

## ANALYSIS OF THE POSSIBILITIES OF APPLICATION OF SYNTHETIC APERTURE SATELLITE RADARS FOR THE POST-WAR ECONOMIC DEVELOPMENT OF UKRAINE

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*Satellites with synthetic aperture radars are a promising technology. It can raise society to a new level of work with information about the environment. SAR satellites can receive detailed information about large areas of territory for a long time. Due to the decrease in the cost of launching and maintaining satellites, the development of information technology and methods, the policies of space agencies to provide satellite data for the free use of SAR satellite applications and their research are becoming more and more relevant. As part of the Russian-Ukrainian war, Ukraine actively and effectively uses satellite images for intelligence and defense purposes. Such experience can become a favorable precedent for the wider use of this technology in the future. Therefore, the purpose of the article is to study the prospects and possible directions of using SAR images in Ukraine for its post-war economic development.*

*The article investigates the use cases of satellite SAR images in different countries (in particular, India, Guatemala, China, and France). Considers the trends of the SAR imaging market in the world and Ukraine. Based on this information, the authors have outlined promising areas for SAR satellite application and the general development of the use of this technology in Ukraine. The research used such research methods as analysis and synthesis, induction and deduction, abstraction, and generalization. According to the results of our research, the main areas of SAR application in the world are scientific, environmental protection, infrastructural and military. The military sphere is becoming more and more relevant given the aggravation of the political situation in the world and the successful use of SAR images by Ukraine for intelligence and defense purposes in the Russian-Ukrainian war.*

*Another revealed consequence of the use of SAR in Ukraine is the creation of prerequisites for the future development of the use of SAR images in this region. Research has singled out promising areas of application of SAR technology, namely: military intelligence, insurance, energy and mining industry, agricultural and public sectors, hydrological research, soil condition monitoring, and urban and infrastructure development. In our opinion, SAR imaging will not gain widespread use in the short term, but its market will grow significantly in the coming years. Shortly, SAR may become a tool for Ukraine to assess the destruction caused by military operations, monitor the state of the territory, rebuild cities and infrastructure, etc.*

*Since the SAR imaging market is actively developing now, Ukraine's unique experience can help it establish itself as one of the main players in the market, which will contribute to the intensive post-war economic development of Ukraine. However, the successful experience of using SAR is not enough for a successful position of Ukraine in this market. Ukraine's success in this area will require a more specialized study of the opportunities and challenges of using SAR imagery. The main topics of further research are the improvement of satellite SAR data processing methods, SAR image time series processing, and analysis, and experiments on the practical application of SAR at the regional level in the areas of infrastructure and environmental monitoring.*

*The practical significance of SAR image research is obvious since the use of SAR satellite data has already shown its effectiveness as a means of detecting concentrations of enemy equipment and fortifications during military operations. Therefore, the further development of Ukraine in this area will allow state institutions and big businesses to collect large data sets about objects and processes on the territory of Ukraine. This will make it possible to objectively assess the amount of destruction caused as a result of the war and optimize the approach to the reconstruction of the de-occupied territories. Later, the development of SAR technologies can help Ukraine effectively monitor the state and dynamics of agriculture, soils, forests, and water resources, warn and respond to natural disasters, monitor the development of cities and the state of infrastructure, etc.*

**Keywords:** *synthetic-aperture radar, satellite images, territory monitoring, mapping, technology, economic development.*

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### INTRODUCTION

The development of methods and technologies for obtaining, processing, and analyzing satellite data has brought humanity to a new level of working with information. During the last decades, satellite images have had a significant impact on scientific research and

practical activities in the fields of mapping and ecology, geology and hydrology, forestry and agriculture, and military and intelligence industries.

