PAPER • OPEN ACCESS

Augmented reality technology as a tool to improve the efficiency of maintenance and analytics of the operation of electromechanical equipment

To cite this article: N I Koteleva *et al* 2021 *J. Phys.: Conf. Ser.* **1753** 012058

View the article online for updates and enhancements.

Augmented reality technology as a tool to improve the efficiency of maintenance and analytics of the operation of electromechanical equipment

N I Koteleva, Y L Zhukovskiy and V Valnev

St. Petersburg Mining University, 2, 21 Line of Vasilyevsky Island, St. Petersburg, 199106, Russia

Email: Koteleva_NI@pers.spmi.ru

Abstract. Today the industry is facing a shortage of skilled workers and an aging workforce, which will eventually lead to a loss of knowledge. But augmented reality technology can connect field workers with experts who are able to provide remote guidance in real time. The subsequent advantage is that the information obtained by AR devices can be used as accumulated successful experience in the future, which facilitates decision-making in specific business processes of the company. With AR, employees gain experience and skills much faster. This paper shows the application of augmented reality technology in the maintenance of electromechanical equipment. The main functions of the augmented reality system for servicing electrical equipment are presented, the solution to the problem of integrating an augmented reality software application with existing automation systems is shown, and the methods of interaction of the developed software module with third-party modules, for example, various analytical modules, etc. are described.

1. Introduction

Today, enterprises in the mineral resource sector face problems of highly dynamic market changes, and, as a result, it is necessary to increase the flexibility of such enterprises to changing conditions [1,2]. This can be done by implementing digital technologies at various stages of production [3, 4]. Since the technological processes of enterprises in the mineral resource complex are energy-intensive, the introduction of digital technologies into energy systems will not only increase production efficiency [5, 6]. But it will also increase safety and significantly reduce the trouble-free operation of electromechanical equipment. In this paper, the technology of augmented reality is considered as a target digital technology [7, 8]. This choice is not accidental, because augmented reality technologies have moved from the stage of conceptual distribution and are fully ready to be implemented in real production. At the same time, the existing theoretical and practical developments in the field of augmented reality, have a number of unresolved problems. Therefore, most modern works in this area contain information about the adaptation of existing practical and theoretical developments in actual production. For the widespread implementation of augmented reality technologies in production processes, it is necessary to solve a number of issues, including: to determine the range of tasks that can be solved using an augmented reality system, to develop a universal methodology for implementing augmented reality systems, to identify the most effective way to implement augmented reality technologies (for example, to develop them as a separate software module, and then solve

integration issues, or immediately develop them as a separate part or an additional module of existing automation systems), etc.

The presented work shows the experience of creating separate software application using augmented reality technology for servicing electromechanical equipment, shows integration issues for this module, defines the range of tasks to be solved, and describes how the developed software module interacts with third-party modules, for example, various analytical modules, etc.

The development of an augmented reality system was carried out for the installation of a «Smart shield» of the laboratory of Mining University (Figure 1).

Figure 1. The «Smart shield» of the laboratory of Mining University

The development of a system was carried out in several stages:

1. development of system functionality;
2. creation of software;
3. configuring communicational channel to link the augmented reality module and analytical module;
4. development of the system testing methodology and conducting testing;
5. development of software to provide video and audio communication with the expert.

2. Literature review

For decades, industrial enterprises have considered lean manufacturing, training, robotics, and automation as the main strategies for improving operational efficiency [9]. Energy and utilities are among the top three in terms of supply of augmented reality AR-glasses and in the overall value chain. AR's ability to improve employee's safety and protect equipment meets the safety priority that companies have traditionally placed on it [10]. According to ABI Research, it is the energy and utilities sector that will account for 17% of the global supply of smart glasses in 2018. Total revenue from the AR market for energy and utilities is expected to grow to $ 18 billion by 2022. AR is able to provide better visualization of underground objects, pipelines in concrete, or complex components that help avoid breakdowns leaks, and reduce the number of accidents [11, 12]. Accordingly, employee safety will be dramatically improved, and the number of errors and total downtime will be reduced [13,14].

