ABSTRACT

Lebedynskyi A. V. Models, methods and information technology for remote monitoring technical objects with non-stationary signals. – Qualifying scientific work as a manuscript.

Thesis for a Doctor of Philosophy degree in Information Technology, speciality 122 «Computer Science». – Kharkiv National Automobile and Highway University, the Ministry of Education and Science of Ukraine, Kharkiv, 2021.

The work was carried out at the Department of Metrology and Life Safety of Kharkiv National Automobile and Highway University of the Ministry of Education and Science of Ukraine.

The object of the study is the process of automated decision-making about the condition of bridge structures on the basis of their non-stationary deflections, obtained by remote measurement.

The subject of the research is models, methods and information technology of providing automated decision-making on the condition of bridge structures on the basis of the results of remote measurement of parameters of non-stationary deflection processes.

The PhD thesis is devoted to the development of models, methods and information technology of remote monitoring technical objects with non-stationary output signals for automatic decision-making on the state of these objects. Bridge structures and autonomous mobile robots were used as technical objects in the research.

Models, methods and information technology of remote monitoring technical objects with non-stationary signals have been presented in the thesis. In contrast to well-known technical solutions, our technology provides sustainability and value of obtained data in real-time mode when analysing non-stationary processes. That was substantiated by 5 patents of Ukraine, obtained by the author and his colleagues.

The dissertation is related to the relevant world-wide problem of real-time analysis of non-stationary processes, the characteristics of which are difficult to

predict, and it is very difficult to extract valuable information in a large data set and to draw conclusions about the process itself.

In Introduction the choice of the theme of the research and topicality of the thesis have been substantiated, the purpose and objectives have been formulated, the object, subject and methods of the study have been defined, the connection of the work with scientific themes according to the Ministry of Education and Science of Ukraine has been shown, the scientific novelty has been provided and practical significance of the results has been formulated.

The first section is devoted to the literature review on the subject of the dissertation, in particular a comprehensive analysis of existing information technologies in systems for remote monitoring technical objects like bridges and landmarks for autonomous mobile robots, their features and their applications. The main shortcomings of existing information technologies of remote monitoring technical objects have been analysed in particular: the complex process of obtaining data about bridge structure conditions using contact methods of measuring deflections and the dynamic amplification factor; the need to restrict traffic on the bridge to obtain information about its condition; the ability to find data about the bridge structure only at one measurement point; a large amount of information to be analysed and selected as useful; the use of complex and time-consuming for implementing methods of finding information about the state of structures while analyzing non-stationary processes, etc.

In the second section the theoretical bases of construction of models, methods and information technology of remote control of bridge constructions were considered. The essence of the existing models of decision-making on the condition of bridge structures was considered, which consists in measuring dynamic amplification factor by finding the ratio of the dynamic deflection to the static one of the bridges in the middle of the longest span. After that, the factor that was found, is compared with threshold value, which is set for a certain type of bridge structure and if this certain threshold is exceeded, a decision will be made on the further operation of this bridge structure. Attention was drawn to the fact that this decision-

making model can be applied to homogeneous deflections of a bridge structure, the fluctuations of which can be described by a stationary process. But if the fluctuations of the BS are a non-stationary process, then the traditional methods and models of decision-making do not work here and new methods are needed, methods of finding information about the state of the bridge structures.

In the third section, the models have been created and the methods in information technologies for remote monitoring bridge constructions have been developed. One of these methods is the method of collecting information on the spatial deflections of the lower surface of bridge structures using non-contact methods of measuring and finding data about bridge structures using a miniature radar that can be located in any convenient place for the operator and a system of secondary emitters located on the lower part of the bridge structures surface. The advantage of the method over the existing ones is the ability to obtain data at several points of the bridge construction, not only one. The model and information technology for determining constancy, data value by remote measuring deflections of the lower part of the bridge structure and information technology of decision-making on the bridge structures conditions with non-stationary input actions have been offered. The model for estimating the sustainability of information obtained from non-stationary processes relative to the reference stationary process has been improved. It differs in data processing about the stationary Hilbert-Huang modes, which allow one to improve the quality of automatic decision-making about the state of any technical object. Information technology for remote monitoring technical objects has been further developed, in contrast to the well-known ones it takes into account the non-stationary nature of input processes and ensures the sustainability of data for decision-making. The information technology for determining the value of measuring data about the bridge structure deflections has been further developed, in contrast to the well-known ones it takes into account the indicators of statistical decisions on the safety of structures, which allows meeting conflicting requirements for data safety and value. The choice of threshold deflections is carried out with the best possible subject to these requirements.

