A set of indicators, criteria and an algorithmic method of comparative evaluation of samples of imitation tools

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Abstract
A 3-D model of corner reflectors of various types and sizes was built on the basis of the analysis of the results of mathematical modeling using the CST Studio automatic decision-making system. As a result of the simulation, the numerical values of the parameters of the effective scattering area were determined, which made it possible to clarify the dependence of the relative change of the effective scattering area of corner reflectors on the shape of the rib, to confirm the hypothesis regarding the quadratic dependence of the effective scattering area on the radiation frequencies. A comparative analysis of the modeling results allowed us to conclude that for different observation angles, the effective scattering area of a small-angle reflector corresponds on average to the effective scattering area of a Mi-8T helicopter. It was also established that large corner reflectors with a rib size of 120 cm are the most appropriate for simulating fighter jets. At the same time, the weight of the corner reflector needs to be significantly reduced, which becomes possible when using light materials, such as foam plastic, which is pasted over with foil of the appropriate thickness. Electrodynamic modeling was confirmed by an experiment in an anechoic chamber. As a direction of further research, conducting experiments on changing the parameters of the effective scattering area of corner reflectors depending on a number of controlled factors was chosen.

Key words: indicator, criterion, passive means of imitation, radio technical means, distortion, radar informative situation.

Introduction

One of the effective methods of misleading the enemy during hostilities is the use of means of simulating heterogeneous physical fields of real objects. At the same time, this method is used to simulate objects on any surfaces and natural backgrounds. Various models of weapons and military equipment are designed to simulate the shape, radar and thermal features, sound parameters, etc. This is due to the fact that the enemy today conducts comprehensive reconnaissance by various means in order to obtain reliable information about objects on the battlefield. One of the most difficult issues in the field of camouflage turned out to be the imitation of radar fields of ground, sea or air objects. For this purpose, corner reflectors of various sizes, shapes and operating principles are used (Methodical recommendations, 2022). The use of corner reflectors, on the one hand, showed a fairly high efficiency for distorting the radar informative situation, and on the other hand, caused an additional need for theory and practice regarding the scientific substantiation of rational parameters and methods of their use.

Problem statement

The raised problematic issue was raised and highlighted in a sufficient number of scientific studies and publications (Yarosh S.P., 2011; Vagapov, V. B., 2002). In particular, (Yarosh S.P., 2011; Vagapov, V. B., 2002; Handbook, 1988) is dedicated to highlighting the theoretical foundations of the construction and application of reconnaissance and control information systems of air defense, radio automation, as well as the design of receiving and amplifying devices. In (Malakias, N. 2019; Sukharevskyi O.Yu., 2020), the scattering characteristics of air and ground radar objects are considered and a method of calculating the radiation characteristics of two-mirror antennas with mirrors of resonant dimensions of finite thickness and conductivity is given. (Asymptotic Solver Overview) presents a software product in the form of an asymptotic solver used for electrodynamic modeling in the frequency domain and based on physical optics. (Balanis, K. A., 2016; Grane K., 1998; Penchel, R.A.) is devoted to the explanation of the basics of antenna theory, an analysis of the parameters and shape of different types of antennas is carried out, the results of the development of axially symmetric antennas with a double reflector from a combination of given geometric parameters are considered, and the development of broadband directional two-reflector antennas in millimeter waves is proposed. (Kong, K.B.; Rafael A. Penchel, 2018; Pereira, R., 2018; AHSAN, MD REZWANUL2016) proposed the design of offset double reflector antennas to improve the level of isolation between the transmitter and receiver antennas, omnidirectional double reflector antennas with an arbitrary direction of the main beam in the plane of the site by connecting conical sections, conducted a quasi-optical analysis of the microwave antenna system with a double reflector. In (Haddadi, A., Oct. 2016), distorted reflector antennas are considered, the results of the analysis of the directional pattern and polarization characteristics are given. At the same time, (Ivanchenko, D. D., 2010) is devoted to the measurement of backscattering for metal open-ended spherical screens, and (Sukharevsky, O.I., 2016) presents the results of modeling the scattering of ultra-broadband pulses by air and subsurface resonant objects based on the solution of integral equations. Research (Sukharevs'kyy, O.I., 2018) is devoted to obtaining the results of mathematical modeling, during which the value of the effective scattering surface of the model of the Su-27 aircraft and trihedral corner reflectors in the high-frequency range of wavelengths was obtained. The characteristics of the secondary radiation of trihedral corner reflectors, which are used as the main scattering element of the proposed radar airborne false target of towed tactical aircraft, are evaluated.