The Electric Power Research Institute (EPRI) has confirmed the importance of AR for industry by piloting the use of AR in the power and utility sectors. Duke Energy's Atheer AR platform has demonstrated the benefits of AR applications in improving productivity and security with free data access. GE Renewable Energy 34% increased the efficiency of the assembly time of technical means, using smart glasses with digital instructions [15]. The Upskill Skylight platform allowed technicians to use their voice to identify specific items, such as wires and pipes, as well as find problem areas, which saves time when reading paper manuals. Together with capabilities such as real-time environmental

monitoring, safety notifications, and workflow instructions can provide fast learning and safety while improving efficiency - a unique and attractive combination for the industry [16].

Today, there is a whole range of developments of augmented reality systems for various industries and industries. In [17], the authors examine the use of augmented reality technology for student learning. The value of the study is to create a new approach to learning and interest among students. The proposed solution uses books as a marker, thereby showing the need to use printed material. A layer with virtual objects appears on the pages of the book that you can interact with. This approach allows you to combine the use of printed and digital information in the learning process. Thus, it is possible to consider the topics under study in more detail and clearly. The disadvantages of the system include the unreliability of the used markers. So, even in the case of a slight damage to the page, the virtual layer of augmented reality may cease to be displayed.

In [18], the authors examine two prototypes of using augmented reality technology as part of the development of Industry 4.0. In the first version, the system displays virtual panels with equipment parameters in real time. The second system allows you to display hints of a remote expert. The advantage of both options is that there is no need to install additional software and there is no need for specialized equipment. The authors propose the implementation of the system on mobile devices (tablet) as a result of wide distribution and availability. The study examined the implementation structure of systems, as well as architectural features for the AR application, but there is no information about the effectiveness of the implementation of the proposed prototypes.

In the paper [19], the authors consider the use of the augmented reality application for maintenance and repair of CNC. This technical solution allows you to consider a three-dimensional model and each part of it separately. Interaction is carried out only with a virtual object that is tied to a marker. The authors propose using the AR application as a training simulator to increase the quality and speed of equipment maintenance, however, the authors do not examine the effectiveness of the technological solution using an example of a real machine.

In [20], the authors consider a method for recognizing objects (parts) using augmented reality technology. The value of the study lies in the study of recognition algorithms for real objects. As the AR market has been growing rapidly lately, augmented reality algorithms are constantly being improved.

In [21], authors consider using virtual reality to train employees for situations that are difficult and expensive to recreate or rare and can be dangerous. The proposed technological solution is a virtual simulator for the maintenance of the Grundfos pump. The authors compared the proposed method with the traditional method of equipment maintenance: for video materials and pair training. The authors note that in practice traditional methods show the best result in time spent and in the number of errors compared to the virtual simulator, however, they note that virtual reality technology is better for learning.

3. Method

The main hypothesis of this work is the hypothesis that the augmented reality system improves the quality of maintenance of electromechanical equipment. Of course, the range of capabilities of the augmented reality system is quite wide. In this paper, the proof of the proposed hypothesis will be carried out in the following areas and evidence of the following hypotheses:

1. Improving the availability of expert support at all stages of maintenance will lead to a reduction in time and improve the quality of work.

2. Improving accessibility and reducing the time for obtaining information about technological, operational data, etc. service information will lead to a reduction in time and an improvement in the quality of work performed.

3. Reducing the time for making decisions by adding analytical functions to the system will lead to a reduction in time and an improvement in the quality of work performed.

The selection of these directions was carried out taking into account significant factors that affect the life cycle of electrical equipment: operating conditions, the competence of technical personnel

servicing electrical equipment, forecasting various types of defects and an accurate assessment of the current state of electrical equipment [22, 23]. At the same time, I would especially like to emphasize that the effectiveness assessment will be carried out according to aggregated factors and, of course, for a more detailed study of the benefits when using the augmented reality system, it is necessary to use a wider range of directions and factors, which will undoubtedly be a matter of further scientific developments on this topic [24].

