
Mathematical modeling
Математическое моделирование

UDC 004.81

<https://doi.org/10.32362/2500-316X-2022-10-2-51-58>**RESEARCH ARTICLE**

Semantics of visual models in space research

Viktor P. Savinykh¹,
Slaveiko G. Gospodinov²,
Stanislav A. Kudzh³,
Viktor Ya. Tsvetkov^{3, @},
Igor P. Deshko³

¹ *Moscow State University of Geodesy and Cartography, Moscow, 105064 Russia*² *University of Architecture, Construction and Geodesy, Sofia, 1164 Bulgaria*³ *MIREA – Russian Technological University, Moscow, 119454 Russia*@ *Corresponding author, e-mail: cvj2@mail.ru***Abstract**

Objectives. The aim of the study is to develop a methodology for assessing the semantics of weakly structured or morphologically complex visual information models. In order to achieve the goal, a criterion for classifying visual models as complex and an algorithm for obtaining a gradient image with several levels of density were introduced. The gradient image is not binary, thus increasing the reliability of finding boundaries or contours. An auxiliary structural visual model was introduced, and a series of images of different densities was used in processing. Next, the concept of a conditional image coordinate system was introduced. This allows for information to be transferred from different visual models to a synthetic resulting visual model.

Methods. Using gradient image processing and constructing a new intermediate structural model allows models with different densities to be linked. A system of conditional image coordinates was introduced and a series of models with different densities to obtain a synthetic image was processed.

Results. The visual models obtained from satellite images with poor visibility of objects were processed in the Sun–Earth–Moon system. The Sun–Earth system was chosen as the basis. A characteristic of space images is the fact that the bright light of the Sun “clogs” the images of other objects with large phase angles. The use of the contouring technique allows for the visibility of images of low brightness and high brightness to be equalised. The shift of the frequency response after detection of all objects enabled the formation of a clear visual model.

Conclusions. In primary visual models, low brightness images were not visible. They appeared when exposure was increased, while high-density objects merged into one. Because of this, it is fundamentally impossible to obtain a high-quality image of all objects, or the complete semantics of a visual model from a single high, medium, or low-density image. In order to obtain the complete semantics of the visual model, a series of images need to be processed with the transfer of images to a common synthetic image. The proposed technique allowed for such problems to be resolved. A comparison of the results obtained using the methods of processing a single image proved the reliability and high information content of the method.

Keywords: mathematical modeling, semantics, visual model, figurative model, visual structural model, information field, information semantics, cognitive semantics, information model, cognitive model

• Submitted: 23.12.2021 • Revised: 10.01.2022 • Accepted: 26.03.2022

For citation: Savinykh V.P., Gospodinov S.G., Kudzh S.A., Tsvetkov V.Ya., Deshko I.P. Semantics of visual models in space research. *Russ. Technol. J.* 2022;10(2):51–58. <https://doi.org/10.32362/2500-316X-2022-10-2-51-58>

Financial disclosure: The authors have no a financial or property interest in any material or method mentioned.

The authors declare no conflicts of interest.

НАУЧНАЯ СТАТЬЯ

Семантика визуальных моделей в космических исследованиях

В.П. Савиных¹,
С.Г. Господинов²,
С.А. Кудж³,
В.Я. Цветков^{3, @},
И.П. Дешко³

¹ Московский государственный университет геодезии и картографии, Москва, 105064 Россия

² Университет архитектуры, строительства и геодезии, София, 1164 Болгария

³ МИРЭА – Российский технологический университет, Москва, 119454 Россия

@ Автор для переписки, e-mail: cvj2@mail.ru

Резюме

Цели. Цель работы – разработка методики для оценки семантики слабо структурированных или морфологически сложных визуальных информационных моделей. Для достижения цели вводится критерий отнесения визуальных моделей к сложным и алгоритм получения градиентного изображения с несколькими уровнями плотности. Градиентное изображение не является бинарным, что повышает надежность нахождения границ или контуров. Вводится вспомогательная структурная визуальная модель, и в обработке используется серия изображений разной плотности. Далее вводится понятие условной системы координат изображения, позволяющей переносить информацию с разных визуальных моделей на синтетическую результирующую визуальную модель.