One of the technologies for obtaining satellite data is synthetic aperture radar (abbreviated SAR). Such radars can record two- and three-dimensional data about objects and processes on the Earth's surface in high resolution under any weather conditions. Currently, SAR satellite imagery is used primarily for scientific research, and land surveillance by government organizations, and large businesses, but the demand for SAR imagery is growing rapidly. For example, NSR Earth Observation Satellite Researchers estimate that revenue from the sale of SAR data and derived products will grow from US\$700 million in 2018 to more than US\$1.7 billion in 2028 [1]. According to the authors, satellites can significantly change the understanding and response of communities to natural and anthropogenic changes in a large area.

After the full-scale military invasion of the Russian army on the territory of Ukraine on February 24, 2022, the world community supports Ukraine in many areas, one of them being space. Satellite images provided to Ukraine by the government and private space companies or published in the media to publicize war crimes have become an important tool in this war. Companies that provide Ukraine with access to SAR satellites stand out among them, examples of such companies are IAI, ICEYE, and the Canadian, German, and European space agencies. Working with SAR images significantly improves Ukrainian intelligence, promptly provides the military headquarters with data for tactical and strategic planning, and allows the recording of war crimes. In this way, Ukrainian specialists not only effectively use the most modern satellite technologies, but also create prospects for their future use for the reconstruction and development of Ukraine.

#### ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

In recent years, there has been a growing demand for SAR imaging. Therefore, the number of scientific publications devoted to this topic is increasing every year. Evidence of this is a significant increase in the number of scientific works containing the phrase "synthetic aperture radar" published in the database of scientific publications Science Direct during 1999 - 2022, shown in Figure 1.

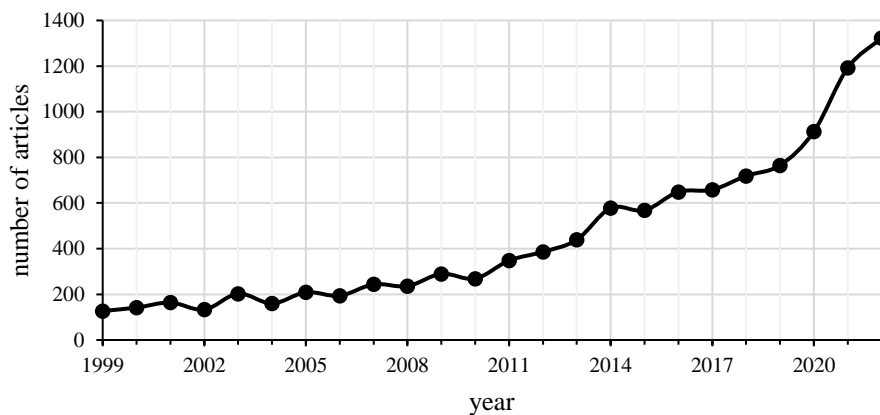


Figure 1 – Number of articles containing the phrase "synthetic aperture radar" published in Science Direct during 1999 - 2022

Source: a database of published scientific studies Science Direct [2]

The most relevant recent publications on the topic of using SAR satellites are studies by Tripathi G. et al. on the topic of using SAR images to map and assess the impact of the 2017 flood in Darbhanga District (India) [3], an article by Bashar M. and Torres-Machi C. on using deep learning for estimating pavement roughness based on SAR data [4],

monitoring of Bara Shigri glacier dynamics using Sentinel-1 SAR data by Sanchayita D. et al. [5]. There are few studies of SAR images of the Ukrainian territory in the scientific literature. Examples of such articles are crop inventory at a regional scale in Ukraine by Kuzul N. and others. [6] and detection of changes in military sites in the Russian-Ukrainian war of 2022 Juntakut P. et al. [7].

Despite the growing popularity of the subject of SAR images, the prospects for their use by government and private institutions are underexplored. The use of SAR satellites in the insurance, urban, and mining fields also needs more attention from scientists.

#### OBJECTIVES OF THE ARTICLE

The purpose of the article is to study the prospects and directions of using satellite SAR images in Ukraine.

#### RESEARCH METHODS

The authors of the study used general scientific methods, including analysis, synthesis, deduction, induction, abstraction, analogy, and generalization.