Three technologies were considered as expert support in the work - system expert support in the form of visualization of user actions necessary for equipment maintenance (tested in three forms - in the form of a video file, on a 3D team assembled on top of the part being serviced, in the form of highlighting (highlighting and color on a real object) of details that require attention of the operating personnel (for example, highlight bolts that need to be unscrewed and the desired type of tool), system expert support in the form of expert advice or prompts with a running line, as well as expert support in the form of an accessible and reliable channel communication with an expert person.

To prove the second hypothesis, the work sought optimal protocols for organizing the communication channel between the augmented reality system and equipment to display its technological and service parameters, as well as other necessary information.

To prove the third hypothesis, an analytical function was connected in the work to determine the activity of the equipment according to the values of technological, service or operational parameters. Special attention in the work was determined by the development of augmented reality system testing methodology. System testing takes place in two stages. At the first stage, a standard system performance test is performed. At the second stage, the following methodology was used to test the system:

1. Tasks for testing were developed. Examples of tasks include: mounting / dismounting equipment, verifying the execution of dispatcher commands locally, finding the cause of a hardware malfunction (working with the system's historical data), software shutdown of devices (working out analytical functions), etc.

2. The teams of testers formed. To test the created software algorithms, 4 groups of people were used - the 1st group - a group that was allowed to use only documentation on paper or the Internet, the 2nd group - a group that could only use the hints and functionality entered into the system, the 3rd group - a group which could use internal hints and functionality, as well as, if necessary, the help of an expert, 4th group - a group that could use only the help of an expert.

3. For each group of testers, the execution time of each task was recorded.

4. Analysis of the results.

4. Implementation

The system uses three approaches to increase the availability of expert support. Adding virtual elements to the system, allowing one to increase the information content about the maintenance of certain elements. To add to the system, three types of objects were used - a 3D model of a device, a video file, software lighting of zones requiring increased attention. 3D model shows in detail the object of maintenance. It can be rotated, disassembled into parts, see what is inside, that is, perform any manipulations virtually without disassembling the real part. A video file is a record of various equipment maintenance activities with sound comments. Software lighting of zones allows you to programmatically highlight with color or light various zones of parts: highlight bolts that need to be removed, show moving elements, etc. Figure 2 shows the appearance of the augmented reality module. The parameter visualization window is shown (Active power, average current, Average phase voltage) with the ability to view the values of other parameters, trends, as well as the ability to control the iC60N circuit breaker. Also, the user has selected the option to depict a 3D model of the device for detailing the features of control of a circuit breaker.

