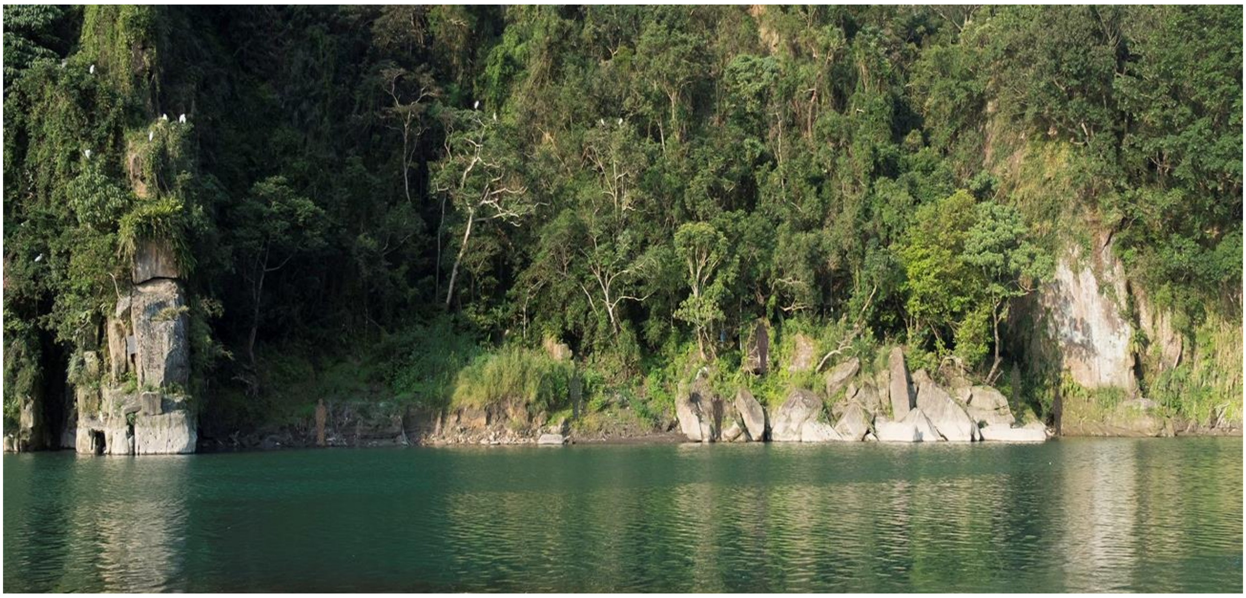
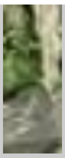
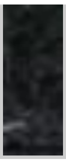
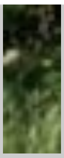
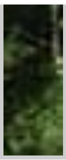
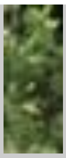
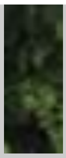
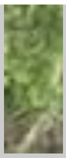


Figure 1. Selected woodland background [3-5].

Table 2. L, a*, and b* values of each location [3-5].*

	1	2	3	4	5	6	7	Average

								
L*	76.1949	47.4693	59.3054	52.4517	67.8591	51.3341	78.3972	61.8588
a*	-4.1246	-0.8253	-7.8107	-7.8344	-7.9443	-6.3474	-7.2132	-6.0143
b*	10.6737	-1.1642	14.5174	13.2100	15.7666	9.3048	16.9961	11.3292