#### RESEARCH RESULTS

Ukraine is going through hard times because of the Russian invasion today. But the history of the 20th century has many examples of post-war «economic miracles». So, Ukraine also has new opportunities for post-war development. One of them is access to the use of SAR satellite images. This opportunity arose after the Serhiy Prytula Foundation purchased a satellite and access to the ICEYE database for a year.

To understand the consequences of these events, it is necessary to explain the main definition. First, let's explain the basic definition. Synthetic-aperture radar is a type of radar that collects data about an object by emitting energy in the range of electromagnetic waves and recording the amount of reflected energy after interacting with the Earth's surface. Usually, radars of this type are installed on aircraft, including satellites, spacecraft, or airplanes. Images obtained from an optical and SAR satellite can be seen in Figures 2, and 3.

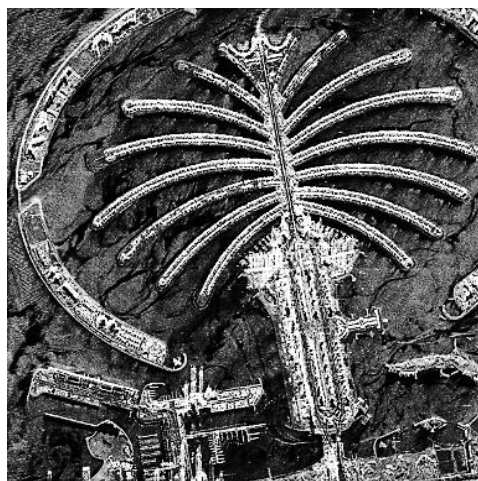


Figure 2 – SAR satellite image of the Palm Islands (UAE)  
©Capella Space



Figure 3 – Optical satellite image of Palm Islands (UAE)  
©Maxar Technologies

Source: Geoimage [8]

Due to their principle of operation, SAR satellites have significant advantages compared to optical ones, which are shown in Figure 4. The wide capabilities of SAR satellites make

them indispensable in many industries. The disadvantage of SAR technology is the much more complicated processing of information received from SAR satellites. In general, it requires the following steps: applying the orbit file, radiometric calibration, de-bursting, multilooking, speckle filtering, and terrain correction [9].

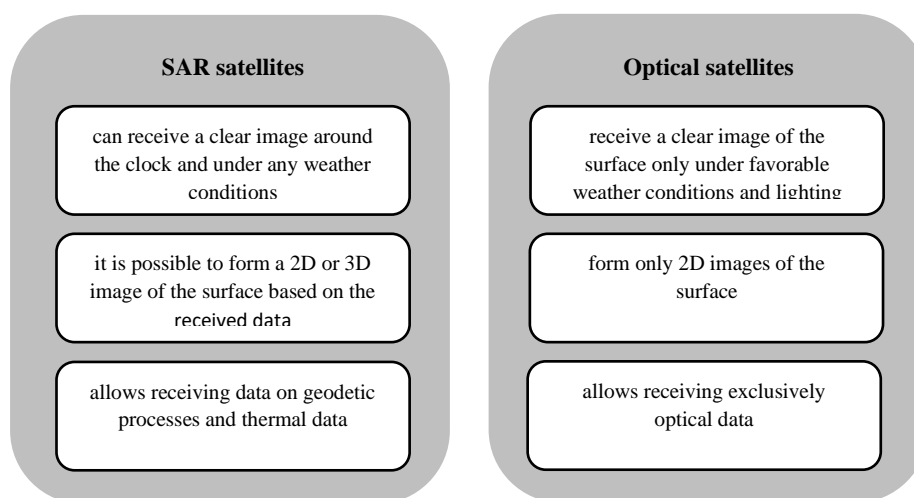


Figure 4 – The main advantages of SAR satellites compared to optical satellites

Due to the reduction in the costs of launching and maintaining satellites, the development of information technology (which has simplified data pre-processing), the policy of the European Space Agency to provide satellite data for free use, increasing competition in the SAR satellite market, this technology has become much more popular in recent decades. According to a market report from Mordor Intelligence, the global SAR market was valued at \$3,3 billion in 2020 and is expected to reach \$6,5 billion by 2026, representing a compound annual growth rate (CAGR) of 11.6% during the period 2021-2026 [10]. However, at the moment, the use of SAR satellites in the world is a wide, but not mass practice. The main users of information from SAR satellites are government organizations, large businesses, and scientists. Given the recent events in Ukraine, the use of SAR satellite images for military and intelligence purposes is becoming more common. According to Scott Herman, CEO of Cognitive Space: «You don't get a better opportunity than this to show how remote sensing can support media storytelling» [11].