Figure 2. The scene of the augmented reality module

The augmented reality software application was developed in the Unity (Unity Technologies) software environment with the Vuforia (Qualcomm) platform installed. This software can be replaced with any other software since modularity was incorporated in the structure of the system as a whole, which allows integrating various software applications. Figure 3 shows the structural diagram of the system. Integration between the augmented reality system and the object ("Smart Shield") is done using the OPC and MQTT protocols. Also, an SQL server is used to create and maintain an archive of system parameter values [25, 26].
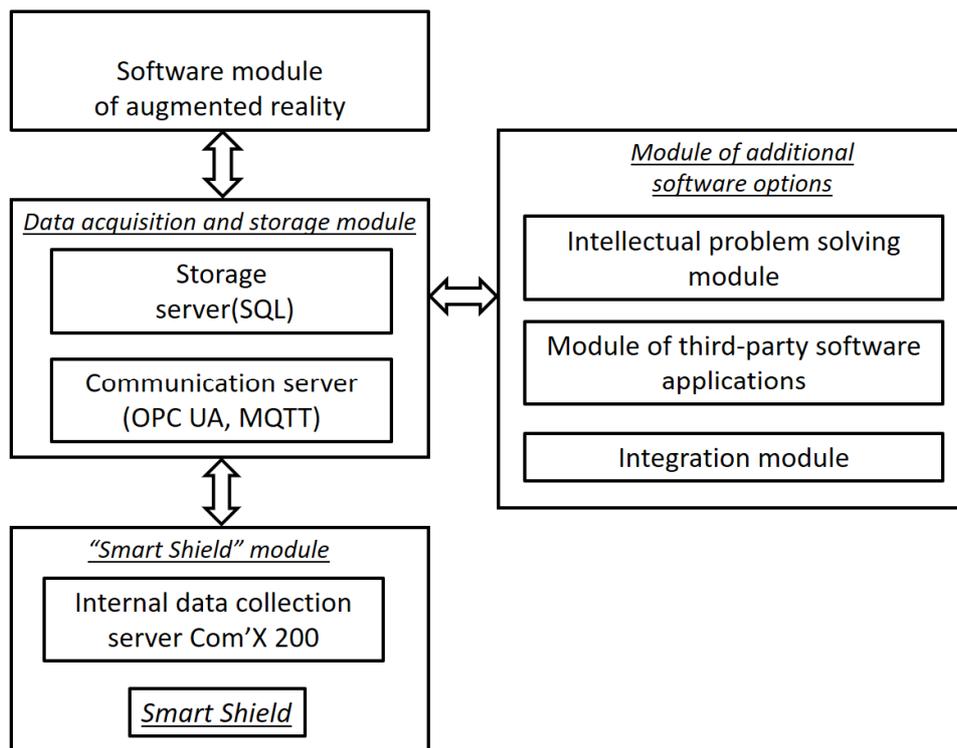

Figure 3. The structure of the system

As an analytical function in the system, the function of determining devices connected to the network by the values of technological parameters is used. The following experimental design was used to develop the system and collect parameters (table 1).

Table 1. Experiment plan

Status of device 1	Status of device 2	Status of device 3	Recording time of parameter (1 min)	Recording time of parameter (2 min)
1	1	1	19:00-19:01	19:15-19:17
1	1	0	19:02-19:03	19:23-19:25
1	0	1	19:04-19:05	19:28-19:30
1	0	0	19:07-19:08	19:30-19:32
0	1	1	19:10-19:11	19:17-19:19
0	1	0	19:12-19:13	19:19-19:21
0	0	1	19:13-19:14	19:21-19:23
0	0	0	19:14-19:15	19:32-19:34

At each time point indicated in the table, the main technological parameters were measured, among which the value of current strength, voltage, active and reactive power, etc. These parameters were used to form training, test and validation samples. These samples were used to create and train a neural network. The neural network was trained to recognize the type of device connected to the network. Thus, the analytical function was implemented and tested.

5. Results

For testing and ranking the utility of functions used as elements of expert support in the system, the rank correlation method was used. 15 testers were invited to act as experts. To conduct the experiment, they were given 2 tasks of mounting and dismounting the circuit breaker from a DIN rail. The functions were divided into groups X1 - use only 3D models, X2 - use only highlighted elements, X3 - use only video files with instructions, X4 - step-by-step instructions in the form of a running line, X5 - communication with an expert directly, X6 - combination of X1 and X4, X7 is a combination of X2 and X4, X8 is a combination of X3 and X4. After performing two operations, testers were asked to evaluate the usability of a particular function and rank for each of them, ranking by ease of use, where 1 is the most convenient, 8 is the least convenient. In cases where the expert doubted, he could put fractional ranks for each of the functions. Figure 4 shows a histogram of the ranking of factors according to expert testers.
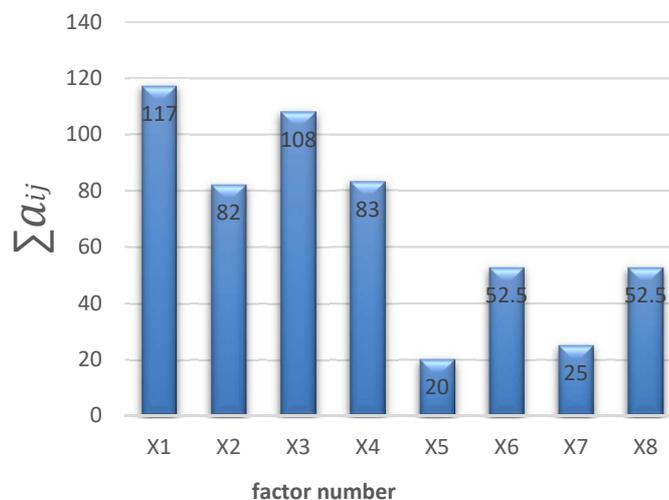
Figure 4. The histogram of the ranking of factors

