Increasing the speed of information transfer and operational decision-making in metallurgical industry through an industrial bot

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In the production of non-ferrous metals, it is difficult to monitor technological parameters and to account for the material balance of the main and auxiliary components which leads to significant losses of raw materials and electricity. The metals industry is characterised by the need to account for, reduce and recycle large volumes of technogenic emissions. With global digitalisation and increased automation, the lack of a dedicated system for analysing and controlling shop floor data reduces the efficiency of environmentally hazardous operations with large quantities of material flows making them uncompetitive and environmentally damaging. Existing software-based material flow monitoring and control systems have a large import dependency. In pyrometallurgical and electrochemical production with multiple material streams the issue of data systematisation for effective control via a process control system needs to be addressed. As an adaptable example, this paper considers the feasibility of dedicated automated systems for accounting for material balances and generating appropriate process control actions through chatbots in metallurgical silicon production. Given the acute shortage of digital platforms for the implementation of MES-like production management systems, the use of application software interfaces chat-bots gaining popularity in services and education is promising. The paper presents a generic architecture of an industrial chatbot developed for the production of metallurgical silicon, describes the interaction of the application with the process control system, as well as an analysis of the results obtained and expected from the implementation. The system can be adapted to similar production facilities of non-ferrous metallurgy.

Key words: metallurgical silicon, automated control, material balance, ore-thermal furnace, ICS, chatbot, MES system.

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Introduction

The issues of energy and resource saving in mineral resource complex are of priority importance for modern economy. In this regard, effective management of technological processes by means of high-tech instrumentation equipment with domestic software defines further development of Russian economy [1, 2]. In non-ferrous metals production effective automation control of multistage processes and flow lines have certain difficulties [3]. For example, in aluminum and copper electrolytic production several dozens of identical equipment are used for which it is necessary to use sequential control of technological parameters of each cell or furnace [4, 5]. Thus, in production with several sources of raw materials processed under conditions of high-temperature, aggressive chemical environment it is very difficult to control technological parameters and take into account material balance that is why there are significant losses of raw materials and electric power [6].

For instance, in silicon production quartz with different chemical compositions is used as raw material which leads to appearance of uncontrollable impurities in the final product. The quartz raw material contains a number of elements which unsatisfactorily affect the performance and efficiency of melting including fine particles. In addition, there are significant direct losses in the form of gas-fume emissions which can amount to more than 40% of the initial charge consumption. Some of the process parameters are not monitored and not predicted due to imperfect operability of the control system [7].

In order to increase resource and energy saving it is urgent to implement an information management system for metallurgical silicon production which along with streamlining of control processes of material and energy balances provides real-time collection of current data for database — BigData, documentation from the beginning of the process to the output of finished products.

To implement such a system in the current geopolitical environment, where the use of specialised digital platforms is not available or is subject to sanctions a radically new solution is needed. One way out in this environment is the implementation of a MES (manufacturing execution system) based on a chatbot which allows efficient and cost-effective solution to the tasks at hand [8, 9].

The concept of an industrial chatbot

A MES-system is required for the efficient control of production processes and for the organisation of stable functional relationships over time. In order to improve these connections, it is rational to use a communication interface (chatbot) which is tailored to the metallurgical production and which directly clarifies the needs of the maintenance personnel and the operators of the process control system. The proposed system (industrial chatbot) helps to meet these requirements according to the set parameters in the production system through automatic communication with technologists or by sending commands to the controller via text or voice.

At present, a selector communication is usually used to switch to manual control of the furnace from automatic mode and occasionally a telecommunication top-level SCADA transmission system disconnecting the industrial facility from the regulation [10]. In the case of metallurgical production, the chatbot conducts communication from the technologist or the control system operator in order to simplify and speed up decision making through online communication, i.e. provide relevant information in the fastest time after processing the data received from the lower level SCADA system. For metallurgical production it is used as an alternative to correspondence with the operator and workshop technologist [11, 12].

A chatbot is a software application that interacts with users in natural language. They are useful in areas such as education, information retrieval, logistics and management. The widespread use of chatbots is due to a number of advantages, such as:

– accessibility to the user regardless of platform;

– ability to integrate the data generated by one chatbot into other systems;

– reliability of ongoing communication;

– simplicity of development and rapid adaptation along with universal application in any industrial environment.