Ukraine was not an exception to the global trend of using satellite images. As Andrii Kolesnyk, a former adviser to the head of the State Space Agency of Ukraine said in an interview with the BBC: «Ukraine was buying satellite images even before the full-scale invasion of Russia. About 30 – 35 million hryvnias per year were allocated for this» [12]. But he also said that it was mostly data from Chinese and Israeli optical satellites. Most of the companies that provided Ukraine with informational support in the form of access to satellite images after February 24, including Maxar Technologies and Planet Lab, also own mostly optical satellites.

The acquisition by the Serhiy Prytula Foundation of access to the ICEYE company database for a year and the capabilities of one of the satellites during its time in orbit had a significant impact on the volume and quality of satellite information for Ukraine. First, Ukraine can now receive data collected by SAR satellites, the advantages of which we have already talked about earlier. Secondly, due to the absence of intermediaries, the speed of obtaining information from satellites increases, which is important for quick decision-making. Thirdly, such a precedent gives Ukrainian specialists experience in working with SAR images and creates opportunities for further cooperation with partners in this field.

Currently, Ukraine's Main Directorate of Intelligence owns the data from the satellites. Therefore, SAR satellite images are used mainly in the military sector. SAR images from satellites help the military to map the territory and detect objects on the surface of the earth (for example, to find buildings, logistics routes, missile sites, camouflaged equipment, etc.) It is most likely that this direction of using SAR images will be the most relevant in the short term for Ukraine. But the acquired satellite of the ICEYE company will remain at the disposal of Ukraine throughout the entire period of its operation. Contacts and partnership relations with space companies and the experience of working with SAR images of Ukrainian specialists will also remain. This creates much wider opportunities for the use of SAR images in Ukraine in the future.

The authors think that the use of images from SAR satellites in Ukraine in different directions is promising for the post-war economic development of Ukraine. The main areas of use of SAR images are described below.

1. Monitoring of urban development. This area is particularly relevant for Ukraine, given the need to rebuild cities that suffered from the Russian invasion. Images from SAR satellites help to analyze the state of cities in almost real-time and display expansion, and changes within them, thus they provide data for planning and decision-making on the development of cities, optimal allocation of resources for their development, etc. An example of the real use of SAR in this area is the study of changes in land use in the city of Hangzhou (China) from 2000-2003, in which the use of SAR technology made it possible to create an accurate map of the city, reflecting its rapid pace of economic growth and development.

2. Analysis of the state of the country's infrastructure. SAR satellite images, which have high resolution, allow monitoring of the state of the road surface, subsidence, and displacement of the soil over a large area, and analyze the situation with problematic areas of infrastructure. Successes in this area would help Ukraine solve problems with infrastructure quality monitoring and increase the country's logistical attractiveness and convenience (its investment attractiveness and population welfare). But according to American scientists, SAR-based methods are useful as a complementary tool rather than a replacement for current technologies and practices, specifically in the sense of the state of good repair [13].

3. Land use analysis and soil condition monitoring. Analysis of time series of SAR satellite images allow timely detection of fluctuations, subsidence, landslides, etc. Previously, such changes in the early stages were often imperceptible and could lead to significant destruction and injuries. But today the SAR startup Synspective, through the analysis of soil deformation carried out in Guatemala City (Republic of Guatemala) during 2018-2021, has proven that the application of SAR technology can be a solution to this problem.