The obtained results of previous studies are quite significant and it is expedient to use them at the stage of substantiation of requirements for false targets to simulate the secondary radiation of various complex objects, which use corner reflectors as a reflective element. But it should be noted that the issue of modeling the use of passive means of imitation to distort the radar informative situation in the previous available studies is not fully covered.

Results and Discussion

The correct selection of indicators and criteria [...] is a crucial, important and difficult stage for improving the algorithmic method of comparative evaluation of samples of imitation tools. They depend, first of all, on the content of tasks, the presence and composition of forces and means involved in the processes of simulating physical fields.

A set of organizational, technical and cost indicators, which are listed in Table 1, were selected as partial indicators of the effectiveness and cost of means of simulating the object's radar field.

Table 1 – A set of partial indicators and criteria of effectiveness-costs of means of simulating the object’s radar field

No	Characteristic	Unit of measurement	Method of determination	Criterion
1	Mass of the kit	kg	measurement	*min*
2	Consumption of inert gas	l	measurement	*min*
3	Time to prepare	min.	statistically	*min*
4	Effective scattering area	m^2	experimentally	*max*
5	Credibility of imitation	–	statistically	*max*
6	Transportability (volume)	m^3	measurement	*min*
7	Cost of the kit	thousand hryvnias	calculation	*min*

In order to take into account, the different priorities of the partial indicators of the efficiency-costs of means of simulating the object’s radar field, an indicator of their importance was adopted – β_j, which is determined by the ranking method.

As a generalized indicator for solving a multi-criteria optimization problem on a set of goals/qualities, the expression is adopted:

$$Q_i = \sum_{j=1}^{J} \beta_j q_{ij} \,, \tag{1}$$

where β_j – the weighting factor *of the j*-th property (characteristics);
q_{ij} – *is* a relative single indicator *of the j*-th property *of the i*-th variant of the SPIRO alternative.

To bring to unity, the obtained values of indicator (2) are normalized:

$$K_j = \frac{Q_j}{\max Q_j} \,. \tag{2}$$

A rational variant of means of simulating the object's radar field is chosen using the optimization criterion:

$$K_p = \max K_i, \text{ де } i = 1...n \,. \tag{3}$$

Consequently, the set of indicators and criteria has gained further development, which allows to fully take into account the set of goals of the organizational and technical processes of distortion of the informational radar situation. In order to solve the multi-criteria problem of evaluation and selection of a rational option among possible alternatives, one of the typical means of imitation needs to improve the existing methods comparative evaluation of samples of simulation tools and develop an algorithm and software product for its implementation.

The essence of the improved algorithmic method of comparative evaluation of samples of imitation means is as follows.

Evaluation of samples of means of imitation consists in evaluating the level of their development according to the classification. During the analysis, the most important options are mainly considered, which determine the main outline of the samples of imitation means and have the greatest impact on the nature of the distortion of the informational radar situation.

The algorithmic method of comparative evaluation of samples of imitation means is assigned for comparison, which to the greatest extent characterize the type of measures under consideration and make it possible to determine comprehensive indicators that take into account all existing properties; assess the compliance of the existing system with the requirements of technical conditions and state standards, as well as compare domestic and foreign options for alternatives to imitation means.

The set of properties of alternatives, which determine their quality, determines their suitability to satisfy certain needs of the process. Each of the properties is characterized by the corresponding characteristics (parameters). In order to compare alternatives to simulation tools, it is proposed to use the method of the progressive benchmark [...], which is the basis of the methodology.