The fourth section discusses the implementation of using the developed models, methods and information technology for technical objects, e.g., for navigating autonomous mobile robots in unfamiliar terrain when GPS is not available. Firstly, it is a system for data collecting and processing based on using dynamic spatial channels for detecting landmarks. These channels are created artificially when scanning the surrounding area with a video camera and compressing data by converting two-dimensional images into one-dimensional ones to identify landmarks against a background similar to landmarks in colour. Secondly, it is a system for collecting data about the chromaticity parameters *R, G, B*, decomposing the dependence of the latter on the spatial coordinate of the image frame in the space of orthogonal Hilbert-Huang modes, and decision-making on the detection of a landmark based on information about the statistical distribution of only the first three Hilbert-Huang modes.

Theoretical and applied results of the thesis have been used in the educational process of the Department of Bridges, Structures and Building Mechanics at KhNAHU for training students (speciality 192 «Construction and Civil Engineering»), in lecture courses «Innovative Directions of Operational Technology of Transport Facilities» and when making preparation for Laboratory Practicum.

The results of the dissertation have been implemented in the project «Development of information-measuring systems and diagnostic systems for static and dynamic objects in the machine-building and road-building industries» (state registration number 0120U104317).

Keywords: information technology, remote control of technical objects, non-stationary signals, bridge construction, autonomous mobile robot, landmark.

LIST OF APPLICANT'S PUBLICATIONS

Scientific papers, in which the main scientific results are published:

1. Poliarus O. V., Lebedynskyi A. V. Metod, model ta informatsiina tekhnolohiia vyznachennia stalosti informatsii pry dystantsiinomu kontroli stanu

tekhnichnykh obiektiv. *Vidkryti informatsiini ta kompiuterni intehrovani tekhnolohii*. 2021. № 92. DOI: 10.32620/oikit.2021.92.12.
(Osobystyi vnesok zdobuvacha: realizatsiia metodu vyznachennia stalosti informatsii, stvorennia hrafichnoho interfeisu korystuvacha)

2. Rezultaty vymiriuvan parametriv mekhanichnykh kolyvan balky z vykorystanniam RLS milimetrovoho diapazonu / R. E. Pashchenko ta in. *Tekhnolohyia pryborostroenyia, nauchno-tekhnycheskyi zhurnal*. 2018. № 2. S. 55-59.
(Osobystyi vnesok zdobuvacha: provedennia eksperymentiv, obrobka otrymanykh rezultativ)

3. Poliarus O. V., Lebedynskyi A. V. Dystantsiine vyznachennia dielektrychnoi pronyknosti betonnoi plyty mostovoi sporudy. *Tekhnolohyia pryborostroenyia, nauchno-tekhnycheskyi zhurnal*. 2019. № 2. C. 62-65
(Osobystyi vnesok zdobuvacha: realizatsiia metodu vyznachennia dielektrychnoi pronyknosti mostovoi sporudy)

4. Measurement of the Bridge Surface Deflections Using Near-Field Amplitude of Secondary Radiators System / O. V. Poliarus et al. *Advances in Science, Technology and Engineering Systems Journal*. 2017. Vol. 2, № 6. P. 217-224.
(Osobystyi vnesok zdobuvacha: provedennia eksperymentiv, obrobka rezultativ eksperymentiv, modeliuvannia systemy iz vtorynnymy vyprominiuvachamy, otrymannia rezultativ modeliuvannia)

5. Influence of Measurements Uncertainty on Uncertainty of Gilbert-Huang Transform Modes / O. Poliarus et al. *Proceedings of 2019 IEEE 8th International Conference on Advanced Optoelectronics and Lasers*, CAOL 2019, Sozopol, Bulgaria, 6-8 September, 2019, pp. 2019. P. 644-647. DOI: 10.1109/caol46282.2019.9019512.
(Osobystyi vnesok zdobuvacha: analiz vplyvu nevyznachenosti vymiriuvan syhnalu na nevyznachenist yoho mod Hilberta-Khuanha, modeliuvannia zalezhnostei mod pry identyfikatsii system, otrymannia rezultativ modeliuvannia).

