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HEURISTIC APPROACH TO TRAJECTORY PLANNING OF N-th NUMEROUS SET OF AUTOMATED CRANES

ZASTOSOWANIE METOD HEURYSTYCZNYCH W PLANOWANIU TRAJEKTORII RUCHU N - LICZNEGO ZBIORU ZAUTOMATYZOWANYCH SUWNIC

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Abstract: *Today new requirements are put for optimization, synchronization and planning the transportation operations supported via n-th numerous set composed by automated cranes, including also their availability. The above needs is the subject of consideration in the paper, and solved based on heuristic approach. The method of i-th cranes operations planning, as well as time-optimal and non-collision moving trajectory of a payload shifted by crane is solved using searching graph algorithm based on heuristic function. The presented approach is possible to apply also to n-th numerous sets of automated cranes. The application of crane set control system was based on supervisory system (HMI/ SCADA system) equipped in user interface for implementing the heuristic knowledge about considered process used to aid decision-making process.*

Keywords: *automated material handling system, crane, supervisory system*

Streszczenie: *Nowe wymagania w zautomatyzowanych procesach transportowych z użyciem n-licznej grupy suwnic dotyczą optymalizacji oraz planowania zadań transportowych realizowanych przez środki transportowe z zapewnioną gotowością. W przedstawionym rozwiązaniu problemu planowania zadań transportowych oraz bezkolizyjnej i optymalnej czasowo trajektorii ładunku przemieszczanego przez suwnice zastosowano heurystyczny algorytm wyznaczania najkrótszej ścieżki w grafie (A*). W rozwiązaniu aplikacyjnym systemu sterowania i nadzorowania procesu transportowego zrealizowano interfejs użytkownika umożliwiający implementację wiedzy o nadzorowanym procesie wspomagającą proces decyzyjny.*

Słowa kluczowe: *zautomatyzowany system transportu bliskiego, suwnica, system nadzorowania*

1. Introduction

The time-optimization of transportation operations realized by material handling devices is important problem to solve owing to rising requirements regarding the productivity and availability of automated manufacturing processes. The problem under consideration in this paper concerns the automated material handling devices, which supports transportation and storage operations with using overhead traveling cranes (WSUT) [9, 10, 11, 12]. The modern automated material handling system (AMHS) is challenged to optimize, organize and synchronize, and next realize with expected precision and time the planed transportation operations based on join activities of selected unit composed based on *n*-th number of cranes. The distinguished tasks, related to optimization and planning, and next to realization of transportation operations can be executed by different levels of control system composed of hierarchical structure. The lower level of control system consists of control devices (mostly used in industrial practice programmable logic controllers PLCs) which realize control-measurement tasks, gathering data from measurement circuits and control algorithm executing: following movement trajectory and positioning a payload in three-dimensional crane's movement mechanisms working space. Owing to meet acceptable for user requirements for availability and accuracy, as well as cycle time of crane's operations, a problem of suppressing the load swing is also addressed to lower level of control system, and solved using open or closed loop control systems, as well as conventional or unconventional methods, based for example on intelligent systems implemented in anti-sway crane control system, e.g. fuzzy logic, artificial neural network, or their hybrids.

Automation and computer aided activities (in all manufacture levels, management, corporate and business levels) moved human function in Man-Machine System (MMS) to the role of supervisor. The above trend is strongly supported by the applied in industry practice the Information and Communication Technologies (ICT), Manufacturing Execution Systems (MES), Enterprise Resource Planning (ERP), as well as higher levels of control systems Human Machine Interfaces (HMI) and Supervisory Control and Data Acquisition (SCADA) software [5, 6, 13]. From the higher levels of control system are expected more and more compound tasks concerned supervising and managing a process, monitoring and diagnosis of process and devices technical states, alarming, reporting, as well as human reasoning and decision making process aiding [7, 8].

In this paper proposed application of higher level of control system, based on HMI/ SCADA application created using Wondarware System Platform programming environment, is used to solve the problems of transportation operations optimization and decision making process supporting in automated material handling system (AMHS) based on join activities of *n*-th number of overhead traveling cranes. The proposed approach to those problems was based on heuristic methods, which were realized using software tools created in HMI/ SCADA application. A problem of cranes operations optimization is addressed in the paper to time-optimal path planning and determining non-collision trajectory of a payload, taking into consideration obstructions localized in three-dimensional transportation space, by using graph searching algorithms with heuristic lower-cost function. The proposed solution was realized using HMI/ SCADA application, and tested on laboratory model of an overhead traveling crane. The HMI/ SCADA application was employed also in tools which allow to create expert system to aid decision making process, based on heuristic knowledge created on-line by supervisor of the process.