The results of testing the augmented reality system during the maintenance of electrical equipment were obtained by four groups of testers. However, after the first experiment, it was found that during the testing the group that used only the expert's help solved the tasks longer than the group that used only the instructions and the Internet. The reason for this was the psychological factor - testers first tried to solve the problem on their own, and only in case of failure turned to the help of an expert. Therefore, it was decided to add a group for testing 5, which solved the problem immediately using the help of an expert. However, this group was introduced only to obtain a result in the entire spectrum of possible options, including in the process of completing tasks only under the guidance of an expert. In reality, the constant involvement of an expert to solve even the simplest tasks will not be able to increase the efficiency of maintenance, since it will require not only a new system, but also new resources in the form of a constantly on-call expert, which is certainly not the best solution. The results are shown in table 2.

Table 2. Results of experiments

	Group №1, time, sec	Group №2, time, sec	Group №3, time, sec	Group №4, time, sec	Group №5, time, sec
Experiment 1					
Equipment dismantling	158	112	122	164	-
Search for failure equipment	246	184	179	280	-
Troubleshooting	740	658	680	720	-
Remotely switching of devices	94	35	24	156	-
Mantling of equipment	80	53	55	86	-
Total time	1318	1042	1060	1406	-
Experiment 2					
Equipment dismantling	170	98	115	150	75
Search for failure equipment	240	198	181	200	192
Troubleshooting	725	754	655	720	614
Remotely switching of devices	82	45	38	90	48
Mantling of equipment	84	47	56	69	50
Total time	1301	1142	1045	1229	979
Experiment 3					
Equipment dismantling	184	110	116	150	79
Search for failure equipment	195	182	165	175	191
Troubleshooting	754	682	624	620	623
Remotely switching of devices	101	51	31	50	42
Mantling of equipment	82	52	68	51	55
Total time	1316	1077	1004	1046	990
Experiment 4					
Equipment dismantling	165	96	115	150	71
Search for failure equipment	256	181	175	214	185
Troubleshooting	690	690	694	655	610
Remotely switching of devices	95	47	40	88	51
Mantling of equipment	88	49	53	66	48
Total time	1294	1063	1077	1173	965
Experiment 5					
Equipment dismantling	169	99	115	150	73
Search for failure equipment	230	175	171	211	189
Troubleshooting	731	735	678	710	620
Remotely switching of devices	98	44	35	73	41
Mantling of equipment	84	50	61	70	53
Total time	1312	1103	1060	1214	976

An interesting fact is that the third group of testers, who were allowed to use the hints with the functionality and expert help, requested expert help only 1 time for all experiments. Their results were very close to the group of testers 2. As can be seen in group 5 in 4 experiments, the time is not very different, which indirectly indicates that the knowledge of the same expert is directly used.