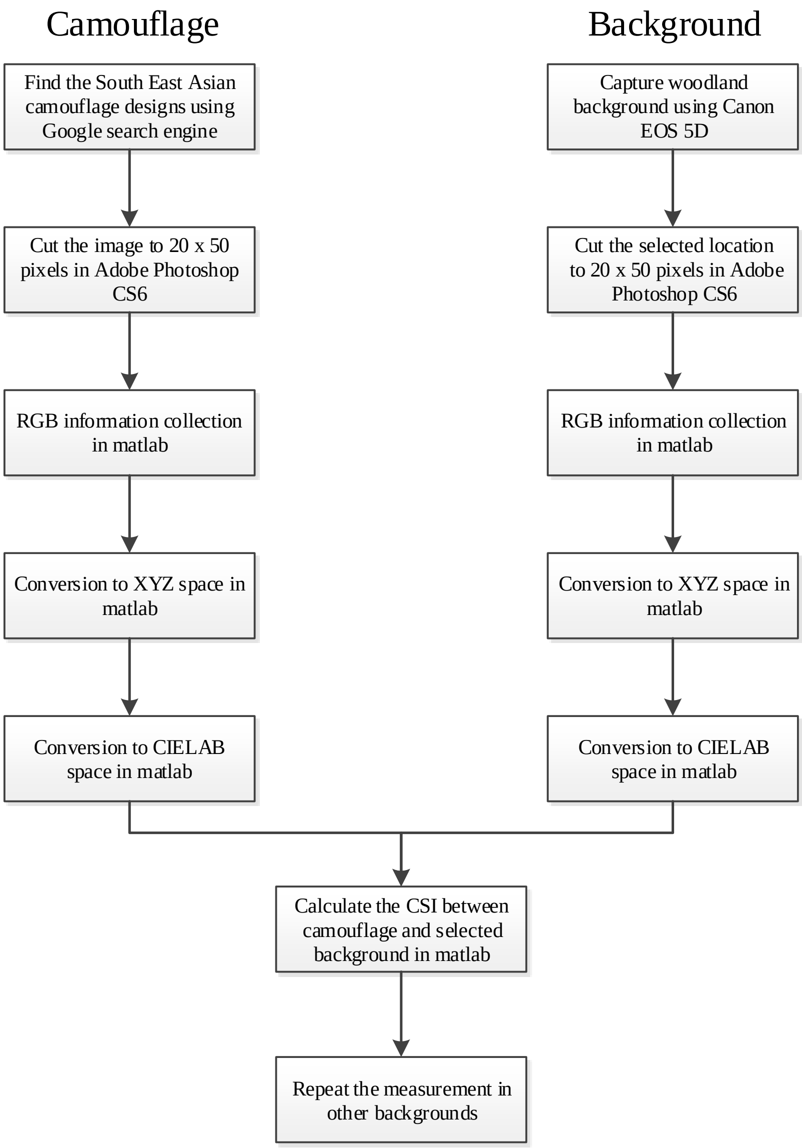


Figure 2. CSI calculation chart [3-5].

Statistical Analysis
Minitab 18 was utilized for the statistical analysis and the results were considered statistically significant when $p \leq 0.05$ [25-28]. ANOVA test was applied to test the significant effect of "Country" on CSI. In addition, Post-hoc Tukey HSD test was also performed to calculate the significant difference between Southeast Asian military camouflages. Post-hoc Tukey HSD test can simultaneously run the multiple comparisons and identifies any significant difference between two means that is greater than expected standard

error. Finally, the ANOVA test was also utilized to test the effect of background to CSI.

RESULTS

The CSI calculation results are presented in Table 3. Based on Table 3, Country "P" had the lowest CSI on background 1, country "T" had the lowest CSI on background 2 and background 6, country "M" had the lowest CSI on background 3, country "MY" had the lowest CSI on background 4, country "BD" had the lowest CSI on background 5, and country "I" had the lowest CSI on background 7. In addition, country V had the highest CSI on background 1, 2, and 7, country "L" had the highest CSI on background 3 and 5, country "I" had the highest CSI on background 4, country "BD" had the highest CSI in background 6.

Regarding the overall concealment performance, country "P" was found to have the lowest average CSI (0.8396) and country "V" had the highest average CSI (0.9124) (Figure 3). However, even country "P" had the lowest CSI, this design was found not suitable to be applied in a dark woodland environment such as backgrounds 2. In these backgrounds, country "T" was found to have the lowest CSI with the values of 0.6858.