2. Heuristic approach to optimization the *n*-th cranes operations

The problem of shortens cranes trajectory planning without collision can be solved by using the graph search algorithms. The Dijkstra's or Bellman-Ford's algorithms obviously seem to be suitable to obtain the best solution of this problem [2]. However the faster algorithms, based on heuristic methods, can be used to solve this problem as well. A best first graph search algorithm allows finding the least-cost path from an initial node to expected (final) node [1, 3, 4]. Considered in the paper A* (A-star) algorithm for *i*-th crane is based on a heuristic function that can be denoted as $f_i(x,y,z)$, where *x* is a *i*-th crane's bridge position, *y* is a trolley position, and *z* is a load position determined by lifting (lowering) crane's movement mechanism in assumed transportation three-dimensional space described by *OXYZ* Cartesian space. The heuristic function $f_i(x,y,z)$ is composed of the path-cost function $g_i(x,y,z)$ and the heuristic lowest-cost function $h_i(x,y,z)$ that estimates the cost from currently considered node to the goal:

$$f_i(x,y,z) = g_i(x,y,z) + h_i(x,y,z) \tag{1}$$

Considering the automated material handling system (AMHS) consisting of *n* transport means (cranes), the problem of transportation operations planning for *n* cranes consists in finding the lowest path-cost functions for *m* specified starting $o_s(x_s, y_s, z_s)$ and desired $o_d(x_d, y_d, z_d)$ points according the condition (2):

$$\mathbf{F} = \mathbf{G} + \mathbf{H} \tag{2}$$

where:

$$\mathbf{F} = \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1m} \\ f_{21} & f_{22} & \cdots & f_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ f_{n1} & f_{n2} & \cdots & f_{nm} \end{bmatrix},$$

$$\mathbf{G} = \begin{bmatrix} g_{11} & g_{12} & \cdots & g_{1m} \\ g_{21} & g_{22} & \cdots & g_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ g_{n1} & g_{n2} & \cdots & g_{nm} \end{bmatrix},$$

$$\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1m} \\ h_{21} & h_{22} & \cdots & h_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ h_{n1} & h_{n2} & \cdots & h_{nm} \end{bmatrix}.$$

The function $g(x, y, z)$ is expressed by a sum of the currently considered node arriving cost (weights of graph edges) and cost from currently considered node to the neighbored node. Whereas the function $h(x, y, z)$ determines the best promising direction of graph searching, by estimating the distance from currently considered node to the goal. The most popular method used to estimate the path-cost from the current node $o_q(x_q, y_q, z_q)$ to the goal is so called Manhattan method (also known as the taxicab geometry or city block distance) that determines the distance between two points as a sum of the absolute differences of their coordinates. In the condition (2), the estimated cost from current nodes to the goals is considered for each transport means:

$$\begin{gathered} \mathrm{h_{ij}(x, y, z)} = \left|\mathrm{x_{qij}} - \mathrm{x_{dij}}\right| + \left|\mathrm{y_{qij}} - \mathrm{y_{dij}}\right| + \left|\mathrm{z_{qij}} - \mathrm{z_{dij}}\right| \\ \forall \mathrm{i} = \{1, 2, \ldots, \mathrm{n}\} \wedge \mathrm{j} = \{1, 2, \ldots, \mathrm{m}\} \end{gathered} \tag{3}$$

The considered *OXYZ* three-dimensional of cranes operating space can be split into absolute number of cubes (Fig. 1), which leads to obtain the graph (composed of sub-graphs) with the set of nodes (specified by intersections of cubes' edges or cubes centers of gravity) and edges.

