Troubleshooting technological aggregates based on machine learning

S A Kosarevskaia¹, A V Shukalov², I O Zharinov³ and O O Zharinov³

¹ Educational and scientific center, Stock Company «Experimental Design Bureau «Electroavtomatika» named after P A Yefimov, 40, Marshala Govorova St., Saint Petersburg, 198095, Russia
² Faculty of Information Security and Computer Technologies, ITMO University, 49, Kronverksky Av., Saint Petersburg, 197101, Russia
³ Department of Problem-Oriented Computing Complexes, Saint Petersburg State University of Aerospace Instrumentation, 67, Bolshaya Morskaia str., Saint Petersburg, 190000, Russia

E-mail: s.kosarevskaya@bk.ru

Abstract. The technological aggregates preventive maintenance problem being researched is resistive against a type of failures. The preventive maintenance is a cyber-production control system function and is done by activation of re-arrangement manipulation system, which is used to eliminate technological aggregates failures. The technological aggregates restoration operation technology is viewed as a man substitution in the Industry 4.0 paradigm. The equipment failure is viewed as an incident of cyber-production functional safety system, which is capable to cause a potential complex damage. The equipment robotized maintenance model is oriented to increase the cyber-production functional reliability and to use the machine learning methods to make intellectual the industrial automatics. They analyze the repair and restoration works mechanisms in the process factory level (the physical workshop) and in the analytical factory level (the virtual cloud) for a cyber-production, which interact with operation system. There is the equipment robotized maintenance algorithm proposed, which gives the data to the control system for its actual state. There is the automatic control system scheme proposed to make a technological aggregates preventive maintenance. An option how to change a failed unit is selected after the technological aggregates conditions pre-history analyzing obtained in the stage of machine learning of collected statistics.

1. Introduction

Business unification with production and advanced technologies into a single eco-system is the Industry 4.0 strategy element to expand the industry functional capabilities to automatize the metal processing companies [1]. Technological innovations implementation into the production cycle made in a special way let create the industrial machines complex control system, which make the continuous cycle of item manufacturing. The base congregation of aggregates unified interaction technology, each of which is a combination of physical and virtual resources (technological aggregate) engages corrective and preventive measures to provide under digital production conditions the industrial object necessary result and exploitation security [2, 3].

The 24 hours functioning cyber-production (CP) full robotizing requires a hierarchy option to create...
the target control system, which use the technological procedures control methods based on the statistic data processing [4, 5]. The technological aggregates (TA) each level control industrial safety is done through program configuration tools for the Internet of Things (IoT) net data exchange technology and the aggregates preventive maintenance technology tools, which are used together into a complex production infrastructure [6].

The data exchange technology is supported into the industrial object control macro level and commutes TA with the production cloud environment virtual server. The aggregate control channels net division is online and lets identify the data received from the equipment and form the regulating influences to correct discrete and continuous production processes [7]. The macro level control automatizing system collects and gives structure to the production data, which is a necessary condition for the prognostication analytical algorithm development to check out the TA functionality. The prognostication analysis is formed with machine learning (ML) methods, which are artificial intelligence technologies [8, 9].

The aggregate preventive maintenance is the CP base architecture informative component, which is to take away the human presence from the industrial object control loop and to organize typical restoration operations completion for the failed TA with net robotized automatics repair section resources [10, 11]. The TA servicing and their failures elimination with manipulators and re-arrangement devices is for the final mono-plant automatizing stage where the CP processes never stop even if an equipment failure detected [12, 13].

The intellectual systems technological servicing today becomes more important for industrial objects where the structural dynamics is presented with the work CP process remote control. A set of measures to provide the CP functional safety engages the diagnosis tools and for aggregate conditions control including mechanical and electronic servicing system [14]. The TA natural deterioration as a matter of servicing influences some unexpected production functioning interruptions and poses new requirements for repair and restoration technologies of the machine physical world.

2. The mathematical robotic technics ML
Failure detection analytical methods appeared in TA are means to provide industrial robots behavior functional safety or a way to solve a hardly formalized Industry 4.0 system task. The irreversible equipment damage violates the production cycle logics and influences the item manufacturing technological time table. The CP control complex system additional functions are based on the ML technology and data analysis, which characterizes processes of physical and information industrial object environments.

The ML technologies are quite general for all TA classes and for CP object dynamic conditions research. The ML is important to prognosticate the industrial automatics probability and to provide production functioning in 24 hours equipment work shift. The mathematical robotic technics as an automatic repair any suspicious TA behavior is to be analyzed in the production natural running.