Metallurgical manufacturing is a new area of application for chatbots, whose use in related areas of the economy has already proven effective [13].

An industrial bot is an ideal tool for optimising standard repetitive tasks, such as the compilation and maintenance of report documentation, extraction and collation of necessary information, bypassing several stages of control action on the control system. Such operations do not require creative solutions and follow a strictly defined algorithm. As a result, the influence of the human factor on process control is reduced in all its simplicity of implementation [14].

Thus, the industrial bot provides the simplest and most straightforward way to interact between the process/production and the customer with instant feedback and no human error-prone feedback. The bot will accept the information, check for errors and store it in the database.

The design and development of a chatbot involves many techniques. Understanding what a chatbot will offer and what category it falls into helps software developers choose the algorithms or platforms and tools to build it. At the same time, it also helps end users understand what to expect from the system in the event of an emergency or abrupt deviations in metallurgical process parameters [15–17].

In terms of business classification, the production bot fulfils the role of an assistant (assistant to the ICS operator (integrated control system)) configured to solve specific tasks. As for technical classification, it is rule-based with a tree-like dialog structure. The dialog between the user and the system follows a path predetermined by the developer. The user or technologist, as the main chat manager, makes decisions but cannot deviate from a predefined production task. In order to avoid failures in the dialogue structure this kind of chatbots must contain a large number of voice control buttons instead of free-form questions.

According to the regulated tolerances provided by the development platform, an open-source platform is preferred for a production chatbot to be better adapted to specific tasks and the main requirement for its design is an accurate representation of information and response generation strategy [18, 19].

Chatbot structure for metallurgical production

The structure of a chatbot for metallurgical silicon production was developed using Aveva's upgraded digital MES platform in the form of the following modules **(Fig. 1)**:

- Short downtime per process operation;
- Accidents or temporary shutdowns of equipment;
- Preventive maintenance.

The system automatically generates records for periods of extremely slow process operation or complete shutdown. The records generated in this module contain the information required to prioritise maintenance, order equipment and improve operational and process procedures. The module provides an easy-to-use interface for furnace operators to analyse the causes of production downtime.

- Product quality control

Analysis, reporting and quality management at all stages of the process. At this stage process parameters affecting product quality are collected against defined tolerance intervals, process regimes, which provides ample opportunity for analysis **(Figs. 3, 4)**.

- Findings and knowledge

Maintaining logs (shift, repair crews, etc.), storing and providing access to various documentation. This is a tool for managing ongoing changes, keeping notes/comments by technologists.

- Process and power consumption

For efficient production management it is necessary to identify the periods of excessive energy consumption and determine the causes (kWh, rub.) as well as to analyse the schedule of energy consumption [20–22].

- Balance of raw material flows (material balance control)

This module is responsible for raw material inventories with product genealogy (production traceability) and for the Actual Material Balance of metallurgical silicon by the furnace that allows decision makers to analyse the impact of quartz raw material quality on metallurgical silicon production quality parameters.

The material balance module is a key module in the metallurgical silicon production control system. By combining the traditional calculation of material balance, taking into account the influence of temperature in the furnace and physical and chemical properties of quartz the balance module provides the following functions: collecting data from the ICS, data processing to display the composition and amount of the formed silica fume depending on the key parameters (temperature in the furnace, particle size distribution and chemical composition of quartz raw materials) in the form of tables and graphical relationships. The module evaluates the preparation of charge materials and transmits information on changes in their composition for quick decision-making on changing technological parameters [23].

"Production_silicon_bot" generates an up-to-date and near real-time picture of exactly what is happening in the production process based on the records of input and output flows of the plant including: materials, consumables, energy, waste, emissions and product output with regard to quality parameters. The chatbot provides an easy-to-use interface for operators analysing production data. Telegram channel was chosen as a working platform for operator-system interaction due to simplicity of implementation and free access in the Russian Federation **(Fig. 5)**. To ensure information security (cybersecurity) user restriction is implemented through access list — telegram user id [24, 25].