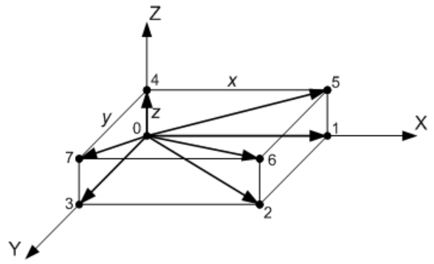

Fig. 1 The sub-graph created by the cube in OXY space

Sub-graph presented in the figure 1 is defining by eight nodes (the points numbered from 0 to 7) and the edges which weights are correlated with velocities of crane's movement mechanisms:

$$\frac{x_i}{y_i} = \frac{V_{xi}}{V_{yi}}; \; \frac{x_i}{z_i} = \frac{V_{xi}}{V_{zi}} \tag{4}$$

where:
$i = \{1, 2, ..., n\}$,
$V_x\,[m/s]$ - the speed of a crane's bridge, along the assumed *OX* axis,
$V_y\,[m/s]$ - the speed of a crane's trolley, along the assumed *OY* axis,
$V_z\,[m/s]$ - the speed of a lifting (lowering) crane's movement mechanism, along the assumed *OZ* axis.

Simplifying the problem under consideration by assuming that the relationship between crane movement mechanisms velocities are constant:

$$\frac{V_{xi}}{V_{yi}} = \text{const}; \; \frac{V_{xi}}{V_{zi}} = \text{const} \tag{5}$$

and denoting $w_{(kl)}(x, y, z)$ as the weight of a edge between *k* and *l* nodes in considered sub-graph (Fig. 1), the cost of the neighboring nodes arriving from the current point $k = 0$ can be formulated for *i*-element of the AMHS as follows:

$$w_{(01)i} = w_{(03)i} = w_{(04)i} \tag{6}$$

$$w_{(02)i} = w_{(05)i} = w_{(07)i} = \sqrt{w_{(01)i}^2 + w_{(03)i}^2} \tag{7}$$

$$w_{(06)i} = \sqrt{w_{(02)i}^2 + w_{(06)i}^2} \tag{8}$$

The successive nodes of a graph composed of sub-graphs presented in the figure 1, from the *j*-th starting $o_s(x_s, y_s, z_s)$ to the *j*-desired $o_d(x_d, y_d, z_d)$ point are specified according the condition which is formulated as:

$$f_{ij}(x, y, z) < g_{ij}(x, y, z) + h_{ij}(x, y, z)$$
$$\forall i = \{1, 2, ..., n\} \wedge j = \{1, 2, ..., m\} \quad (9)$$

The algorithm of the load trajectory designing which takes into consideration the obstructions that can be found in the *OXYZ* transportation space is presented in the figure 2.