6. Discussion

The proof of the main hypothesis of the work is carried out through the proofs of three secondary hypotheses. Increasing the availability of expert support is obvious, since in all experiments, a group that did not use expert support in any form performed the tasks for the longest time from 1294 to 1318 seconds. The expected result is a reduction in time to solve tasks performed under the guidance of an expert. These groups in almost all experiments performed tasks with a minimum amount of time. However, an expert was involved on an ongoing basis, which is not permissible. Since the goal is to develop a system with built-in elements of expert support without the involvement of third parties, the actions carried out under the guidance of an expert were more likely to be purely experimental in nature and were essentially the reference value of the system. The closest to this standard was the group No. 3, which could use internal tips and functionality, as well as, if necessary, the help of an expert. Moreover, as noted earlier, she used the advice of a real expert only once. On average, all functions of group 3 spent 1049.2 seconds against 977.5 seconds of group 5. This is only 7% more time. This result can be considered evidence that the augmented reality system with built-in expert support at all stages of maintenance will reduce the time and improve the quality of work performed on the maintenance of electromechanical equipment.

7. Conclusion

The augmented reality system is an effective tool for servicing electromechanical equipment. The development and implementation of expert support elements in the system during maintenance and repair of equipment will increase efficiency, reduce production costs, and extend the life of the devices. Obtaining information on the progress of the technological process, as well as information on the status of devices in real time, allows one more justified and faster to make various decisions on the maintenance of electromechanical equipment. Further research will mainly focus on the development of system modules that allow you to simply and quickly add information about the maintenance of various types of equipment used in production. In addition, various analytical functions will be developed, allowing one not only to perform service maintenance of devices, but also to assess their actual condition [27, 28]. Predict and warn of the development of defects. The implementation of these analytical modules will significantly increase the life of the equipment and prevent possible consequences associated with the failure of the equipment and its breakdowns.

References

[1]   Kazanin O I, Sidorenko A A and Sementsov V V 2014 Determination of technology parameters of the thick steep gassy seams mining with sublevel caving and coal discharge mining system *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu* **6** 52–58

[2]   Trushko V L, Protosenya, A G 2019 Prospects of geomechanics development in the context of new technological paradigm *Journal of Mining Institute* **236** 162-166 DOI: 10.31897/pmi.2019.2.162

[3]   Litvinenko V S 2019 Digital economy as a factor in the technological development of the mineral sector. *Natural Resources Research* **29(3)** 1521-1541 DOI:10.1007/s11053-019-09568-4

[4]   Makhovikov A B, Katuntsov E V, Kosarev O V, Tsvetkov P S 2019 Digital transformation in oil and gas extraction *Innovation-Based Development of the Mineral Resources Sector: Challenges and Prospects - 11th conference of the Russian-German Raw Materials* 531-538

[5]   Klyuev R V, Bosikov I I and Alborov A D 2020 Research of Non-sinusoidal Voltage in Power Supply System of Metallurgical Enterprises *Lecture Notes in Electrical Engineering* **641** LNEE 393-

400

[6]   Murashov I, Frolov V and Kadyrov A 2018 Development of the arc plasma torch operation mathematical model for spheroidization of fine-dispersed powders *Journal of Physics: Conference Series* **1058(1)** 012024

[7]   Pashkov E N, Martyushev N V and Ponomarev A V 2014 An investigation into autobalancing devices with multireservoir system *IOP Conf. Ser.: Mat. Sci.* **66(1)** 012014

[8]   Baranov G D, Nepomuceno E G, Vaganov M A, Ostrovskii V Y and Butusov D N 2020 New Spectral Markers for Broken Bars Diagnostics in Induction Motors *Machines* **8(1)** 6

[9]   Frolov V Y, Kvashnin A O and Murashov I V 2018 Nonstationary mathematical model of a magnetic arc blast system *Proceedings of the 2018 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering, ElConRus*

[10]   Zhukovskiy Y L and Koteleva N I 2019 Electrical equipment maintenance system with elements of augmented reality technology *IOP Conference Series: Materials Science and Engineering* **643(1)** 012024

[11]   Moreland J, Estrada J, Mosquera E, Toth K, Silaen A K and Zhou C Q 2020 Integrating Fluid Simulation with Virtual Die Casting Machine for Industry 4.0 and Operator Training *Minerals, Metals and Materials Series* 1026-1031

