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# Objects Camouflage Possibilities Analysis in the Modern Military Conflicts Conditions

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**Abstract**
The article analyses the methods of camouflage used in modern military conflicts. The article gives a historical overview of camouflage of military equipment and personnel since the beginning of the twentieth century. The mathematical and physical principles that should be taken into account in the manufacture of camouflage nets are discussed, the requirement for which is the difficulty in recognizing and differentiating between an artificial surface and real terrain. The mathematical model of a camouflage net pattern is a fractal, a self-similar scale-invariant object of non-integer topological dimension. From the point of view of physics, the fractal dimension is a statistical value that demonstrates how densely a fractal fills a space. This means, in particular, that by dividing a photo of a real surface into cells and then counting the number of black cells in relation to all of them (in the simplest case of a photo of a winter forest, for example), you can find out the average indicator of the landscape's scale similarity, which can be reproduced on a camouflage grid. In the context of active military operations caused by russian aggression, for effective camouflage, it is proposed to use the concepts and methods of fractal geometry in the manufacture of camouflage means, in particular camouflage nets, to maximize the imitation of natural landscapes and structures that will not be easy to recognize.

## INTRODUCTION

By camouflage we understand both a natural phenomenon (mimicry of the animal world) and a kind of combat support (a set of measures to artificially create the illusion of a natural surface). From a purely historical point of view, man has borrowed from the observation of wild animals the idea of using patterns, colors and shapes to replicate the environment, to blend in with it, to become invisible to enemies or prey [1]. Indians, for example, painted their faces and bodies in natural colors – greens, greys, browns – to blend in with the trees, grass and bushes they hunted against. At the beginning of the Anglo-Boer War, the British soldiers in their bright red uniforms were an easy target for the Boers, who were mostly dressed in ordinary farm clothes, grey or dark brown. It was then that the British changed the color of their uniforms to khaki, the color of road dust. During the First World War, camouflage began to be used not only in military uniforms, but also in the painting of, for example, warships (Fig. 1), so that the enemy was unable to correctly determine the distance to the target, thanks to the well-known optical illusion (Fig. 2) [2]. At the same time, the first camouflage nets appeared – covers that were thrown over tanks and then over stationary structures in order to mislead the enemy as to the presence and location of the forces and means of the party to the armed conflict. Special units were created to camouflage their positions and scout out hidden enemy positions. Avant-garde artists, including cubists, and leading designers were involved in these units.

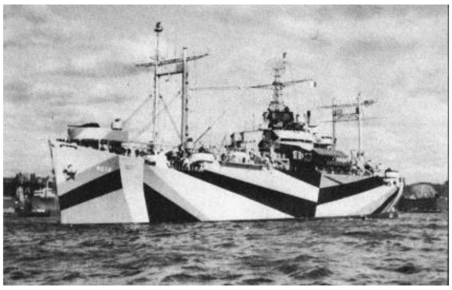

**Figure 1.** Example of warships camouflage

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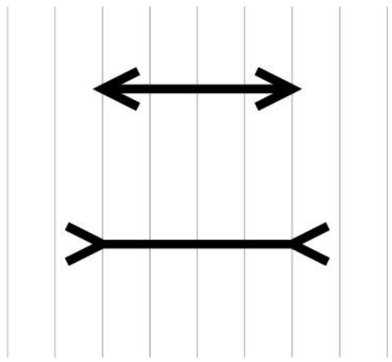

**Figure 2.** Scheme of the optical illusion

During the Second World War, combatants wore uniforms that were not monochromatic, but had a certain pattern, with patches of different sizes and colors. And while certain Wehrmacht units had their uniforms sewn centrally, the fighters of the Ukrainian Insurgent Army, for example, 'tweaked' their uniforms themselves with the help of berry juice (blueberries). It was also the ability to create certain illusions that formed the basis of Allied operations such as Fortitude and Overlord (Fig. 3) [3].

**Figure 3.** Camouflage examples during Fortitude and Overlord operations

## PROBLEM ANALYSIS AND RECOMMENDATIONS

Today, advances in technology make it possible, for example, to take an aerial photograph of an area, print the image onto fabric and then cover military equipment or engineering structures with it. However, this type of camouflage is too expensive and not effective in the face of rapid developments in the theatre of operations. Therefore, a modern camouflage net is usually a mesh base to which either strips of fabric or fabric with undulating slits are attached. This paper discusses the mathematical and physical principles that should be taken into account when designing a camouflage net that is as difficult as possible to detect both visually by an enemy observer and by an artificial intelligence system on aerial photographs.