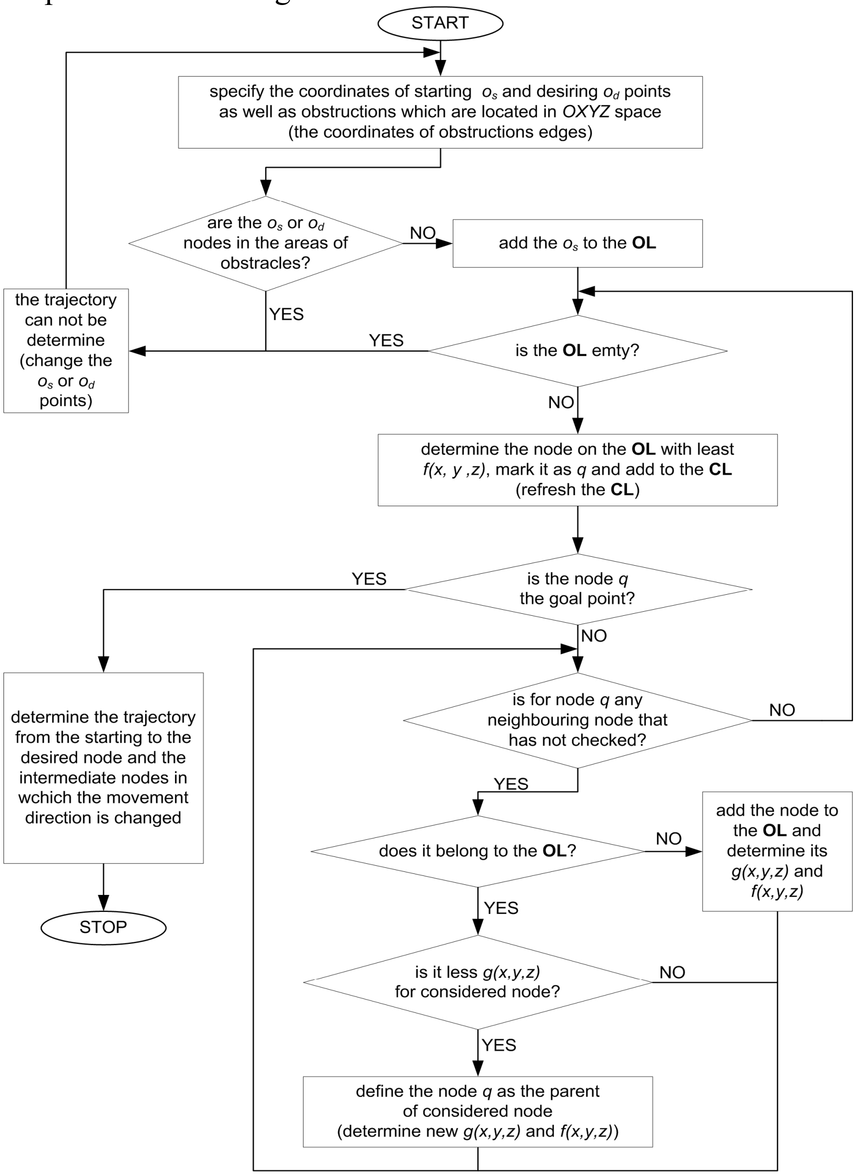

Fig. 2. The algorithm of designing the payload shifting trajectory of the i-th crane based on A method*

Starting with this algorithm, user defines the coordinates of starting and desiring points (nodes $o_s(x_s, y_s, z_s)$ and $o_d(x_d, y_d, z_d)$), as well as the coordinates of obstructions. According the algorithm the two lists (sets) of considered nodes are created: **OL** open list and **CL** closed list. The algorithm starts from the node o_s, marking it as the current node q that is placed on the **CL**, and checks the neighboring nodes placing then on the **OL** set with determined $g(x, y, z)$ and $h(x, y, z)$ costs, and $f(x, y, z)$ function for each node.
The condition (9) determines which of considered neighboring node is the next q node. The direction of designed path moving is specified by the $h(x, y, z)$ heuristic function (3). The algorithm in each step checks if from current q node to the considered neighboring node is possible to get with lower cost $g(x, y, z)$. When the path from starting point to the goal is found, the trajectory of load movement is determined by specifying the intermediate nodes (coordinates of trajectory points in the *OXYZ* space) where the movement direction (one of three crane movement mechanisms) is changed, that leads to reduce the set of trajectory intermediate points.
The presented solution of an *i*-th crane control system was tested on the laboratory object. The control system was built using the PLC (FX2N series, manufactured by *Mitsubishi*), on which the control algorithm was implemented, and PC platform with HMI/SCADA application, which realized the described algorithm of planning non-collision trajectory of a payload (Fig. 3).
The experimental results confirmed expected from control system quality, regarding to design the trajectory of a payload, as well as following this trajectory by executing crane's mechanisms. A payload deviation from fixed trajectory has not exceed during experiments assumed tolerance:

$$e_{x,y,z} = |x_t - x| = |y_t - y| = |z_t - z| = 0{,}06[m] \tag{10}$$

where:
x_t, y_t, z_t - coordinates of a fixed trajectory.

The obtained results confirmed as well the correctness of hardware-software architecture of proposed application realized using PC platform with HMI/ SCADA application used for supervising lower control system.

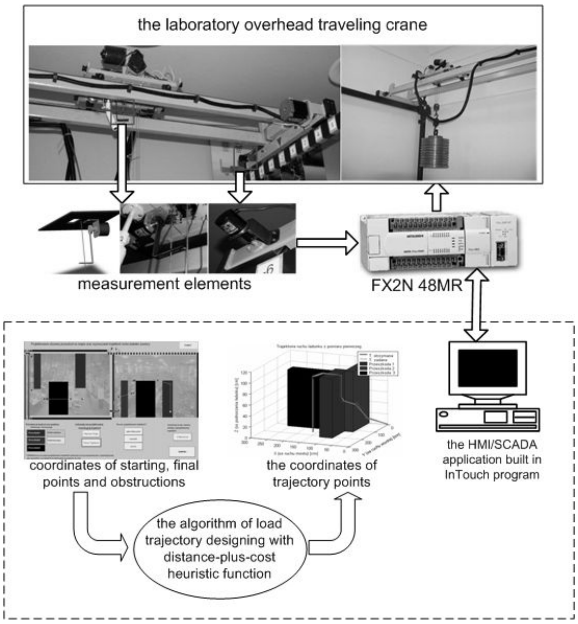

Fig. 3 The application of i-th crane control system based on PLC and PC platform with HMI/SCADA application