To evaluate the degree of conformity of alternatives to imitation means by comparing them with a standard against which there is no state standard and general requirements or quantitative indicators. Determining compliance with the requirements consists in comparing the comprehensive indicator of the alternatives of the proposed means of imitation, which is evaluated, with the comprehensive basic indicator.

Initial data for calculations there are characteristics of alternatives to simulation tools offered that are compared.

Sequence and formulas for calculations.

Choose a sample of alternatives to the proposed means of imitation, which are divided by functional characteristics into the same types of alternatives to the proposed means of imitation (subsequent procedures are carried out only between the same type of options).

For the selected options of alternatives to simulation tools, it is proposed to establish a complete list of characteristics that reflect their properties, and summarize numerical values $\{A_{ij}\}$-characteristics for each option.

The priority of *the j* -th characteristic (parameter) is evaluated. To determine the priority of the characteristics (β_j), the ranking method […] is used. Ranking means the procedure for establishing the significance of characteristics based on their ordering.

For this, a survey of a group of *G* experts is conducted. Each *g*-th expert defines a set of numbers C_{jg}, $j = \overline{1, J}$, which reflect his view on the priority of technical and cost characteristics of imitation tools. Each expert must arrange the characteristics in the order of their significance (importance) and assign to each of them the numbers of the natural series: 1, 2, 3, etc. The rank of the indicator is determined by its number, if there are no others in its place in the row. When in one place we have several indicators that do not differ (have linked ranks), then the rank of each of them is equal to the arithmetic mean of their new numbers. At the same time, the number of ranks of indicators is equal to *R.*

When determining the coefficients C_{jg}, it is assumed that there is a linear relationship between the rank and the importance of the characteristics of the alternative variant of the means of imitation. Then the coefficients C_{jg} are determined according to the formula

$$C_{jg} = 1 - \frac{r_{jg} - 1}{R}, \quad (4)$$

where r_{jg} – is the rank of the corresponding *j*-th characteristic of the alternative variant of the means of imitation offered according to the opinion of *the g*-th expert.

After that, the $C_{jg\ values}$ are normalized

$$\beta_{jg} = \frac{C_{jg}}{\sum_{j=1}^{J} C_{jg}}; \sum_{j=1}^{J} \beta_{jg} = 1 \cdot \tag{5}$$

The final value of the importance coefficients β_j is calculated by averaging the values β_{jg} received from all experts. When the competence of the experts in the group is considered the same

$$\beta_j = \frac{1}{G} \cdot \sum_{g=1}^{G} \beta_{jg}; \ g = \overline{1,G}\,. \tag{6}$$

The reliability of the results of the expert assessment is characterized by the degree of consistency of the assessments provided by the experts. For this, the concordance coefficient (W) is used, which is determined by formulas

$$W = \frac{12B}{G^2 \cdot (R^3 - R) - G \cdot \sum_{g=1}^{G} T_g}; \ g = \overline{1,G}\,, \tag{7}$$

$$B = \sum_{l=1}^{R} \left(\sum_{g=1}^{G} r_{\lg} - \frac{1}{R} \sum_{l=1}^{R} \sum_{g=1}^{G} r_{\lg} \right)^2; l = \overline{1,R}\,, \tag{8}$$

$$T_g = \sum_{\phi=1}^{H_g} \left(h_{\phi g}^3 - h_{\phi g} \right), \tag{9}$$

where T_g – is the index of connected ranks in *the g*-th ranking. When there are no matching (connected) ranks, T_g=0;
H_g is the number of groups of equal ranks in *the g* ranking;
$h_{\phi g}$ – is the number of equal ranks in φ the th ranking group of the connected ranks during the ranking by *the g* th expert.

The value of the concordance coefficient is in the range 0 < W < 1. At the same time, W = 0 means the complete opposite, and W = 1 – complete coincidence of rankings. The probability is considered good when W = 0.7–0.8.