Методы. Использование градиентной обработки изображений и построение новой промежуточной структурной модели, которая позволяет связывать модели с разной плотностью. Введение системы условных координат изображения. Обработка серии моделей с разной плотностью для получения синтетического изображения.

Результаты. Проведена обработка визуальных моделей, полученных с космических снимков со слабой различимостью объектов. Обработаны снимки в системе «Солнце – Земля – Луна». В качестве базиса выбрана система «Солнце – Земля». Для космических снимков характерно то, что яркий свет Солнца «забивает» изображения других объектов с большими фазовыми углами. Применение методики оконтуривания позволило выровнять изображения объектов слабой яркости и большой яркости. Смещение частотной характеристики после выявления всех объектов позволило сформировать четкую визуальную модель.

Выводы. На первичных визуальных моделях изображения слабой яркости не видны. При увеличении экспозиции они появляются, но объекты высокой плотности могут сливаться в один. Из-за этого по одному снимку высокой, средней или слабой плотности принципиально невозможно получить качественное изображение всех объектов или полную семантику визуальной модели. Для получения полной семантики визуальной модели необходима обработка серии изображений с переносом изображений на общее синтетическое изображение. Предложенная методика позволяет решать такие задачи. Сравнение полученных результатов с методами обработки одного изображения показывает надежность и большую информативность метода.

Ключевые слова: математическое моделирование, семантика, визуальная модель, образная модель, визуальная структурная модель, информационное поле, информационная семантика, когнитивная семантика, информационная модель, когнитивная модель

• Поступила: 23.12.2021 • Доработана: 10.01.2022 • Принята к опубликованию: 26.03.2022

Для цитирования: Савиных В.П., Господинов С.Г., Кудж С.А., Цветков В.Я., Дешко И.П. Семантика визуальных моделей в космических исследованиях. *Russ. Technol. J.* 2022;10(2):51–58. <https://doi.org/10.32362/2500-316X-2022-10-2-51-58>

Прозрачность финансовой деятельности: Авторы не имеют финансовой заинтересованности в представленных материалах или методах.

Авторы заявляют об отсутствии конфликта интересов.

INTRODUCTION

The widespread use of semi-structured visual models is caused by their application in many areas: radiation diagnostics, space research, radar images, thermal images, laser scanning systems, etc. At the present time, the processing of such images to obtain the semantics of the image is a matter of relevance.

Each model has a presentation or description form and a content part. The morphology or formal representation of the model and its semantics therein is a matter of discussion. The semantics of any model refers to its semantic content, including the description of its structure and spatial relationships. The semantics of a visual model is related to the extent to which it provides information [1, 2]. In many informational and visual models, the formalism of the model and its content are created separately. In practice, these technological stages of creating a model are called formalization and collection of semantics. This is because a formal model can have different meanings and should not be rigidly bound to semantics. The same formal model can have different meanings. For example, the image of a rectangle on a visual model may represent a house, a land plot, an engineering structure, or a computational unit (in an algorithm diagram). The meaning of the visual model or its semantics is determined by analyzing additionally collected information. This technique is practiced in geoinformatics, in which metric and attribute information is collected separately.

Among visual models, two types of models can be distinguished according to the criterion of perception. The first type consists of well-structured and recognizable visual models with clear contours and known objects. Examples are snapshots of an urban area, scanned images of drawings, or maps. This type of visual models can be characterized by the term “objective.” For this type of visual models, there is a natural decomposition. The semantics can be easily collected separately and then combined with the model. The second type consists of visual models with fuzzy contours or their absence,

and images of objects of an unknown class. This type of visual models can be characterized by the term “figurative” or “morphological.” Collecting semantics separately for such models is a difficult matter. This type of models is found in space research, in the processing of radar images, and in X-ray images. There is no natural decomposition for this type of visual models. Therefore, the decomposition problem becomes an additional task. The problem of the semantics of such visual models is closely related to the extraction of implicit knowledge [3]. The general problem of the content accuracy of visual models belongs to the field of artificial intelligence. This problem is indirectly connected to the information field [4, 5], information relations, and information-cognitive semantics. The term “information perception” and the term “cognitive perception” can also be added. The semantics of visual models has cognitive and informational components. Therefore, both of these factors must be investigated when analyzing the semantics of visual models.