3. Decision making process aiding using heuristic knowledge

The HMI/ SCADA application was equipped in tools that allow creating heuristic base of knowledge consisting of a model of considered process, and base of knowledge about occurrences that can appear in the process. The core of proposed system are tools which allow to create hierarchical structure of supervised process (systems $\{s_1, s_2, ..., s_i\}$, subsystems $\{sub_1, sub_2, ..., sub_j\}$, components $\{c_1, c_2, ..., c_k\}$), and implement the heuristic knowledge about considered process (defined by users occurrences, their conditions, symptoms, dangerous and effects, as well as information about preventive-removing reactions) which is used by alarming and reporting mechanism of application to aid the human reasoning in Man-Machine System (MMS) (Fig. 4). The application allows to on-line create by users the expert system consisting information about reasons, effects, dangerous, preventive and removing reactions on appeared occurrences to aid decision-making process and to aid fast diagnosing of failures and abnormal states. Realized HMI/ SCADA application consists of tools and mechanisms that enable user to realize main functions in created supervisory system (Fig. 5):

- heuristic knowledge about process made by operator and/or process engineers: determining the structure of the process, defining or modifying states (which can occurred in considered process), specifying their priorities and defining or modifying (in base of knowledge information about causes, effects and hazards) connected with appeared in process events, as well as possibility of taking preventive or correcting operations (to aim counteract or eliminate the effects of disadvantageous events),

- tools which enable defining conditions of the event which was formulated in the base of knowledge as a function of input variables changes (exceeding the lower and/or upper limit value, deviation of input variables courses from tolerance zones, exceeding velocity input signals from acceptable value),

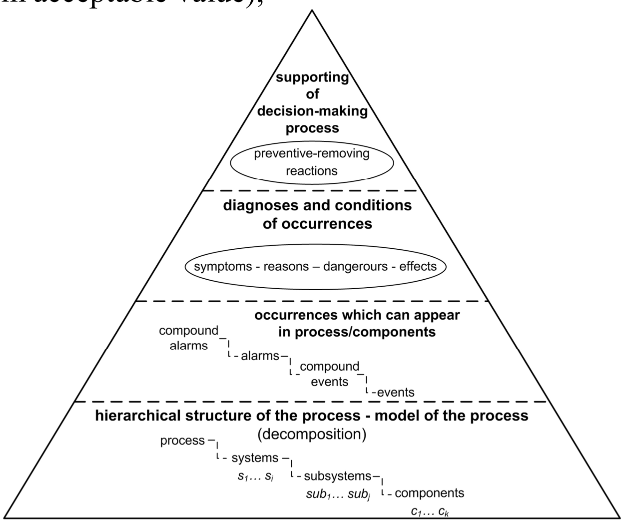

Fig. 4 The structure of heuristic base of knowledge used to aid decision-making process in MMS

- tools which enable to device/ system control and visualization of changes occurred in supervised process, monitoring course of input variables changes, changes of states defined in base of knowledge and their conditions, as well as their analyzing which can be realized in real-time or *off-line* (using historical date).

The system under consideration was realized using Wondarware System Platform and InTouch programming environment. The application operation was verified successfully during tests carried out on laboratory model of an overhead traveling crane with hoisting capacity Q=150 [kg], localized in the Laboratory of Automated Transportation Systems and Devices at AGH University of Science and Technology. The control system was based on the PLC (FX2N series, manufactured by *Mitsubishi*) exchanging data with PC platform using DAServer application.