"Production_silicon_bot" works with data coming from the SCADA system or Historian server. This data is

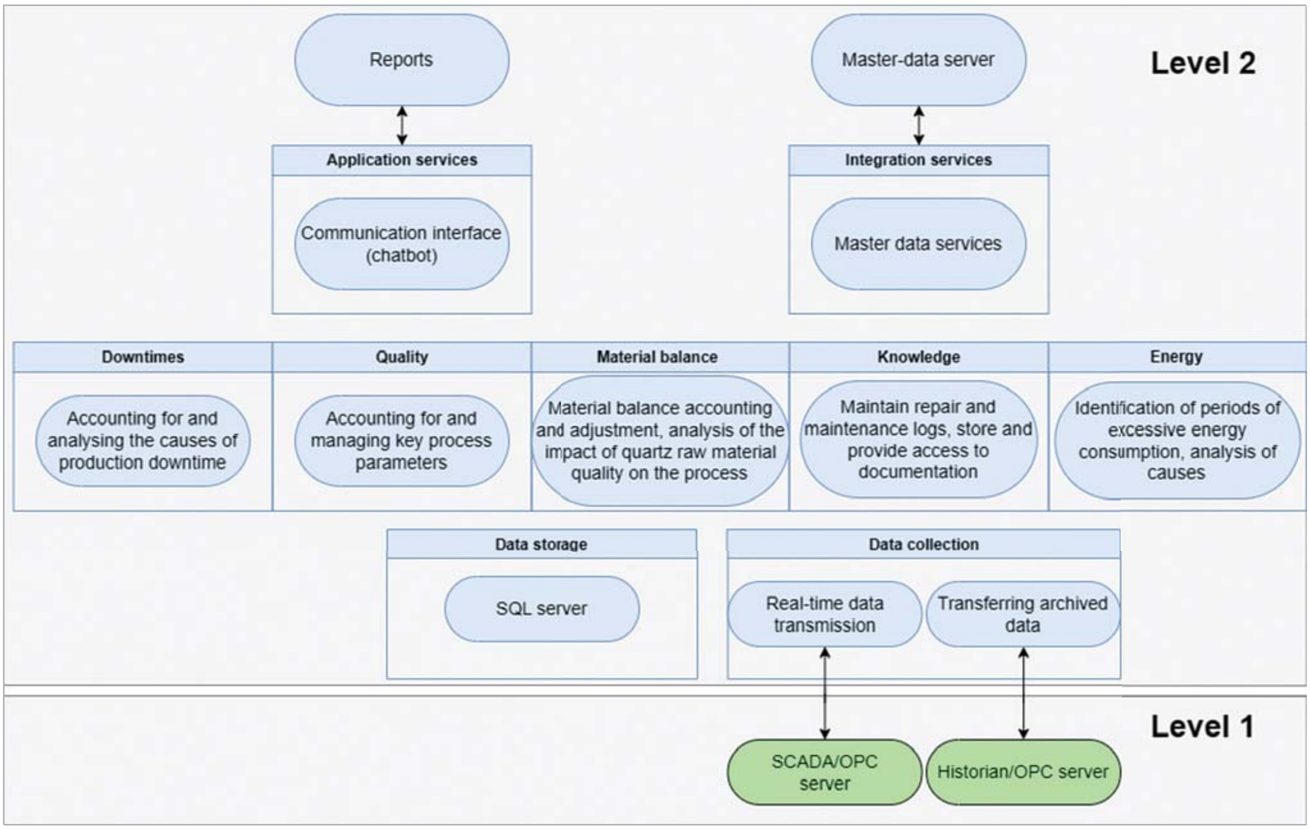
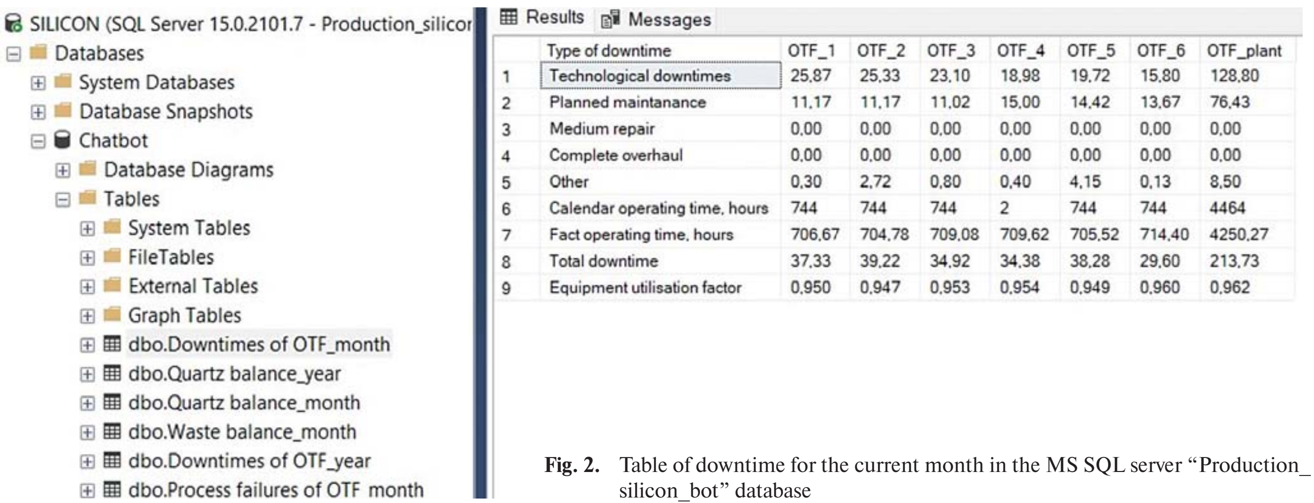