The TA processes control system engineering requires a pre-classification of industrial equipment technical conditions and to develop some criteria when the blocking tool is engaged including measures against alarms. The production robotic technics functionality failures lead to financial losses for the company owner and could be dangerous for the object itself and for the environment. The failure equipment private cases detection lets identify with parameters each failure and form the control object possible conditions register in the physical and virtual worlds. The Industry 4.0 production TA ML scheme is given in figure 1.

Integration of physical and informative spaces implying the production functions into the cyber-environment creates the base to build the industrial object universal control system keeping in mind the entire technological aggregates class. The control digital logics being used in the applicable processes level supposes some TA prophylactic servicing before they are out of order. The prognostication analytics controls failure sensitive technological processes dynamics distributed in many TA units and monitors the material tide statistics. The following must be analyzed [15, 16]:
• the production equipment and some parts (tools) left resource, which changes their conditions characteristics into production process;
• materials and components left resource, which influences the TA without alarms stopping probability and which requires the necessary actions to prevent a failure;
• the TA functionality testing results with integrated diagnosis means (when the failed unit is detected), which are saved into centralized or distributed industrial object safety register and other.

![Figure 1. The Industry 4.0 production TA ML scheme.](image)

The distinctive features of TA units failures in the aggregate diagnosis conditions parametric space reflect the data signature, which are adequate for the CP physical environment. The description iterative laws of industrial object failure parameters let automatically detect production processes non-normal changes in the TA interaction net level. The technological aggregate telemetry creates data selection (discrete time row), which will be multi measured for statistic processing with ML methods.

The TA control learning technologies are based on data analysis intellectual methods, which are inside the industrial objects information tides. Technological processes deviation from normal properties in the statistically important deviations level during the normal machine running is interpreted by the control system as a potential production threat, which is sufficient to make a decision of the problem TA blocking or localized with an equipment segment failure.

The CP individual and collective protection means presented in the IT (Information Technology)-infrastructure unite the sensors and commands data to optimize the object industrial safety control process. The data signatures and technological aggregates conditions correlations keeping is systemized in a related knowledge base placed on a CP cloud platform. Equipment conditions identification is done with the program monitoring tools of the technological parameters values being monitored, which characterizes the physical laws of production processes completion. The protection and blocking system activation threshold is defined with statistical methods in the control system learning stage.

The technological aggregates control ML applies CP structure mathematical description as a determined system with a set of dynamic conditions. Each production operation completion fact information and the engaged TA status (structural and typical technological processes model) is transmitted to analytic server, which shows the statistic prognostication of the equipment deterioration.
Analytical platform to detect a data dissonance in the output parameters and processes is associated with a particular bunch of failures. A control object parameters signatures class, which shows an unexpected situation appeared is transmitted to the macro level (digital production avatar) to change the production control logic and substitute the planned TA servicing with a servicing according to its conditions.

3. TA robotized servicing

The industrial object protection with preventive maintenance methods, which is done with a manipulator and re-arranger is a production control system function and is based on the ML methods, which use prognostication monitoring tools. The TA servicing methods transfer to a real mechanical and electronic robot to be completed is an important automatizing factor, which is a practical technological aggregates ability to adaptation and learning.

The preventive maintenance operational technology reflects the CP technological maturity level where the distributed resources are fully coordinated with an artificial intelligence with an expert system advanced component for the industrial object protection and machines blocking. The TA ML is the physical processes mathematical simulation, which naturally lead to the equipment failure and technological aggregates control object working-out to reduce the tide of appearing failures. In the TA control signals level repair and restoration production works are based on the technological aggregates telemetry analytical means connected to the industrial IoT net. The control system scheme for the production TA repair and restoration works is given in figure 2.

The preventive maintenance mechanical actions are done with the following algorithm [17, 18]:

- the ML technology searches for a technological aggregate, which functional behavior process contains some deviations from the norm;
- the technological aggregate with non-normal behavior is cut to the current supply with protection and blocking system;
- the micro level control system generates signals (CP elements re-grouping) to correct item manufacturing technological route to orient the transport manipulator robots for non-functioning aggregates assembly units exclusion from the movement tide;
- the macro level control system generates signals for manipulator and re-arranger to complete restoration works for non-functioning aggregates with methods and norms established for a CP;
- manipulator and re-arranger extracts the aggregate failed unit (the consumed material stock is replenished, which is used in technological process, changes the faulty tool and other depending on the failure type);
- a restored aggregate completes a set of integrated machine and program diagnosis tests or they might be given with the macro level control system to confirm that the equipment works properly and it is ready to be integrated to the functioning production complex;
- the transport system sends the aggregate failed unit to the scrap isolation section and the working components warehouse receives a new unit type to be repaired and manipulator and re-arranger move to the preventive maintenance machines box.