1. RESEARCH METHODOLOGY

The study was carried out using the methods of gradient, statistical, comparative, and qualitative analysis. Publications in the field of analysis and processing of semi-structured images, as well as satellite images were used as materials.

2. RESEARCH RESULTS

2.1. Formation of a visual model

Unlike other information models, visual information models must have three characteristics: morphology, topology, and spatial relationships. In some cases, the topology defines the structure. Topology and spatial logic are most often present in visual models of the first type. In visual models of the second type, there are only morphological features and spatial relationships. Two types of visual models can be used to construct formational schemes.

Figure 1 shows the scheme for constructing a visual model of the first type. The source of information is a spatial image (a snapshot of a spatial image), which contains clear boundaries and allows a natural decomposition of the objects comprising this image.

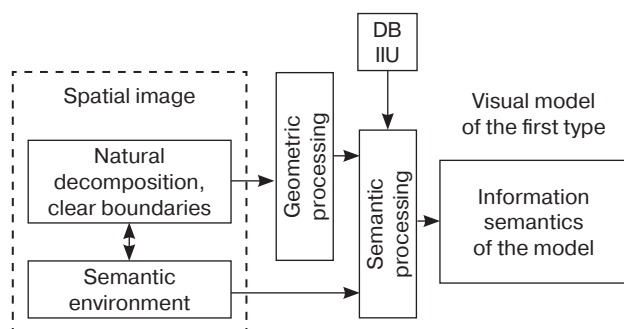


Fig. 1. Block-diagram of a model of the first type.
DB IIU—Database of information interpretation units

Natural decomposition and clear boundaries allow an independent semantic environment to be identified and each part of the spatial image (map, urban area) to be described. Natural decomposition and clear boundaries make it possible for the visual model to be divided into morphological and semantic parts. In Fig. 1, this is shown by a double-sided arrow between the semantic environment and the morphological part. For visual models of the first type, the morphological part and semantics can be separated at the level of model components. This separation enables independent processing of the morphological part and subsequent semantic processing of information. This leads to a formation of the semantics of the model which can be called informational.

A special database of interpretive units is used to form the semantics of the model. It can be a symbol classifier or a thesaurus. The visual model conveys the meaning of the spatial image in a compact form. In

order to convey the same semantics using a natural or artificial language, large informational descriptions are needed.

Figure 2 shows the scheme for constructing a visual model of the second type.

According to the diagram in Fig. 2, the spatial image does not contain clear boundaries and clear decomposition of parts. Therefore, the semantics of the parts of the image, as well as the image as a whole, is implicit. This image is conveyed not in the form of separated parts, but as an informational situation containing objects and implicit relations. Therefore, the first stage of processing and extracting the meaning of such an image is the associative decomposition of the situation. It relies on a database of associations contained in the cognitive domain of an expert [6] or an intelligent processing system [7]. There are a large number of software tools which assist the expert in the analysis and interpretation of images. Such a software product can be used to simplify the image and create a model that combines different images of the same object.

The cognitive and informational semantics of the visual model is created as a result of processing, since the cognitive factor affects its creation at the level of associative decomposition. For visual models of the second type, the semantics is more informative compared to the semantics of models of the first type.

2.2. Experimental studies

When processing space images, the concept of “primary images” should be introduced. These are pictures taken by cameras directly in the process of observation without any processing.

The following figures show the results of experimental work. Figure 3 shows a visual model, which is the primary image obtained during the initial survey. It gives an image of three spatial objects: the