Fig. 1. Structure of a PMIS for metallurgical silicon production based on the chatbot "Production_silicon_bot"



	Type of downtime	OTF_1	OTF_2	OTF_3	OTF_4	OTF_5	OTF_6	OTF_plant
1	Technological downtimes	25,87	25,33	23,10	18,98	19,72	15,80	128,80
2	Planned maintanance	11,17	11,17	11,02	15,00	14,42	13,67	76,43
3	Medium repair	0,00	0,00	0,00	0,00	0,00	0,00	0,00
4	Complete overhaul	0,00	0,00	0,00	0,00	0,00	0,00	0,00
5	Other	0,30	2,72	0,80	0,40	4,15	0,13	8,50
6	Calendar operating time, hours	744	744	744	2	744	744	4464
7	Fact operating time, hours	706,67	704,78	709,08	709,62	705,52	714,40	4250,27
8	Total downtime	37,33	39,22	34,92	34,38	38,28	29,60	213,73
9	Equipment utilisation factor	0,950	0,947	0,953	0,954	0,949	0,960	0,962

Fig. 2. Table of downtime for the current month in the MS SQL server "Production_silicon_bot" database

stored in a relational database hosted on Microsoft SQL Server **(Fig. 2)**. The Yandex.Cloud platform is used to avoid the limitation on the volume of files sent to Telegram where reports are stored and supplemented while the bot itself provides the user with data in the form of a link to a cloud storage document [26–28]. The use of highly rated software of the Russian company allows solving a number of problems simultaneously, such as guaranteeing data security (servers are located in Russia), storage, processing and visualisation of any type and volume of data, organisation of work with the system by the service personnel.

In the production of metallurgical silicon with complexity of material flows, a large number of uncontrollable parameters and emissions require a solution to the issue of systematization of data for effective management through the ICS. This could be solved using a Telegram bot interface. The use of bots in "dirty" production facilities with a large number of material flows contributes to the implementation of a closed cycle enterprise and a reduction of the carbon footprint.

"Production_silicon_bot" is a limited type of MES system with a simplified interface. However, given the fact that access to quality foreign digital platforms is difficult the use of a chatbot user interface is an optimal alternative.

The advantages of this solution include:
- low implementation cost;
- convenience and simplicity of use;
- quick response;
- no requirements for the power of the device involved;
- sufficient level of security;
- no need to initialise additional software to run the "helper" in question.