The diagnosis analysis results of the production TA being monitored to add up the failure and breakdowns statistics, which is used with the ML technology to prognosticate the aggregate behavior under 24 hours exploitation load conditions. The collateral result is the CP necessity calculation of material and technical provision, which is necessary to complete an uninterrupted item manufacturing technological cycle.

The manipulator and re-arranger executive organs navigation to the influence object is for mathematical calculation supported by positioning and navigation technologies for the aggregates movable components, which are advanced systems for the industrial automatics. Failed unit change inside the aggregate comes down to the typical actions defined after equipment diagnosis results in control points. The aggregate behavior functioning model is noted with the production control system during the mono-plant starting point as data signatures format, which corresponds to the feature
industrial objects conditions space.

Figure 2. The control system scheme for the production TA repair and restoration works (IMS – information and measuring system).

Technological process changes for the faulty aggregate restoration period is based on CP object dynamic model, which is within the control system as a virtual image (mathematical analogue) of the equipment real environment. The production processes virtual modelling in real time let receive metadata with statistical methods, which comparison with the fact measurements leads to control signals work-out for non-faulty functioning cyber-environment. The production situations being detected variety including technological aggregate conditions require a more complicated (accurate) mathematical tools of working with production data time rows.

The robotized TA repair process operator control is made through monitoring workshop remote control panel made on the standard iPad console base. Avatar communication (manager) with the CP environment is done in the mode «demand-response» in machine equipment commands and terms, which can be understood by humans and technical systems. The monitoring control system analyzes the production data content and in particular time moments (discrete ones) activates manipulator and re-arranger to service according to the technical aggregates conditions. All manipulator and re-arranger movements are controlled and displayed online to the operator who passively watches the routine machine equipment repairing operations being executed.

The CP assets repairing process manual control transfer is done if a failure detected and as a consequence there are some data signatures not registered in the base. The equipment fault taking-out if such a failure occurred is done by the operator with virtual instructions and hints, which are generated with the control system using an encyclopedic bunch of knowledge, which are placed in the company cloud server. The repairing machine environment learning for the not known before failures types are trained through virtual robots models and a set of actions stipulated with the operator (reference) is saved in the CP context base to cover up the entire machine equipment park.
4. Conclusion

The TA robotized servicing way is a component to solve the production information problem related to non-defined technological aggregate control process and with a data mass mathematical processing. To transform classical mechanical and electronic systems engaged in the Industry 3.0 into some independently functioning TA (calculation component and automatic control integrated systems carriers) led to a new class of current tasks related to the CP exploitation assets.

The CP auxiliary system central component is a robotized box of manipulators and re-arrangers, which make repair and restoration works and preventive maintenance of TA. The aggregates technical servicing automatizing and transfer exclusively to robotized technologies is in agreement with the Industry 4.0 concept main points, which is being implemented today to the production key segments, which were expanded the customized product was manufactured.

Because of the production cyber-automatics servicing matter complex character and uninterrupted production cycle the faults elimination is for control technical means and the artificial intelligence, which identifies automatically the being controlled aggregate conditions with their parameters. The working aggregates data signatures proximity degree to the reference signatures obtained in the ML stage and saved in the data base is understood with the computerized control system as one of the known object conditions, which in some cases require a non-planned servicing.

The TA servicing procedure depends on the mathematical data processing quality registered on a given scale and which is being circulated in the production environment and the aggregate itself is capable to interact directly with manipulator and re-arranger. By-operation decomposition of repair and restoration works and machine park functionality check is made with ML methods during the industrial object run in the field tests.

The TA robotized servicing control mechanism transparency and detailing are provided in two mono-plant levels:

- in the process factory level equipment uniting physical components including executive objects, which influence the production environment conditions in a significant way for TA working modes control system, which function with general rules:
- in the analytical factory level uniting groups of measuring detectors, IoT wireless sensor nets and ML algorithms, which may react to the data tides properties changes, which reflect the fact load for electrical and mechanical units of TA.

The mono-plant control system distribution in levels may apply the production processes autonomous regulation loops, which affect the discrete and uninterrupted parts of technological lines. The general control loop (external) processes data into informative and physical levels and completes all calculations and mechanical works independently, which is the personification of the CP absolute automatizing idea.

The technological process result under the random equipment failures conditions is based on the prognostication accuracy in a given interval of the TA technical conditions and the failed component restoration time, which are crucial for the industrial object functioning. To increase the equipment condition prognostication accuracy they pre-process the production data in the aggregate physical level. To reduce the equipment robotized repair time they apply online modelling of the TA behavior many scenarios (including the equipment necessity prognostication in the parts and tools changing) to solve particular production tasks.

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