[12]   Marinin M A, Khokhlov S V and Isheyskiy V A 2019 Modeling of the welding process of flat sheet parts by an explosion *Journal of Mining Institute* **237(1)** 275-280 DOI: 10.31897/pmi.2019.3.275

[13]   Geng J, Song X, Pan Y, Tang J, Liu Y, Zhao D and Ma Y 2020 A systematic design method of adaptive augmented reality work instruction for complex industrial operations *Computers in Industry* **119** 103229

[14]   Khokhlov S, Safina E and Vasiliev V 2018 Risk-oriented approach implementation in departments ranking and teaching staff motivation *Int. J. for Quality Research* **12(2)** 501-516 DOI:10.18421/IJQR12.02-12

[15]   Alavikia Z and Shabro M 2019 Pragmatic Industrial Augmented Reality in Electric Power Industry *34th International Power System Conference PSC 2019* 9081538 25-32

[16]   Bose A, Safa M, Siddi S B, Anand M R and Kumar V 2020 Implementation of dynamic lighting & augmented reality (DLAR) smart home system for deaf and hard-of-hearing (DHH) residents *International Journal of Advanced Science and Technology* **29 (6)** 2724-2738

[17]   Chalapathi Raju K, Yugandhar K, Bharathi D V N and Vegesna N 2018 3D Based Modern Education System Using Augumented Reality *Proceedings of the 6th IEEE International Conference on MOOCS Innovation and Technology In Education, MITE 2018* 8747078 37-42

[18]   Fernández del Amo I, Erkoyuncu J, Vrabič R, Frayssinet R, Vazquez Reynel C and Roy R 2020 Structured authoring for AR-based communication to enhance efficiency in remote diagnosis for complex equipment *Advanced Engineering Informatics* **45** 101096

[19]   Guler O and Yucedag I 2018 Developing an CNC lathe augmented reality application for industrial maintenance training *ISMSIT 2018 - 2nd International Symposium on Multidisciplinary Studies and Innovative Technologies, Proceedings* 8567255

[20]   Rana K and Patel B 2019 Augmented reality engine applications: A survey *Proceedings of the 2019 IEEE International Conference on Communication and Signal Processing, ICCSP 2019* 8697999 380-384.

[21]   Osnabrugge J and Van Den Berg B 2019 Increasing uptime and performance by using digital twins in dredging diagnostics *22nd World Dredging Congress WODCON 2019* 427-436

[22]   Pashkov E N, Martyushev N V and Masson I A Vessel ellipticity and eccentricity effect on automatic balancing accuracy *IOP Conference Series: Materials Science and Engineering* **66** 012011

[23] Frolov V Y, Neelov A A, Zhiligotov R I and Bystrov A V 2018 Identification of the protection parameters of the local electrical network taking into account the detuning of the inrush current *Proceedings of the 2018 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering, ElConRus, 2018* 626-628

[24] Vostrov K, Frolov V and Safonov E 2017 Development of current limiting device for short and autonomous networks *22nd Symposium on Physics of Switching Arc, 2017* 182-185

[25] Saveliev A, Malov D, Tamashakin M and Budkov V 2017 Service and multimedia data transmission in IoT networks using hybrid communication devices *MATEC Web of Conferences. – EDP Sciences* **113** 02010

[26] Saveliev A, Malov D and Tamashakin M 2018 Transfer of housekeeping and multimedia data in IoT-networks using hybrid intercoupler *13th Int. Scientific-Technical Conf. on Electromechanics and Robotics "Zavalishin's Readings" MATEC Web of Conferences* **114** 02010

[27] Baranov GD., Matus K.I., Vaganov M.A., Bubnov E.A. 2019 Spectral analysis algorithm for the diagnosis of electrical machines *Proceedings of the 2019 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering, ElConRus 2019* 8657020 424-429

[28] Frolov V Ya and Ivanov D V 2018 Calculation of a Plasma Composition and its Thermophysical Properties in Cases of Maintaining or Quenching of Electric Arcs *Journal of Physics: Conference Series* **1058(1)** 012040