Name	Measurement unit	Scheduled	Furnaces						Plant
			1	2	3	4	5	6	
No-load voltage	V	210	188.72	191.21	196.40	194.71	192.01	193.67	192.79
current intensity	кA	45	42.46	41.44	40.96	39.53	39.95	38.10	40.41
Electrical power	MW	6.6	6.57	6.50	6.60	6.31	6.29	6.05	6.39
Ratio I/U		0.214	0.22	0.22	0.21	0.20	0.21	0.20	0.21
Load MW per hour	kg	214	216.07	212.94	221.24	210.42	208.91	202.41	211.99
Average hourly output	kg	550	499.27	484.03	545.88	514.21	522.85	535.01	520.66
Average hourly output since the beginning of the year	kg	550	532.06	529.50	540.51	552.71	527.41	526.73	537.80

Fig. 3. Current month's report of the quality module in the electrothermal workshop "Production_silicon_bot"

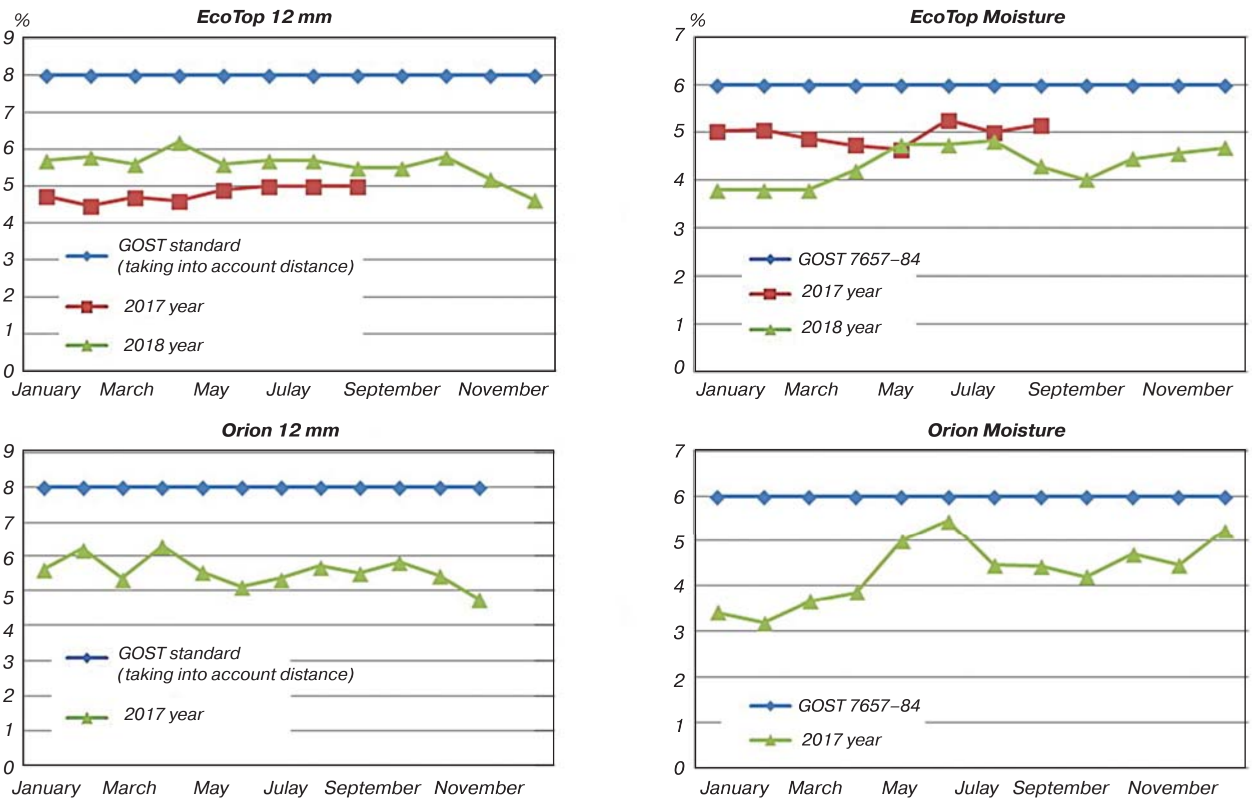


Fig. 2. Table of downtime for the current month in the MS SQL server "Production_silicon_bot" database