4. Hydrological research and monitoring of water resources. Hydrological research has always required considerable training and a large amount of equipment. With the use of SAR satellite images, mapping and monitoring the state of surface water bodies has become much easier and cheaper. This can help solve the problem of dumping waste into rivers and improper disposal of waste by enterprises, the relevance of these topics for Ukraine. Also, satellite images are often used to track boats (including poaching). Such use of SAR would help Ukraine control merchant vessels in the waters of the Black and Azov Seas. An example of such use of SAR is the assessment of the impact of the crisis caused by Covid-19 on the frequency of ships entering the waters of the French Mediterranean Sea in 2020.

5. State sphere. Obtaining accurate and up-to-date information about the state of large areas is extremely important for decision-making in the public sector. The SAR satellite is one of the most effective tools that have such capabilities. In particular, SAR satellites' images can help Ukrainians detect crimes: illegal construction, extraction of natural minerals (in particular, amber), deforestation, fishing, etc. Exposing such types of illegal businesses can be one of the tools for solving the problem of the shadow economy in Ukraine.

6. Insurance. SAR satellite images can be a reliable source for assessing damage and destruction caused by natural disasters or military actions (this is currently very relevant for Ukraine), monitoring the activities of entities, etc. Thus, the automation of property and loss assessment becomes less time-consuming, which allows insurance companies to free up human resources. A successful example of this application of SAR imaging abroad is the study of the consequences of the flood in the Darbhanga area (India) in 2017. According to the authors of the study: «These findings are crucial ... to assess flood impacts» [3].

7. Agricultural business. There are many possibilities for using images from SAR satellites in the agricultural field. For example, SAR time series can help with crop inventory, crop cycle monitoring, plant biophysical changes, etc. Research aimed at creating long-term inventories of crop types has already been conducted in Ukraine (in the Belotserkivskiyi district of the Kyiv region). According to the authors of this study: «It allows one to monitor compliance of crop rotation rules, which are necessary for the preservation of soil degradation. In particular, violations of winter wheat, winter rapeseed, sunflower, and maize were identified» [6]. Continuation of research in this field can increase the efficiency of the use of land resources in Ukraine and the profitability of the agrarian business.

8. Energy and mining industry. As mentioned earlier, SAR satellite images allow for soil condition monitoring. This opportunity is important for the energy and mining industry. The territory of Ukraine is rich in deposits of oil, gas, coal, etc. So, businesses in Ukraine can use SAR images for geological exploration operations, prevention of accidents at the mining site, and control of construction or production work on a large scale (in particular oil or gas exploration works, construction, and maintenance of oil pipelines). This use of SAR images can increase Ukraine's energy security

It should not be expected that the use of SAR satellite images will be implemented in all the listed areas in post-war Ukraine in the short term. After all, SAR is an economically valuable highly specialized tool that requires considerable effort for data processing. Therefore, the main users of SAR are likely to remain government institutions and large businesses.

However, the increase in the number of non-state space companies launching small constellations of SAR satellites, and the simplification of processing and analysis of big data will increase the level of use of satellite SAR images in Ukraine. In addition, SAR can become a tool for assessing large-scale destruction caused by military actions, monitoring the state of the territory (forests, water resources, agricultural land, infrastructure), rebuilding cities, etc. The effectiveness of the use of SAR satellites in the Russian-Ukrainian war and the tension in the international political situation may increase interest in the use of SAR satellites in the field of defense and intelligence. Given this, the value of Ukrainian specialists who have gained experience in the practical use of SAR during military operations will increase.

The other most likely area of use for SAR is the prediction, monitoring, and assessment of the consequences of natural disasters (the number of which is expected to increase shortly due to global warming). Developing the use of SAR in other industries will likely take more time and effort, but overall, the market for SAR imaging will continue to grow rapidly. Ukraine has a chance to be at the forefront of these changes. Figure 5 shows the approximate sequence of the introduction of SAR in various areas.

Consolidation of Ukraine in the market of SAR technologies will make it a more investment-attractive country with a better level of ecology, will increase the welfare of the population and the efficiency of production in an intensive way. Of course, future success will require a more specialized study of the opportunities and challenges of SAR imaging applications.