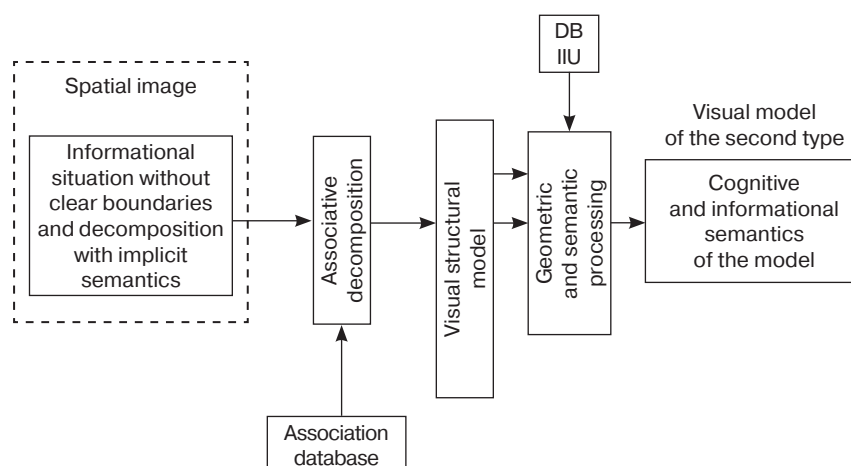


Fig. 2. Block-diagram of a model of the second type

Moon, the Earth, and the Sun. Due to the direct light of the Sun “clogging” the brightness of the reflected light of other objects, the images of objects are barely visible.

The objects in Fig. 3 have the following characteristics: the distance to the Moon is 10897 km; the apparent diameter of the Moon is $15^{\circ}48'33.8''$ and the phase angle is 166.6° ; the distance to the Earth is 406300 km; the visible diameter is $1^{\circ}46'16.0''$ and the phase angle is 152.3° . The distance to the Sun is 0.99124 AU and its visible diameter is $32'16.2''$. Recall that the phase angle is called the angle in the Sun–object–observer system. This angle is defined as the angle between the incident and reflected light from the object, as perceived by the observer [8].

The image is poorly recognizable, so a gradient processing or a structural visual model was made for it, shown in Fig. 4.

The structural visual model plays the role of a map. It can be schematized, vectorized and made into vector tracing paper to be superimposed on other image options. Figure 5 shows this vector tracing paper or structural vectorized model.

The structural vectorized model shows three basic objects and a conditional object, the position of which needs to be determined.

Between Fig. 5 and Figs. 3 and 4 there is a complete informational geometric correspondence [9]. The model in Fig. 5 is a typical informational spatial model [10]. This allows for measurements to be made, in order to “connect” informational factors to visual ones.

In Fig. 5, the symbol S stands for the Sun, E for the Earth, M for the Moon, and O for an arbitrary cosmic body. A visual structural model or a geometric model allows a conditional image coordinate system relative to the selected objects to be established. For Fig. 5 it is the Earth–Sun direction. The second axis is perpendicular to this direction. By measuring the distances on the image from an arbitrary body to the selected objects, the coordinates of the object in the conditional coordinate system can be determined using the formulae:

$$\begin{aligned} N &= 2 S_{SOE}/B_{SE}, \\ L &= (R_E^2 - N^2)^{1/2}. \end{aligned} \quad (1)$$

All parameters are shown in Fig. 5. In (1), S_{SOE} is the area of the triangle SOE calculated through the lengths of its sides. It should be emphasized that the N and L values are conditional image coordinates, corresponding to spatial relationships rather than to real spatial coordinates. The characteristic curve can be adjusted by means of computer processing. Enhancing

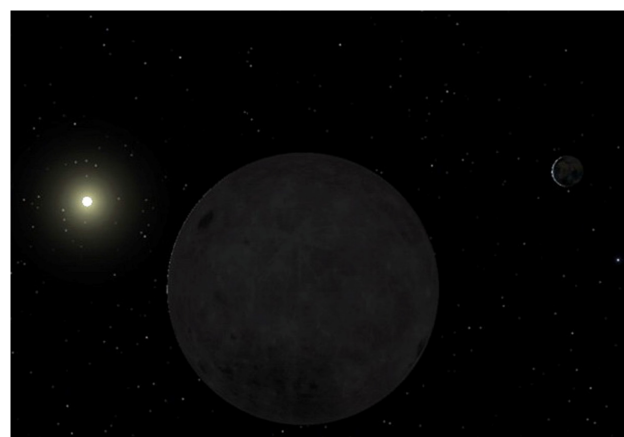


Fig. 3. Primary image of the Sun, the Earth, and the Moon



Fig. 4. Structural visual model obtained on the base of gradient processing of the primary image

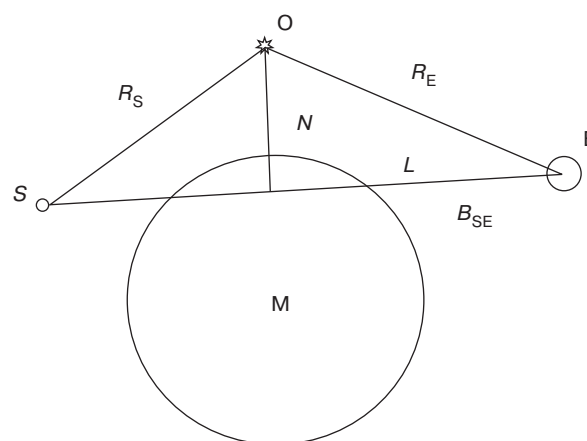


Fig. 5. Vectorized or geometric model to superimpose a series of images

weak light tones and general equalization of tones gives the image shown in Fig. 6.