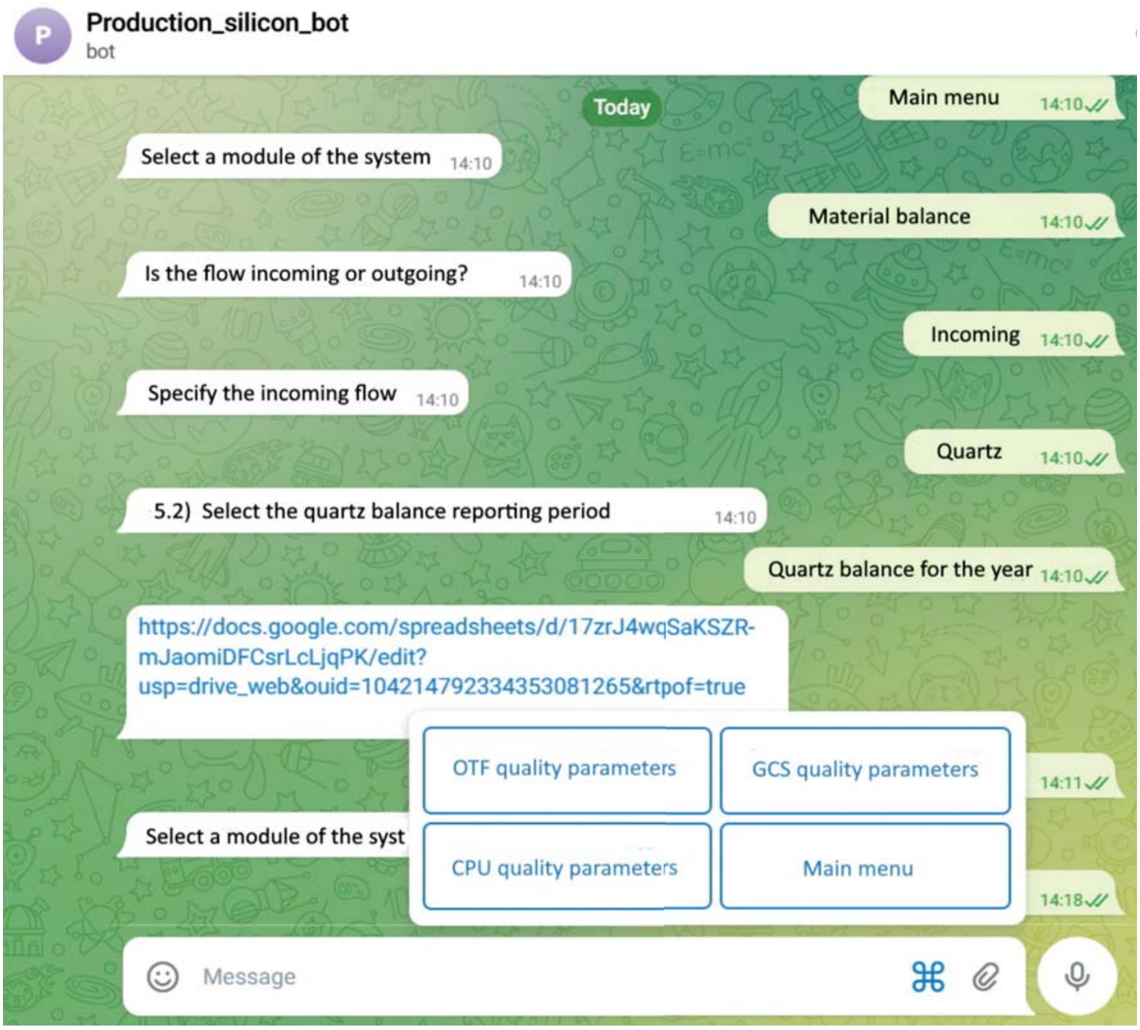


Fig. 5. Working window of the "Production_silicon_bot" user

As for direct loses, in metallurgical production they are related to a long delay in decision-making, when a machine or metallurgical furnace is in an unbalanced state for a long time resulting in direct losses of raw material and energy.

In the current geopolitical realities, the developed system of production data recording and analysis is a profitable solution for the metallurgical industry.