6. Poliarus O. V., Poliakov Y. A., Lebedynskyi A. V. Measurement of Bridges Dynamic Deflections Using Arrays of Secondary Radiators. *IEEE Ukrainian Microwave week (UkrMW).* 2020. № 1. P. 97-100.
(Osobystyi vnesok zdobuvacha: provedennia eksperymentiv, obrobka rezultativ eksperymentiv, modeliuvannia systemy iz vtorynnymy vyprominiuvachamy, otrymannia rezultativ modeliuvannia)

7. Poliarus O., Poliakov Y., Lebedynskyi A. Detection of landmarks by autonomous mobile robots using camera-based sensors in outdoor environments. *IEEE Sensors Journal*. 2021. Vol. 21, № 10. P. 11443-11450. DOI: 10.1109/JSEN.2020.3010883.
(Osobystyi vnesok zdobuvacha: provedennia rozkladannia zobrazhen fonu ta oriientyru na skladovi kolorovosti, stvorennia hrafikiv zalezhnostei, znakhodzhennia zakoniv rozpodilennia ymovirnostei, otrymannia rezultativ modeliuvannia)

Published works for approbation purpose:

8. Poliarus O. V., Lebedynskyi A. V. Method for Determining Information Stability in Information Technologies at Technical Objects. *Computer technology and mechatronics* : proceedings of the third international scientific and methodical conference, Kharkiv, 27-28 May 2021. Kharkiv: KhNAHu, 2021. P. 145-147.
(Osobystyi vnesok zdobuvacha: dopovidav ta brav uchast u obhovorenni rezultativ, realizuvav metod vyznachennia stalosti informatsii, pidhotuvav osnovnu chastynu tekstu)

9. Poliarus O. V., Poliakov Ye. O., Lebedynskyi A. V. Method of determining measurement information value for bridges safety. *Problemy nadzvychainykh sytuatsii. Materialy konferentsii.* : Materialy Mizhnarodnoi naukovo-praktychnoi konferentsii «Problems of Emergency Situations», m. Kharkiv, 20-21 travnia 2021. Kharkiv: Natsionalnyi universytet tsyvilnoho zakhystu Ukrainy, 2021. C. 77-78.
(Osobystyi vnesok zdobuvacha: dopovidav ta brav uchast u obhovorenni rezultativ, realizuvav metod vyznachennia tsinnosti informatsii, pidhotuvav osnovnu chastynu tekstu)

10. Poliarus O. V., Krasnov S. M., Lebedynskyi A. V. Metod dystantsiinoho vyznachennia koefitsiienta dynamichnosti mostovoi sporudy vymiriuvalnoiu informatsiinoiu systemoiu maloi vartosti. *Metrolohiia, informatsiino-vymiriuvalni tekhnolohii ta systemy* : Materialy 7-yi Mizhnarodnoi naukovo-tekhnichnoi konferentsii «Metrolohiia, informatsiino-vymiriuvalni tekhnolohii ta systemy» (MIVTS-2020), h. Kharkiv, 28-29 sichnia 2020. Kharkiv: Ukrainskyi metrolohichnyi zhurnal, 2020. C. 110-111.
(Osobystyi vnesok zdobuvacha: brav uchast u obhovorenni rezultativ, promodeliuvav metod vyznachennia koefitsiienta dynamichnosti mostovoi sporudy vymiriuvalnoiu informatsiinoiu systemoiu maloi vartosti, pidhotuvav osnovnu chastynu tekstu)

11. Lebedynskyi A. V. Otsinka statsionarnosti za dopomohoiu metodu zvorotnoho rozpodilennia. *Metrolohichni aspekty pryiniattia rishen v umovakh roboty na tekhnohenno nebezpechnykh obiektakh* : Materialy Vseukrainskoi naukovo-praktychnoi internet konferentsii zdobuvachiv vyshchoi osvity i molodykh uchenykh, m. Kharkiv, 4-5 lystopada 2019. Kharkiv: KhNADU, 2019. C. 173-175. URL:
https://dl.khadi.kharkov.ua/pluginfile.php/58643/mod_resource/content/1/sbornik_konf_2019.pdf. (data zvernennia: 19.11.2020).

12. Lebedynskyi A. V. Zastosuvannia peretvorennia Hilberta-Khuanha v IT-tekhnolohiiakh. *Kompiuterni tekhnolohii i mekhatronika* : Zbirnyk naukovykh prats za materialamy mizhnarodnoi naukovo-praktychnoi konferentsii «Kompiuterni tekhnolohii i mekhatronika», m. Kharkiv, 28-29 Travnia 2020. Kharkiv: KhNADU, 2020. C. 114-117.