The image of objects in Fig. 6 is given in pseudo-colors. In Fig. 6, the stars which are not visible in the first picture are clearly visible. The Sun has a clearly visible halo as a set of concentric circles of different brightness. Based on Fig. 5, it is possible to estimate the locations



Fig. 6. The image obtained by processing the primary image

of recognizable objects in Fig. 6. Albeit not the primary ones, they are derived from the image shown in Fig. 3.

Using and obtaining a visual structural model (VSM) allows for a series of images of different densities and different detail to be processed. VSM objects of different density and visibility to be combined into a general visual model.

This approach is based on transition from a visual model to a geometric informational model and the subsequent use of geometric image processing [11]. It is already being applied in the processing of aerospace images [12], albeit with the implementation of regression methods and direct measurements of images. The primary images (for example, Fig. 3) do not have high measurable properties. The method proposed eliminates the measurement of the primary image and uses a clear geometric model (Fig. 5). This model allows not only measurements to be performed, but for the quality of the primary image to be improved and made more visual (Fig. 6).

CONCLUSIONS

The semantics of visual models contain not only attributive characteristics, but also the characteristics of their visibility and spatial relationships. When analyzing

REFERENCES

1. Nomokonov I.B. Descriptiveness X-ray image. *Slavyanskii forum = Slavic Forum*. 2015;2(8):233–239 (in Russ.).
2. Nomokonov I.B. The semantic informativeness. *European Journal of Medicine. Series B*. 2015;3(4):141–147.
3. Bolbakov R.G. Tacit knowledge as a cognitive phenomenon. *European Journal of Technology and Design*. 2016;1(11):4–12.
4. Tsvetkov V.Ya. Information field and information space. *Mezhdunarodnyi zhurnal prikladnykh i fundamental'nykh issledovaniy = International Journal of Applied and Fundamental Research*. 2016;1–3:455–456 (in Russ.). Available from URL: <https://applied-research.ru/ru/article/view?id=8536>

complex visual models which display complex or unrecognizable images, the use of an intermediate visual structural model is advisable. This model can be created either only based on gradient characteristics (Fig. 4), or with subsequent vectorization and addition of objects “invisible” in the image (Fig. 5). The introduction of a new concept of VSM creates conditions for the serial processing of images with different spectral characteristics. VSM allows images from different spectral ranges to be combined. For complex visual images, the concept of an informational visual situation is acceptable.

Informational visual situation unites objects and the relations between them. For complex images such as X-ray or radar images, such a model is the primary concept. The studies conducted give grounds for the concept of VSM to be introduced. It is advisable that such a model be created from images with maximum details. At the same time, it can be supplemented with other pictures. The VSM model can depict objects invisible to the human eye in the primary image. This research sets out the grounds for introducing the concept of “semantics of complex visual images.” Complex visual images are difficult to describe in language, so they can be viewed as a coded message. Visual images are informative, so they require less memory. This technique allows different images to be processed altogether and renders objects which are poorly recognizable in primary images to become visible. The proposed technique makes it possible for visual images obtained by other sensors, such as thermal or acoustic, also to be processed.

Authors' contribution

V.P. Savinykh—obtaining and processing satellite images, qualitative and comparative analysis of images.

S.G. Gospodinov—analysis of algorithms for processing space images and compilation of an algorithm for chosen technique.

S.A. Kudzh—development of the image processing technique.

V.Ya. Tsvetkov—development of the image overlay technique and justification of the choice for the image coordinate system.

I.P. Deshko—algorithm implementation, software debugging, and computer processing.