Conclusion

With global digitalisation and increased automation, the lack of a dedicated system for analysing and controlling shop floor data makes silicon production, as well as other multi-stage industries, uncompetitive in the global market. The concept of using an industrial chatbot (BOT) within the framework of an existing system of detailed operational planning of production process management in metallurgy allows to solve this problem bypassing the functional levels of the overall management system. Thus, it is possible to formulate character features and advantages of an industrial BOT:

- increased speed of information transfer from the upper to the lower level of the ICS;
- forecasting of technological situation through two-way communication;
- reduction in the number of transfer functions in the ICS;
- transfer influence on control systems through PI or PID controllers;
- increasing the level of information security.

The disadvantages of bots include some problems with supporting telecommunication communication in industrial interference conditions, which is solved quite easily with the help of wireless signal repeaters from the base station. In addition, the operators' workplaces are far enough away from the sources of interference (electric arc furnaces). There are also wired shielded internet connections in addition to the wireless types, which are minimally susceptible to interference.

The introduction of this system in non-ferrous metals and their alloys production environments can significantly improve the efficiency of process control with domestic automation systems and software.

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References

1. Litvinenko V., Bowbrick I., Naumov I., Zaitseva Z. Global Guidelines and Requirements for Professional Competencies of Natural Resource Extraction Engineers: Implications for ESG Principles and Sustainable Development Goals. *Journal of Cleaner Production*. 2022. Vol. 338. 130530.

2. Litvinenko V. S. Correction to: Digital Economy as a Factor in the Technological Development of the Mineral Sector. *Natural Resources Research*. 2020. Vol. 29, Iss. 3. pp. 1521–1541.

3. Safiullin R. N., Afanasyev A. S., Reznichenko V. V. The Concept of Development of Monitoring Systems and Management of Intelligent Technical Complexes. *Journal of Mining Institute*. 2019. Vol. 237, Iss. 3. pp. 322–330.

4. Saevarsdottir G., Magnusson T., Kvande H. Reducing the Carbon Footprint: Primary Production of Aluminum and Silicon with Changing Energy Systems. *Journal of Sustainable Metallurgy*. 2021. Vol. 7, Iss. 3. pp. 848–857.

5. Petrov P. A., Shestakov A. K., Nikolaev M. Yu. Use of Multifunctional Crust Breaker and Machine Vision System for Acquisition and Processing of Aluminium Reduction Cell Data. *Tsvetnye Metally*. 2023. No. 4. pp. 45–53.

6. Ugolnikov A. V., Makarov N. V. Application of Automation Systems for Monitoring and Energy Efficiency Accounting Indicators of Mining Enterprises Compressor Facility Operation. *Journal of Mining Institute*. 2019. Vol. 236, Iss. 2. pp. 245–248.

7. Leonova M. S., Timofeeva S. S. Environmental and Economic Damage from the Dust Waste Formation in the Silicon Production. *IOP Conference Series: Earth and Environmental Science*. 2019. Vol. 229. 012022.

8. Jask S., Skorp A., Holczinger T., Chovan T., Abonyi J. Development of Manufacturing Execution Systems in Accordance with Industry 4.0 Requirements: a Review of Standard- and Ontology-Based Methodologies and Tools. *Computers in Industry*. 2020. Vol. 123. 103300.

9. Ojeda Pardo F. R., Sänchez Figueredo R. P., Belette Fuentes O., Quiroz Cabascango V. E., Mosquera Urbano A. P. Metallographic Properties Evaluation of the Specimens Obtained by the Vibratory Method (Cast Iron ISO 400-12). *Journal of Physics Conference Series*. 2022. Vol. 2388, Iss. 1. 012058.

10. Rozs R., Ando M. Collaborative Systems, Operation and Task of the Manufacturing Execution Systems in the 21st Century Industry. *Periodica Polytechnica Mechanical Engineering*. 2020. Vol. 64, Iss. 1. pp. 51–66.

11. Bhushan R., Kulkarni K., Pandey V. K., Rawls C., Mechtley B., Jayasuriya S., Ziegler Ch. ODO: Design of Multimodal Chatbot for an Experiential Media System. *Multimodal Technologies and Interaction*. 2020. Vol. 4, Iss.4. p. 68.