Table 3. The results of Camouflage Similarity Index (CSI).

Background	Camouflage Similarity Index (CSI)									
	BD	C	I	L	M	MY	P	S	T	V
Background 1	0.8559	0.9016	0.7351	0.9292	0.7932	0.8865	0.7921	0.8095	0.9171	0.9647
Background 2	0.9553	0.9118	0.9195	0.8031	0.9653	0.8494	0.8897	0.9588	0.6858	0.9878
Background 3	0.8728	0.8836	0.8746	0.9309	0.8416	0.8488	0.8582	0.8434	0.8905	0.8740
Background 4	0.9144	0.9085	0.9222	0.9201	0.8525	0.8327	0.8863	0.9024	0.8547	0.8764
Background 5	0.8325	0.8983	0.7843	0.9404	0.7944	0.8352	0.7664	0.7986	0.8912	0.8809
Background 6	0.8785	0.8770	0.8699	0.8540	0.8437	0.7785	0.8350	0.8522	0.7241	0.8127
Background 7	0.8887	0.9167	0.8383	0.9666	0.8513	0.9026	0.8499	0.8556	0.9545	0.9903
Average	0.8854	0.8996	0.8491	0.9050	0.8489	0.8477	0.8396	0.8601	0.8454	0.9124
Max	0.9553	0.9167	0.9222	0.9666	0.9653	0.9026	0.8897	0.9588	0.9545	0.9903
Min	0.8325	0.8770	0.7351	0.8031	0.7932	0.7785	0.7664	0.7986	0.6858	0.8127

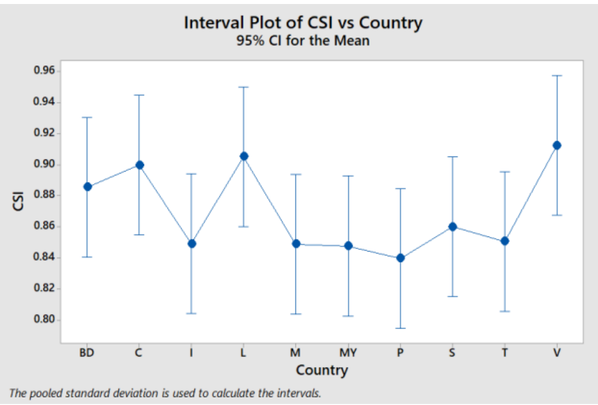


Figure 3. Interval plot of CSI vs Country.

ANOVA test result for "Country" vs CSI is presented in Table 4. Interestingly, there was no significant effect of "Country" to CSI (P-value:0.161). In addition, Table 5 shows the Post-hoc Tukey HSD test to show the difference between "Country". Similar to ANOVA test, there was no significant difference between each country, therefore, it can be concluded that the existing Southeast Asian military camouflages had a similar level of concealment on the selected 7 locations.

Table 4. ANOVA test for "Country" vs CSI.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Country	9	0.04843	0.005381	1.52	0.161
Error	60	0.21200	0.003533		
Total	69	0.26043			

Table 5. The results of Post-hoc Tukey HSD test.

Country	Subset for alpha = 0.05	
	1	2

S	**.8005**	
BD	**.8326**	.8326
T	**.8545**	.8545
P	**.8586**	.8586
M	**.8627**	.8627
MY	**.8752**	.8752
L		**.8999**
I		**.9022**
C		**.9037**
V		**.9119**
Sig.	.139	.090

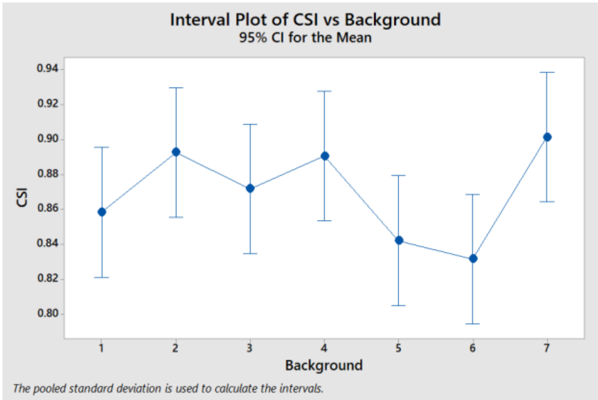


Figure 4. Interval plot of CSI vs Background.