СПИСОК ЛИТЕРАТУРЫ

1. Номоконов И.Б. Информативность рентгеновского изображения. *Славянский форум*. 2015;2(8):233–239.
2. Nomokonov I.B. The semantic informativeness. *European Journal of Medicine. Series B*. 2015;3(4):141–147.
3. Bolbakov R.G. Tacit knowledge as a cognitive phenomenon. *European Journal of Technology and Design*. 2016;1(11):4–12.
4. Цветков В.Я. Информационное поле и информационное пространство. *Международный журнал прикладных и фундаментальных исследований*. 2016;1–3:455–456. URL: <https://applied-research.ru/ru/article/view?id=8536>

5. Gospodinov S.G. Semantic tree in the information field. *Slavyanskii forum = Slavic Forum*. 2018;3(21):73–79 (in Russ.).
6. Kudzh S.A., Tsvetkov V.Ya. Cognitive expert assessment. In: Silhavy R. (Ed.). *Artificial Intelligence in Intelligent Systems. proceedings of Computer Science On-line Conference. Ser. "Lecture Notes in Networks and Systems."* 2021. V. 229. P. 742–749. https://doi.org/10.1007/978-3-030-77445-5_66
7. Zafar B., et al. Intelligent image classification-based on spatial weighted histograms of concentric circles. *Comput. Sci. Inf. Syst.* 2018;15(3):615–633. <https://doi.org/10.2298/CSIS180105025Z>
8. Savinykh V.P. Determination of the linear parameters of the planet by measuring the angular diameter. *Russian Journal of Astrophysical Research. Series A*. 2021;7(1):28–34 (in Russ.).
9. Ozherel'eva T.A. Information conformity and informational morphism in the information field. *ITNOU: Informatsionnye tekhnologii v nauke, obrazovanii i upravlenii*. 2017;4(4):86–92 (in Russ.).
10. Lototsky V.L. Spatial information modeling. *European Journal of Computer Science*. 2016;1(2):38–46.
11. Egoshkin N.A. Dynamic models of geometric image processing in Earth remote sensing systems. *Tsifrovaya obrabotka signalov = Digital Signal Processing*. 2017;1:8–12 (in Russ.).
12. Zlobin V., Ereemeev V. *Obrabotka aerokosmicheskikh izobrazhenii (Aerospace image processing)*. LitRes; 2018. 287 p. (in Russ.).
5. Господинов С.Г. Семантическое дерево в информационном поле. *Славянский форум*. 2018;3(21):73–79.
6. Kudzh S.A., Tsvetkov V.Ya. Cognitive expert assessment. In: Silhavy R. (Ed.). *Artificial Intelligence in Intelligent Systems. proceedings of Computer Science On-line Conference. Ser. "Lecture Notes in Networks and Systems."* 2021. V. 229. P. 742–749. https://doi.org/10.1007/978-3-030-77445-5_66
7. Zafar B., et al. Intelligent image classification-based on spatial weighted histograms of concentric circles. *Comput. Sci. Inf. Syst.* 2018;15(3):615–633. <https://doi.org/10.2298/CSIS180105025Z>
8. Савиных В.П. Определение линейных параметров планеты по измерению углового диаметра. *Russian Journal of Astrophysical Research. Series A*. 2021;7(1):28–34.
9. Ожерельева Т.А. Информационное соответствие и информационный морфизм в информационном поле. *ИТНОУ: Информационные технологии в науке, образовании и управлении*. 2017;4(4):86–92
10. Lototsky V.L. Spatial information modeling. *European Journal of Computer Science*. 2016;1(2):38–46.
11. Егоскин Н.А. Динамические модели геометрической обработки изображений в системах дистанционного зондирования Земли. *Цифровая обработка сигналов*. 2017;1:8–12.
12. Злобин В., Еремеев В. *Обработка аэрокосмических изображений*. ЛитРес; 2018. 287 с.