As you know, in natural landscapes there are almost no regular structures (Fig. 4), straight lines, squares, cubes, i.e. objects with integer Hausdorff dimension (the dimension of a point is zero, a smooth curve is one, a smooth plane is two, a smooth surface is three), natural objects are described by non-integer Hausdorff dimension and are fractal (i.e. they are too wide to be considered one-dimensional and too narrow to be considered two-dimensional, i.e. their dimension lies between one and two) [4–10].

The concept of a fractal originated when researchers were faced with the problem of determining the length of a coastline (Fig. 5), and then spread to many physical units, since the real natural world does not have perfect lines, planes and surfaces. The more detailed the scale of the measuring device, the longer the coastline in particular, and any fractal in general, will be [11–15].

**Figure 4.** Regular structures of natural landscapes

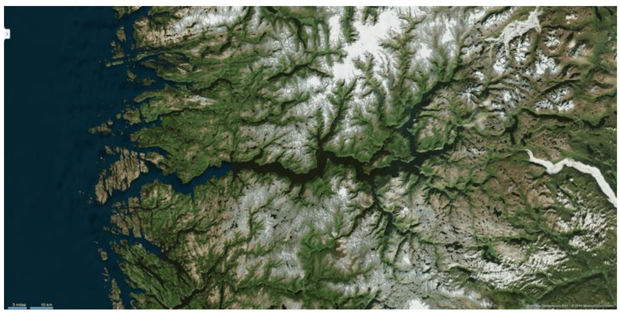

**Figure 5.** To problem of determining the coastline length

Let's define dimensionality from a purely mathematical point of view, applicable to any metric space and requiring only the distance between points. Let $X$ be a metric space. For real $p > 0$ and $\varepsilon > 0$ let $m_p^\varepsilon = inf \sum_{i=1}^{\infty}(diamA_i)^p$ where the lower boundary is taken over all such countable coverings $\{A_i\}$ of the space $X$ that $diamA_i < \varepsilon$. The Hausdorff dimension of the space $X$ is the $sup\{pm_p(X) > \varepsilon\}$ where $m_p(X) = \sup_{\varepsilon>0} m_p^\varepsilon(X)$ the dimension depends on the metric on $X$ and is not, generally speaking, an integer. The mathematical prototype of a fractal is a Cantor set, which is constructed by removing the central thirds of the line segments, its Hausdorff dimension is *ln2/ln3* (Fig. 6). A Cantor set in two dimensions is, for example, a Sierpinski carpet, whose construction is based on the sequential removal of the central squares (Fig. 7), its Hausdorff dimension is *ln8/ln3*.

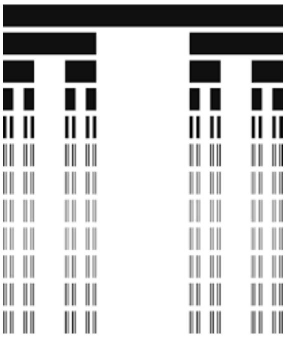

**Figure 6.** Cantor set

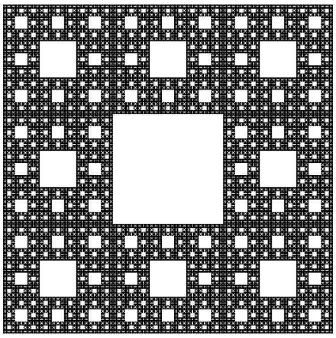

**Figure 7.** Sierpinski carpet

According to Mandelbrot, who proposed the very concept of a fractal, it is a set of points characterized by self-similarity, and its Hausdorff dimension does not coincide with the topological one. In other words, an important feature of fractal objects is their self-similarity, which allows the whole branch to be reconstructed more or less plausibly from a fragment of the branch. This is the basis of computer image compression methods.

Now let the fractal be covered with cells of size $\varepsilon$. The sum over such a cover is analogous to the sum in the definition of the Hausdorff dimension $\sum \varepsilon^p \sim \varepsilon^{-D}\varepsilon^p$, where $D$ is the cellular dimension. If $p > D$, then the sum approaches zero at $\varepsilon \to 0$. If $p = D$ the sum is finite. For $p < D$ the sum is infinite; $p = D$ – is the largest value of $p$ at which the sum is greater than zero. The above construction forms an obvious connection between the Hausdorff dimension and the cellular dimension.

The cellular dimension introduced above replaces the Hausdorff dimension in real physical systems, since the transition to infinitesimals is not feasible in practice.