13. Lebedynskyi A. V., Yanushkevych S. D. Otsinka tochnosti aproksymatsii nestatsionarnykh syhnaliv empirychnymy modamy Hilberta-Khuanha. *Kompiuterni tekhnolohii i mekhatronika* : Zbirnyk naukovykh prats za materialamy mizhnarodnoi naukovo-praktychnoi konferentsii «Kompiuterni tekhnolohii i mekhatronika», m. Kharkiv, 30-31 Travnia 2019. Kharkiv: KhNADU, 2019. C. 109-112.

(Osobystyi vnesok zdobuvacha: dopovidav ta brav uchast u obhovorenni rezultativ, otsinyv tochnist aproksymatsii nestatsionarnykh syhnaliv empirychnymy modamy Hilberta-Khuanha, pobuduvav hrafiky, pidhotuvav osnovnu chastynu tekstu)

14. Lebedynskyi A. V. Hilbert-Huang Transform and its Application. *Studentstvo. Nauka. Inozemna mova* : Zbirnyk naukovykh prats studentiv, aspirantiv ta molodykh naukovtsiv, m. Kharkiv, 20-21 Travnia 2019. Kharkiv: KhNADU, 2019.

15. Lebedynskyi A. V. Podhotovka eksperymentalnykh dannykh kolebanyia modely balky mosta k obrabotke. *Mosty, tuneli i dorohy: stan, problemy utrymannia ta perspektyvy pidvyshchennia dovhovichnosti* : Vseukrainska naukovo-praktychna Internet konferentsiia, m. Kharkiv, 25-26 March 2018. Kharkiv: KhNADU, 2018. URL: https://dl.khadi.kharkov.ua/pluginfile.php/49375/mod_resource/content/2/SBORNYK.pdf. (data zvernennia: 25.08.2021).

Scientific works that additionally represent the scientific results of the dissertation:

16. Sposib dystantsiinoho vyznachennia koefitsiienta dynamichnosti i formy deformovanoi poverkhni mostovykh sporud abo inshykh velykohabarytnykh obiektiv: pat. 124207 Ukraina. № 201710597; zaiavl. 01.11.2017; opubl. 26.03.2018.

(Osobystyi vnesok zdobuvacha: brav uchast u obhovorenni rezultativ, pidhotuvav osnovnu chastynu tekstu, proviv modeliuvannia, otrymav i obrobyv rezultaty modeliuvannia)

17. Sposib dystantsiinoho vyznachennia koefitsiienta dynamichnosti i formy deformovanoi poverkhni mostovykh sporud abo inshykh velykohabarytnykh obiektiv: pat. 118730 Ukraina. № 201710596; zaiavl. 01.11.2017; opubl. 25.02.2019.

(Osobystyi vnesok zdobuvacha: brav uchast u obhovorenni rezultativ, pidhotuvav osnovnu chastynu tekstu, proviv modeliuvannia, otrymav i obrobyv rezultaty modeliuvannia)

18. Sposib dystantsiinoho vyznachennia dynamichnykh prohyniv i formy deformovanoi poverkhni mostovykh sporud abo inshykh velykohabarytnykh obiektiv: pat. 146478 Ukraina. № 202005999; zaiavl. 21.09.2020; opubl. 24.02.2021.

(Osobystyi vnesok zdobuvacha: brav uchast u obhovorenni rezultativ, pidhotuvav osnovnu chastynu tekstu, proviv modeliuvannia, otrymav i obrobyv rezultaty modeliuvannia)

19. Sposib vyiavlennia tsylindropodibnykh nazemnykh oriientyriv pry navihatsii avtonomnykh mobilnykh robotiv: pat. 146486 Ukraina. № 202006061; zaiavl. 22.09.2020; opubl. 24.02.2021.

(Osobystyi vnesok zdobuvacha: brav uchast u obhovorenni rezultativ, pidhotuvav osnovnu chastynu tekstu, proviv modeliuvannia, otrymav i obrobyv rezultaty modeliuvannia)

20. Sposib vyiavlennia tsylindropodibnykh oriientyriv pry navihatsii avtonomnykh mobilnykh robotiv: pat. 146487 Ukraina. № 202006062; zaiavl. 22.09.2020; opubl. 24.02.2021.

(Osobystyi vnesok zdobuvacha: brav uchast u obhovorenni rezultativ, pidhotuvav osnovnu chastynu tekstu, proviv modeliuvannia, otrymav i obrobyv rezultaty modeliuvannia)