About the authors

Viktor P. Savinykh, Academician at the Russian Academy of Sciences, Dr. Sci. (Eng.), Professor, President, Moscow State University of Geodesy and Cartography (4, Gorokhovskiy per., Moscow, 105064 Russia). Pilot-Cosmonaut, Twice Hero of the Soviet Union, State Prize Laureate, RF President Prize Laureate, Laureate of the RF Government Prize. E-mail: president@miigaik.ru. Scopus Author ID 56412838700. <https://orcid.org/0000-0002-9303-5952>

Slaveiko G. Gospodinov, Dr. Sci. (Habil.), Professor, Vice-Rector for Research, University of Architecture, Civil Engineering and Geodesy (1, Hristo Botev Blvd., Lozenets residential complex, Sofia, 1046 Bulgaria). Academician at the International Academy of Sciences of Eurasia, Academician at the K.E. Tsiolkovsky Russian Academy of Cosmonautics. E-mail: sgospodinov@mail.bg. <https://orcid.org/0000-0002-6127-4342>

Stanislav A. Kudzh, Dr. Sci. (Eng.), Professor, Rector, MIREA – Russian Technological University (78, Vernadskogo pr., Moscow, 119454 Russia). E-mail: rector@mirea.ru. Scopus Author ID 56521711400, ResearcherID AAG-1319-2019. <https://orcid.org/0000-0003-1407-2788>

Viktor Ya. Tsvetkov, Dr. Sci. (Eng.), Dr. Sci. (Econ.), Professor, Department of Instrumental and Applied Software, Institute of Information Technologies, MIREA – Russian Technological University (78, Vernadskogo pr., Moscow, 119454 Russia). Laureate of the Prize of the President of the Russian Federation, Laureate of the Prize of the Government of the Russian Federation, Academician at the Russian Academy of Education Informatization (RAO), Academician at the K.E. Tsiolkovsky Russian Academy of Cosmonautics. (RACC). E-mail: cvj2@mail.ru. Scopus Author ID 56412459400, ResearcherID J-5446-2013. <http://orcid.org/0000-0003-1359-9799>

Igor P. Deshko, Cand. Sci. (Eng.), Associate Professor, Department of Instrumental and Applied Software, Institute of Information Technologies, MIREA – Russian Technological University (78, Vernadskogo pr., Moscow, 119454 Russia). E-mail: dip@mirea.ru. <http://orcid.org/0000-0002-8311-4067>

Об авторах

Савиных Виктор Петрович, академик РАН, д.т.н., профессор, Президент Московского государственного университета геодезии и картографии (105064, Россия, Москва, Гороховский пер., д. 4). Летчик-космонавт, Дважды Герой Советского союза, Лауреат государственной премии, Лауреат премии Президента РФ, Лауреат премии Правительства РФ. E-mail: president@miigaik.ru. Scopus Author ID 56412838700. <https://orcid.org/0000-0002-9303-5952>

Господинов Славейко Господинов, доктор наук, профессор, проректор по НИР Университета архитектуры, строительства и геодезии (1046, Болгария, София, ж.к. Лозенец, бул. Христо Ботева, д. 1). Академик международной академии наук Евразии, Академик Российской академии космонавтики им. К.Э. Циолковского. E-mail: sgospodinov@mail.bg. <https://orcid.org/0000-0002-6127-4342>

Кудж Станислав Алексеевич, д.т.н., профессор, ректор ФГБОУ ВО «МИРЭА – Российский технологический университет» (119454, Россия, Москва, пр-т Вернадского, д. 78). E-mail: rector@mirea.ru. Scopus Author ID 56521711400, ResearcherID AAG-1319-2019. <https://orcid.org/0000-0003-1407-2788>

Цветков Виктор Яковлевич, д.т.н., д.э.н., профессор, профессор кафедры инструментального и прикладного программного обеспечения Института информационных технологий, ФГБОУ ВО «МИРЭА – Российский технологический университет» (119454, Россия, Москва, пр-т Вернадского, д. 78). Лауреат Премии Президента РФ, Лауреат Премии правительства РФ, Академик Российской академии информатизации образования (РАО). Академик Российской академии космонавтики им. К.Э. Циолковского (РАКЦ). E-mail: cvj2@mail.ru. Scopus Author ID 56412459400, ResearcherID J-5446-2013. <http://orcid.org/0000-0003-1359-9799>

Дешко Игорь Петрович, к.т.н., доцент кафедры инструментального и прикладного программного обеспечения Института информационных технологий, ФГБОУ ВО «МИРЭА – Российский технологический университет» (119454, Россия, Москва, пр-т Вернадского, д. 78). E-mail: dip@mirea.ru. <http://orcid.org/0000-0002-8311-4067>

Translated by E. Shklovskii

Edited for English language and spelling by Dr. David Mossop