The concept of a fractal can be generalized to the case of non-self-repeating structures, the so-called self-affine fractal. It is invariant after simultaneous but quantitatively different scale changes along different directions in space. To fully characterize a self-affine fractal, one needs as many dimensions as there are independent directions in space. Self-affine fractals cannot be obtained by simply stretching a self-similar structure, because the ratio of the stretch values in different directions is different.

In physics, the fractal dimension is a statistical measure of how densely a fractal fills space. In particular, this means that if you divide a photograph of a real surface into cells and then count the number of black cells in relation to the total number of cells (in the simplest version of a photograph of a winter forest, for example), you can find the average indicator of the scale similarity of the landscape, which can be reproduced on a camouflage grid (Fig. 8).

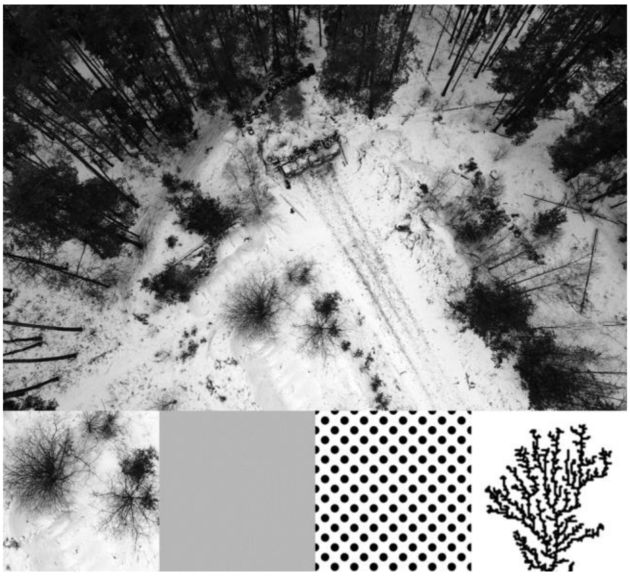

**Figure 8.** Camouflage grid. Photo by Viktor Horobets

While for a winter camouflage net it may be sufficient to calculate one fractal dimension (the ratio of black to white), in other seasons it is necessary to take into account other colors of the landscape: green, brown, grey, yellow, etc., which should be taken into account in the production [16–20].

In addition to analyzing the dimensionality of the surface color, it is equally important to reproduce natural fractals – tree branches, bushes, shadows and wrinkles in the terrain – to create an imitation of a landscape that is as close to reality as possible. Despite the fact that the camouflage mesh is flat, it is possible to create the illusion of a third dimension, pseudo-volume, by using the appropriate pattern. This pattern reproduces the shadows that would be cast by plants and wrinkles in the terrain in reality.

## CONCLUSIONS

In the context of active military operations caused by russian aggression, for effective camouflage it is proposed to use the concepts and methods of fractal geometry in the manufacture of camouflage means, in particular camouflage nets, in order to maximize the imitation of natural landscapes and structures that will not be easy to recognize both visually by an enemy observer and by an artificial intelligence system on aerial photographs (Fig. 9).

**Figure 9.** Camouflage aerial photographs

## DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s).

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## Аналіз можливостей маскування об'єктів в умовах сучасних військових конфліктів

Ігор Білецький, Ганна Дульфан, Лідія Піддубна, Наталія Шишко

**Анотація.** В статі проведено аналіз методів маскування, які застосовуються в умовах сучасних військових конфліктів. Дано історичний екскурс щодо камуфлювання військової техніки і особового складу починаючи з початку XX сторіччя. Обговорюється математичні і фізичні засади, які повинні бути враховані при виготовленні маскувальних сіток, вимогою до яких є складність у розпізнанні і диференціації штучної поверхні, і реального рельєфу. Математичною моделлю патерна маскувальної сітки є фрактал, самоподібний маштабно-інваріантний об'єкт нецілої топологічної вимірності. З точки зору фізики, фрактальна вимірність є статистичною величиною, яка демонструє наскільки щільно фрактал заповнює простір. Це означає, зокрема, що розбивши скажемо фото реальної поверхні на клітини, а потім підрахувавши кількість чорних клітин, по відношенню до всіх (у найпростішему варіанті фото зимового лісу, наприклад) можна дізнатися усереднений показник масштабної подібності ланшафта, який і відтворити на маскувальній сітці. В умовах активних військових дій, спричинених російською агресією, для ефективного маскування пропонується при виготовленні засобів камуфлювання, зокрема маскувальних сіток, застосовувати уявлення і методи фрактальної геометрії, для максимальної імітації природних ландшафтів і структур, які будуть не зручними для розпізнавання.

**Ключові слова:** фрактал, патерн, вимірность Гаусдорфа, камуфляж, маскувальна сітка.

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