If the characteristics are considered to be equal in importance, then the priority indicator of each of them is determined by a ratio of the type 1/J, where J is the total number of characteristics of the evaluated options of SPIRO alternatives.

For each characteristic, a criterion rule is established (table 1), according to which the best (conditional reference) sample of imitation means is chosen step by step from the entire sample

$$A_{ej} = \max A_{ij}, i = \overline{1 \ldots N} \tag{10}$$

or

$$A_{ej} = \min A_{ij}, i = \overline{1 \ldots N}\,, \tag{11}$$

where A_{ij} is the absolute value *of the j*-th property *of the i*-th sample being compared;
And $_{eh}$ is the absolute value of this property in the standard (basic).

Determine the relative personal indicators of each variant of the alternative of means of imitation for each characteristic, which for the properties "more is better"

$$q_{ij} = \frac{A_{ij}}{A_{ej}}, \quad (12)$$

and for properties "more is worse"

$$q_{ij} = \frac{A_{ej}}{A_{ij}}. \quad (13)$$

For properties that are expressed as "is" or "is not"

$$q_{ij} = \begin{cases} 1, A_{ij} \text{ - є}, \\ 0, A_{ij} \text{ - немає.} \end{cases} \quad (14)$$

For any properties $q_{ij} = 1$, if $A_{1j} = A_{2j} = ... A_{nj} = A_{ej} \neq 0$.

A weighted average complex indicator of the preference *of the i*-th variant of the means of imitation, which determined by formula (1). After that, the obtained values of the complex indicator of the preference of alternatives to the means of imitation are normalized in relation to the largest value according to formula (2).

Choose a rational variant of the means of simulating the radar field of the object using the optimization criterion (3). The ranks of each variant of the alternative means of imitation are established according to the level of technical and economic excellence. They draw a conclusion about the priority of the evaluated samples. Advantages and performance requirements that need improvement for existing simulation tools are identified.

To automate calculation processes according to the proposed method, a software product was developed in the Python programming language, the listing of which is shown in Figure 1.

Thus, during the research, the algorithmic method of comparative evaluation of samples of imitation tools was improved, which, unlike the existing ones, contains probabilistic, cost indicators and criteria and comprehensively takes into account the organizational and technical requirements and the priority of partial indicators, which allows solving the multi-criteria problem of choosing on a set of goals.