Figure 5 – The sequence of areas of use of SAR in Ukraine

## CONCLUSIONS

In recent years, SAR satellite images have become the subject of many studies. SAR is an effective tool for obtaining large amounts of data about objects and processes on the Earth's surface. The uniqueness of the technology is the possibility of round-the-clock use in any weather conditions and the high resolution of modern radars. Currently, the practical application of this technology is not widespread, but there are a sufficient number of cases that confirm the effectiveness of using SAR images in many areas (in particular, the successful experience of using SAR in India, Guatemala, China, and France is considered).

The main areas of SAR application in the world are scientific, environmental protection, infrastructure, and military spheres. The military sphere gained more popularity after the example of the effective use of SAR images by Ukraine for intelligence and defense purposes in the Russian-Ukrainian war. Another identified consequence of the use of SAR in Ukraine is the creation of prerequisites for the future spread of the use of SAR images in this region, which will contribute to its post-war economic development. Prospective areas of application of SAR technology are military intelligence, insurance, energy and mining industry, agricultural and public sectors, hydrological research, soil condition monitoring, and development of cities and infrastructure.

Widespread use of SAR images in the short term is unlikely. Because this technology has a rather specialized use and requires a lot of resources to receive and process data. However, the increasing number of space companies owning SAR satellites and the simplification of data processing and analysis will make the use of satellite SAR images more common. Thanks to this, SAR can become a tool for Ukraine to assess the destruction caused by military operations, monitor the state of the territory, rebuild cities and infrastructure, etc. This will lead to the post-war economic development of Ukraine: will make Ukraine a more investment-attractive, ecologically and economically developed country. Therefore, conducting further research on this topic is very promising for the Ukrainian academic community and society. The identified main directions of further research in the field of using SAR satellite images are the improvement of methods of processing primary data of SAR satellites, processing, and analysis of time series of SAR images, experiments on the practical application of SAR at the regional level in the areas of infrastructure and environmental monitoring.

## SUMMARY

*Яценко В.В., Могильна К.О. Аналіз можливостей застосування супутникових радарів з синтетичною апертурою для післявоєнного економічного розвитку України.*

*Супутники з радарними з синтетичною апертурою є перспективною технологією, яка здатна вивести суспільство на новий рівень роботи з даними про навколишнє середовище. SAR супутники дозволяють*

отримувати цілодобову детальну інформацію про великі ділянки території протягом довгого часу. Завдяки зменшенню витрат на запуск і утримання супутників, розвитку технологій і методів роботи з інформацією, політиці космічних агентств з надання частини даних для безкоштовного використання застосування SAR супутників та їх дослідження стають все більш актуальними. У рамках російсько-української війни Україна почала активно використовувати супутникові зображення для розвідувальних та оборонних цілей. Робота в цьому напрямку може стати сприятливим прецедентом для більш широкого застосування SAR технологій в майбутньому. Тому метою дослідження обрано дослідження перспектив і можливих напрямків застосування SAR зображень в Україні з метою її повосенного економічного розвитку.

У роботі розглянуто кейси застосування SAR зображень у різних країнах світу (зокрема, Індії, Гватемалі, Китаї і Франції). Розглянуто тенденції ринку SAR зображень у світі та Україні. На основі цієї інформації висунуто припущення щодо перспективних сфер застосування SAR супутників та загальному розвитку використання цієї технології в Україні. У ході дослідження користувалися такими методами, як аналіз і синтез, індукція і дедукція, абстракція і узагальнення. За результатами дослідження основними сферами застосування SAR у світі є наукова, природоохоронна, інфраструктурна та військова. Остання стає все більш актуальною з огляду на загострення політичної ситуації у світі та успішне застосування SAR зображень Україною для розвідувальних та оборонних цілей у російсько-українській війні.