ANOVA test result for Background vs CSI is presented in Table 6. Identical to the ANOVA test result for "Country" to CSI, there was no significant effect of Background to CSI (p-value: 0.068), indicating the fairness of the selected 7 background.

Table 6. ANOVA test for Background vs CSI.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Background	6	0.04307	0.007178	2.08	0.068
Error	63	0.21736	0.003450		
Total	69	0.26043			

DISCUSSION

Considering different terrains and different climatic conditions, camouflaging is a challenging task for defense applications [2,29-31]. The purpose of this study was to evaluate the military camouflage effectiveness across Southeast Asian countries using Camouflage Similarity Index (CSI). CSI value ranges from 0 to 1 and the best value 0 is achieved if the selected camouflage perfectly blends with the selected background [11]. Ten existing military camouflage across Southeast Asian countries were evaluated under seven different locations (20x50 pixels) from one selected woodland background [3-5].

Country "P" was found to have the lowest CSI value particularly due to the overall L* value (61.4336) was close to the average overall L* value of the background (61.8588). In addition, the overall b* value (10.6875) was also close to the average overall b* value of the background (11.3292). However, even Country "P" had the lowest average CSI, the overall b* value was relatively far from the background, indicating that further enhancement was required to derive lower CSI. Two of our previous studies suggested applying response surface optimization [3] and particle swarm optimization [4] for enhancing the selected military camouflage. These two methods could be very effective for enhancing the military camouflage of Country "P" particularly for finding the shift of a* value.

A very interesting phenomenon was found in the Country "V". Country "V" was found to have the highest average CSI indicating that one color was not effective for the camouflage concealment. An international standard of 4 colors [3] was perhaps a better version of military camouflage since the combat background mostly consists of several colors such as green, khaki green, yellow, and even black.

Despite the substantial and clear study results, there are several limitations while generalizing the findings of the current study. First, the lack of proper military camouflage collection. Instead of collecting the design by proper method, the camouflages were collected by using the Google search engine. The lack of proper military camouflage collection would lead to the CSI value. Second, the combat background was limited to the selected woodland background. More diverse combat backgrounds should be used for comprehensive analysis. Last but not least, both camouflages and locations were cut into 20x50 pixels. The future camouflage related research should consider the repeated pattern of the selected design before cutting into smaller pixels. It would also very interesting to evaluate the eye behavior on the military camouflage [33-35]

CONCLUSIONS

Military camouflage plays a critical survivability component of the front-line soldiers. The purpose of this study was to investigate the camouflage effectiveness across selected countries using Camouflage Similarity Index (CSI). CSI ranges from 0 to 1 and the best value 0 is achieved if camouflage perfectly blends with the background. Ten existing military camouflage across Southeast Asian countries were evaluated under seven different locations (20x50 pixels) from one selected woodland background. The results show that country "P" was found to have the lowest average CSI (0.8396) and country "V" had the highest average CSI (0.9124). Post-hoc Tukey HSD showed that there was no significant difference between the camouflage effectiveness of each country, indicating that each camouflage had an equal level of concealment on the selected woodland background. In conclusion, most of the existing military camouflages were found to have a similar level of concealment in the selected 14 backgrounds. The results of this study could be very beneficial for Southeast Asia military organizations, academicians, and camouflage manufacturers in terms of finding the enhanced direction from the current design.

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COMPETING INTERESTS
There is no conflict of interest.

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