We will conduct an evaluation to verify the improved algorithmic method and software product.

```python
# Порівняльне оцінювання альтернатив зразків засобів
# для спотворення повітряної радіолокаційної інформативної обстановки
# Автор: Богун А.М.

import numpy as np
import re
import pandas as pd
import matplotlib.pyplot as plt
import argparse
import os


# Встановлення аргументів командного рядка
def set_argument():
    string_parser = argparse.ArgumentParser()

    # Додавання аргументу командного рядка
    string_parser.add_argument('--file', metavar='excel file name', type=str,
help='excel file name', required=True)
    args = string_parser.parse_args()
    if args.file is not None:
        excel_file_path = args.file
    config_folder = os.path.abspath(excel_file_path)

    return config_folder


# Обробка даних
def processing():
    # Отримання абсолютного шляху Excel-файлу
    file_path = set_argument()
    print(f"file: {file_path}")

    # Перевірка, чи існує Excel-файлу в локальній файловій системі
    if not os.path.exists(file_path):
        print(f"Файл [{file_path}] не існує!")
        exit()

    # Зчитування вхідних даних із Excel-файлу
    list_sheet = pd.ExcelFile(file_path).sheet_names
    df = pd.read_excel(file_path, sheet_name=list_sheet[0])
    df = df.dropna(how='all')
    df = df.dropna(axis=1, how='all')
    # prepare columns
    df_name = df[0:1]
    columns_name_part1 = df_name.columns.tolist()
    columns_name_part2 = df_name.iloc[0].values.tolist()
    for i in range(len(columns_name_part1)):
        # Заміна
        reg = re.compile('Unnamed: [{\d}]')
        columns_name_part1[i] = reg.sub('Абсолютні значення ',
columns_name_part1[i])
        if columns_name_part1[i] == 'Абсолютні значення':
            columns_name_part1[i] = 'Абсолютні значення '

    columns_name_part2 = ['' if pd.isna(x) else x for x in columns_name_part2]
    columns_name = [columns_name_part1 + columns_name_part2 for
columns_name_part1, columns_name_part2 in zip(columns_name_part1,
columns_name_part2)]
    df = df.iloc[1:]
    df.columns = columns_name

    abs_value = []
    for i in range(len(df.columns)):
        if 'Абсолютні значення' in df.columns[i]:
            abs_value.append(df.columns[i])
    abs_value

    # Застосування критеріїв (min/max)
    df = df.assign(max_value=df[abs_value].values.max(1),
min_value=df[abs_value].values.min(1))
    df.loc[df['Критерій'] == 'max', 'Критеріальне значення'] = df['max_value']
    df.loc[df['Критерій'] == 'min', 'Критеріальне значення'] = df['min_value']

    # Відносні значення
    cn_sum_list = []
    for value in abs_value:
        column_name = value.replace('Абсолютні значення', 'Відносні значення')
        df.loc[df['Критерій'] == 'max', column_name] =
df[value]/df['Критеріальне значення']
        df.loc[df['Критерій'] == 'min', column_name] = df['Критеріальне
значення']/df[value]
        decimals = 2
        df[column_name] = df[column_name].apply(lambda x: round(x, decimals))
        # Рівень технічної досконалості
        cn = column_name.replace('Відносні значення', "" )
        df[cn] = df[column_name] * df['Важливість']
        cn_sum_list.append(cn)

    # Рівень технічної досконалості
    sum_df = pd.DataFrame(df[cn_sum_list].sum()).T.round(decimals=2)
    max_val = sum_df.max(axis=1)
    for col in sum_df.columns:
        sum_df[col] = sum_df[col]/max_val
    sum_df = sum_df.round(decimals=2)

    # values = [0.73, 1.0, 0.77, 0.81] - приклад
    values = sum_df.iloc[0].values.tolist()
    # titles = ["ИМП", "ИМП-2", "РЕМ", "ММП"] - приклад
    titles = sum_df.columns.tolist()
    print(titles)

    show_result(values, titles)

# Відображення кінцевого результату
def show_result(values, titles):
    if len(values) != len(titles):
        print("Неможливо відобразити результат")
        return

    # Відображення в консолі
    print("Результат обрахунку:")
    for i in range(len(values)):
        print(f"{values[i]:.3f}\t{titles[i]}")

    # Відображення у вигляді гістограм
    x_pos = np.arange(len(values))
    # Створення bars
    plt.bar(x_pos, values)
    # Додавання підписів для осі x-axis
    plt.xticks(x_pos, titles)
    # Додавання назви гістограми
    plt.title("Рівень технічної досконалості")

    plt.show()

if __name__ == "__main__":
    processing()
```

Figure 1 – Listing of a software product in the Python programming language

Conclusions

Therefore, the performed mathematical modeling made it possible to specify the dependence of the relative change of EPR KV on the shape of the edge, to confirm the hypothesis regarding the quadratic dependence of EPR on radiation frequencies.

A comparative analysis of the modeling results allowed us to conclude that for different observation angles the EPR of a small KV varies from 0.2 to 140 m ^{2} (on average 20...40 m ^{2}), which corresponds to the EPR of a Mi-8T helicopter.

It was also established that the most appropriate for simulating fighter jets are large KVs with a rib size of 120 cm. At the same time, the weight parameters of this KV need a significant reduction, which becomes possible when using light materials (for example: foam plastic), which is pasted over with foil, approximately 20 microns.

Electrodynamic modeling was confirmed by an experiment in an anechoic chamber of the radio engineering faculty of Igor Sikorsky Kyiv Polytechnic Institute.

In the future, there is a need to highlight the results of experimental studies regarding the change of EPR parameters depending on low controlled factors.

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