Іншим виявленим наслідком застосування SAR в Україні є створення передумов для майбутнього поширення використання SAR зображень у цьому регіоні. У статті виокремлено перспективні галузі застосування SAR технології, а саме: військова розвідка, страхування, енергетична та добувна промисловість, аграрний та державний сектори, гідрологічні дослідження, моніторинг стану ґрунту, розвитку міст та інфраструктури. На думку авторів, SAR зображення не набудуть повсюдного використання у короткостроковій перспективі, проте ринок їх застосування значно зростає протягом наступних років. Уже найближчим часом SAR може стати для України інструментом оцінки руйнувань внаслідок військових дій, моніторингу стану території, відбудови міст та інфраструктури тощо.

Оскільки ринок SAR зображень активно розвивається зараз, унікальний досвід України може допомогти їй закріпитися у якості одного з головних гравців ринку, що сприятиме інтенсивному повосенного економічного розвитку України та добробуту її населення. Проте для такого вектору розвитку не достатньо виключно позитивного досвіду використання SAR, успіх України у цій сфері вимагатиме подальшого більш спеціалізованого вивчення можливостей та викликів застосування SAR зображень. Основними напрямками подальших досліджень є удосконалення методів обробки первинних даних SAR супутників, обробки та аналізу часових рядів SAR, експерименти з практичного застосування SAR на регіональному рівні у сферах моніторингу інфраструктури та стану навколишнього середовища.

Практична значущість досліджень SAR зображень є очевидною, оскільки використання даних SAR супутників уже показало свою результативність, як засіб виявлення скупчень ворожого техніки та укріплень під час військових дій. Тож подальший розвиток України у цій сфері дозволить державним інституціям та великому бізнесу реалізувати збір значних масивів даних про об'єкти та процеси на території України, що дозволить об'єктивно оцінити обсяги руйнувань завданих внаслідок військових дій та оптимізувати підхід до відбудови деокупованих територій. Пізніше розвиток SAR технологій може допомогти Україні ефективно моніторити стан та динаміку сільського господарства, ґрунтів, лісів та водних ресурсів, попереджувати та реагувати на стихійні лиха, слідувати за розвитком міст та станом інфраструктури тощо.

**Ключові слова:** радар з синтетичною апертурою, супутникові зображення, моніторинг місцевості, картографування, технології, економічний розвиток.

#### REFERENCES (IN LANGUAGE ORIGINAL)

1. Kasaboski D. Eo SAR: trick or treat?. *Northern Sky Research*. URL: <https://www.nsr.com/eo-sar-trick-or-treat/> (дата звернення: 06.11.2022).
2. *Science Direct*. URL: <https://www.sciencedirect.com/> (дата звернення: 06.11.2022).
3. Flood inundation mapping and impact assessment using multi-temporal optical and SAR satellite data: a case study of 2017 flood in Darbhanga district, Bihar, India / G. Tripathi та ін. *Water resources management*. 2020. Т. 6, № 34.
4. Bashar M. Z., Torres-Machi C. Deep learning for estimating pavement roughness using synthetic aperture radar data. *Automation in construction*. 2022. № 142.
5. Monitoring the dynamics of Bara Shigri glacier using Synthetic Aperture Radar data of Sentinel-1 satellite and effect of climate on mass balances / S. Das та ін. *Advances in space research*. 2021. Т. 68, № 10.
6. Crop inventory at regional scale in Ukraine: developing in season and end of season crop maps with multi-temporal optical and SAR satellite imagery / N. Kussul та ін. *European journal of remote sensing*. 2018. Т. 51, № 1.
7. Juntakut P., Aemlaor P., Jantakat Y. Detecting Change in Military Sites Using Satellite Imagery Case Study: Russia-Ukraine War in 2022. *Defence technology academic journal*. 2022. Т. 4, № 10.
8. What is SAR and inSAR? *Geoimage*. URL: <https://www.geoimage.com.au/blog/what-is-sar-and-insar/> (дата звернення: 06.11.2022).
9. Meyer F. Spaceborne synthetic aperture radar – principles, data access, and basic processing techniques. *SAR handbook: comprehensive methodologies for forest monitoring and biomass estimation* / ред.: A. Flores та ін. 2019. С. 21–44.