12. Patidar A., Koul R., Varshney T., Agarwal K., Patil R. Al-Based Chatbot to Solve Modern-Day Enterprise Business Problems. *International Journal of Advanced Research in Science, Communication and Technology*. 2021. Vol. 9, Iss. 1. pp. 180–186.

13. Krishna A. C. Chatbot for Apparatus Control Based on Artificial Intelligence. *Journal of Xi'an University of Architecture & Technology*. 2022. Vol. XIV, Iss. 1. pp. 42–47.

14. Salvi S., Shetty Sh. Al Based Solar Powered Railway Track Crack Detection and Notification System with Chatbot Support. *2019 Third International conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC)*. 2019. pp. 565–571.

15. Adamopoulou E., Moussiades L. An Overview of Chatbot Technology. In: *Artificial Intelligence Applications and Innovations. AIAI 2020. IFIP Advances in Information and Communication Technology*. Vol. 584. 2020. pp. 373–383.

16. Zakirova G., Pshenin V., Tashbulatov R., Rozanova L. Modern Bitumen Oil Mixture Models in Ashalchinsky Field with Low-Viscosity Solvent at Various Temperatures and Solvent Concentrations. *Energies*. 2023. Vol. 16, Iss. 1. 395.

17. Casillo M., Colace F., Fabbri L., Lombardi M., Romano A., Santaniello D. Chatbot in Industry 4.0: An Approach for Training New Employees. *Proceedings of the IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE)*. 2020. pp. 371–376.

18. Fedorova E. R., Pupysheva E. A., Morgunov V. V. Settling Parameters Determined During Thickening and Washing of Red Muds. *Tsvetnye Metally*. 2023. No. 4. pp. 77–85.

19. Lokman A. S., Ameedeen M. A. Modern Chatbot Systems: a Technical Review. *Proceedings of the Future Technologies Conference (FTC) 2018. FTC 2018. Advances in Intelligent Systems and Computing*. Vol. 881. 2019. pp. 1012–1023.

20. Clarizia F., De Santo M., Lombardi M., Santaniello D. E-Learning and Industry 4.0: A Chatbot for Training Employees. In: *Proceedings of Fifth International Congress on Information and Communication Technology. Advances in Intelligent Systems and Computing*. Vol. 1184. 2021. p. 445–453.

21. Opalev A., Alekseeva S. Methodological Substantiation of the Choice for Optimal Modes of Equipment Operation During the Stage-Wise Concentrate Removal in Iron Ores Beneficiation. *Journal of Mining Institute*. 2022. Vol. 256. pp. 593–602.

22. Aramja A., Kamach Q., Elmeziane R. Companies' Perception Toward Manufacturing Execution Systems. *International Journal of Electrical and Computer Engineering (IJECE)*. 2021. Vol. 11, Iss. 4. pp. 3347–3355.

23. Shestakova I., Morgunov V. Structuring the Post-COVID-19 Process of Digital Transformation of Engineering Education in the Russian Federation. *Education Sciences*. 2023. Vol. 13, Iss. 2. 135.

24. Negri E., Berardi S., Fumagalli L., Macchi M. MES-Integrated Digital Twin Frameworks. *Journal of Manufacturing Systems*. 2020. Vol. 56, Iss. 6. pp. 58–71.

25. Boykov A. V., Payor V. A. Machine Vision System for Monitoring the Process of Levitation Melting of Non-Ferrous Metals. *Tsvetnye Metally*. 2023. No. 4. pp. 85–90.

26. Yolkin K. S., Yolkin D. K., Kolosov A. D., Shtayger M. G. Technologies, which Allow to Reduce an Impact of Metal Silicon Production on the Environment. *IOP Conference Series Materials Science and Engineering*. 2018. Vol. 411. 012028.

27. Tarabarinova T. A., Golovina E. I. Capitalization of Mineral Resources as an Innovation Ecological Strategy. *Geology and Mineral Resources of Siberia*. 2021. Iss. 4. pp. 86–96.

28. Shestakov A. K., Petrov P. A., Nikolaev M. Y. Automatic System for Detecting Visible Emissions in a Potroom of Aluminum Plant Based on Technical Vision and a Neural Network. *Metallurgist*. 2023. Vol. 66, Iss. 9-10. pp. 1308–1319.

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