10. Mordor intelligence. *Synthetic aperture radar market - growth, trends, covid-19 impact, and forecasts (2022 - 2027)*. 2021. URL: <https://www.mordorintelligence.com/industry-reports/synthetic-aperture-radar-market> (дата звернення: 06.11.2022).
11. Erwin S. Commercial spy satellites put Russia's Ukraine invasion in the public eye. *Space news*. URL: <https://spacenews.com/satellite-imaging-companies-increase-profile-as-they-track-russias-invasion-of-ukraine/> (дата звернення: 06.11.2022).
12. Ковалевська Є. Супутник ICEYE: що саме купив Притула і як воно допоможе ЗСУ. *BBC News Україна*. URL: <https://www.bbc.com/ukrainian/news-62603951> (дата звернення: 06.11.2022).
13. Evaluation of synthetic aperture radar satellite remote sensing for pavement and infrastructure monitoring / A. Ozden та ін. *Procedia engineering*. 2016. № 145. С. 752–759.

## REFERENCES

1. Kasaboski, D. (2019, 30 October). *Eo SAR: Trick or treat?* Northern Sky Research. <https://www.nsr.com/eo-sar-trick-or-treat/>
2. Science Direct. <https://www.sciencedirect.com/>
3. Tripathi, G., Pandey, A. C., Parida, B. R., & Kumar, A. (2020). Flood inundation mapping and impact assessment using multi-temporal optical and SAR satellite data: a case study of 2017 flood in Darbhanga District, Bihar, India. *Water Resour Manage*, (34).
4. Bashar, M. Z., & Torres-Machi, C. (2022). Deep learning for estimating pavement roughness using synthetic aperture radar data. *Automation in Construction*, 142.
5. Das, S., Taloor, A. K., Singh, A. K., & Kothiyari, G. C. (2021). Monitoring the dynamics of Bara Shigri glacier using Synthetic Aperture Radar data of Sentinel-1 satellite and effect of climate on mass balances. *Advances in Space Research*, 68(10).
6. Kussul, N., Lavreniuk, M., Shelestov, A., & Skakun, S. (2018). Crop inventory at regional scale in Ukraine: Developing in-season and end of season crop maps with multi-temporal optical and SAR satellite imagery. *European Journal of Remote Sensing*, 51(1), 627–636.
7. Juntakut, P., Aemlaor, P., & Jantakat, Y. (2022). Detecting change in military sites using satellite imagery case study: Russia-Ukraine war in 2022. *Defence Technology Academic Journal*, 4(10).
8. *What is SAR and insAR?* (2021, 29 September). Geoimage. <https://www.geoimage.com.au/blog/what-is-sar-and-insar/>
9. Meyer, F. (2019). Spaceborne synthetic aperture radar – principles, data access, and basic processing techniques. In A. Flores, K. Herndon, R. Thapa & E. Cherrington (ed.), *SAR Handbook: Comprehensive Methodologies for Forest Monitoring and Biomass Estimation*. (p. 21–44). NASA.
10. *Synthetic aperture radar market - growth, trends, covid-19 impact, and forecasts (2022 - 2027)* (Mordor intelligence). (2021).
11. Erwin, S. (2022, 27 February). Commercial spy satellites put Russia's Ukraine invasion in the public eye. *Space news*. <https://spacenews.com/satellite-imaging-companies-increase-profile-as-they-track-russias-invasion-of-ukraine/>
12. Kovalivska, E. (2022, 19 August). Suputnyk ICEYE: shcho same kupyv Prytula i yak vono dopomozhe ZSU. *BBC News Ukraine*. <https://www.bbc.com/ukrainian/news-62603951>
13. Ozden, A., Faghri, A., Li, M., & Tabrizib, K. (2016). Evaluation of synthetic aperture radar satellite remote sensing for pavement and infrastructure monitoring. *Procedia Engineering*, 145, 752–759.