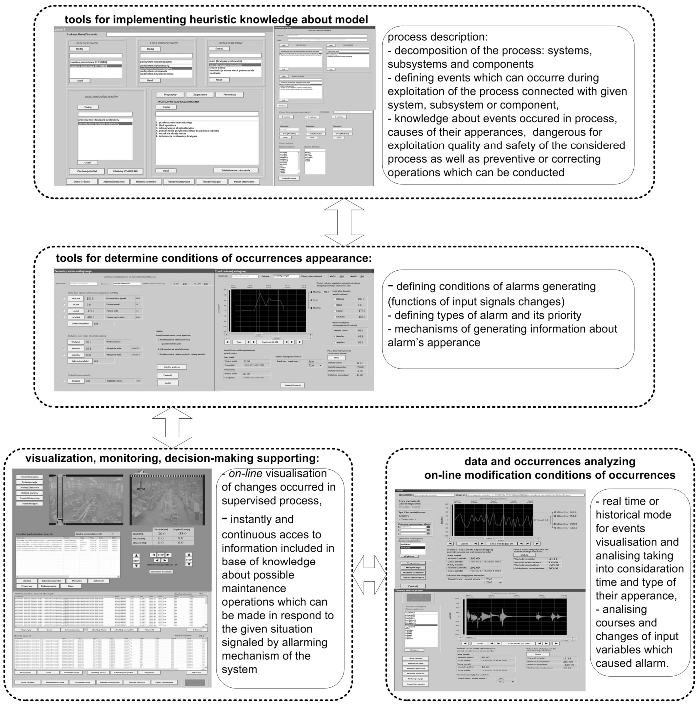

Fig. 5 Tools and mechanisms of HMI/ SCADA system enable to realize main functions in supervisory system composed with n-th crane set

4. Conclusions

Automation and computer aided activities moved human function in Man-Machine System to the role of supervisor. However the unconventional methods, based on intelligent systems, can be used to realize tasks often more efficiency when conventional methods are unreliable. The higher levels of control systems, supervisory and managing systems required more and more frequently tools which allow to built expert systems consisting of information about process (heuristic knowledge) to provide solutions, advice and suggestions to common situations encountered throughout supervising the process. The presented application is an interface for user to implement his heuristic knowledge about process, which is used by reporting and alarming mechanism aiding human reasoning and decision-making process.

The modern automated material handling system (AMHS) is challenged to optimize, organize and synchronize, and next realize with expected precision and time the planed transportation operations. For this reason the problem addressed and solved using heuristic approach, and presented in the paper, was planning operations realized in automated material handling system by *n*-th numerous (distributed) cranes set, as well as designing time-optimal and non collision trajectory of a payload handled by an *i*-th overhead traveling crane. The application, which solved above problem using the best first graph search algorithm (A*), and realized designed trajectory, was based on a PLC and PC platform with HMI/ SCADA application exchanging data with lower level of crane control system, and tested on laboratory object with acceptable results.

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References

1. Dechter R., Judea P.: *Generalized best-first search strategies and the optimality of A*.* Journal of the ACM 32(3), pp. 505–536, 1985.
2. Dijkstra E.: *A note on two problems in connexion with graphs. Numerische Mathematik*, vol. 1, pp. 269–271, 1959.
3. Hart P. E., Nilsson N. J., and Raphael, B.: *A formal basis for the heuristic determination of minimum cost paths.* IEEE Transactions on Systems Science and Cybernetics, vol. SSC4, no 2, pp. 100–107, 1968.
4. Koenig S., Likhachev M., Liu Y., and Furcy D.: *Incremental heuristic search in AI.* Artificial Intelligence Magazine 25 (2), pp. 99–112, 2004.
5. Molina A., Panetto H., Chen D., Whitman L., Chapurlat V., and Vernadat F.: *Enterprise Integration and Networking: Challenges and Trends.* Studies in Informatics and Control 16/4, Informatics and Control Publications, pp. 353-368, 2007 (ISSN 1220-1766).
6. Panetto H., and Molina A.: *Enterprise Integration and Interoperability in Manufacturing Systems: trends and issues.* Computers in Industry, 59/5, Elsevier, pp. 641-646, 2008 (ISSN 0166-3615).
7. Smoczek J., and Szpytko J.: *The HMI/SCADA in control systems and supervision processes of manufacturing transport.* Journal of KONES, Powertain and Transport, vol. 15, no 3, pp. 499–507, 2008.
8. Smoczek J., and Szpytko J.: *Interoperable approach to HMI and supervisory systems in Man-Machine Systems.* Proceeding of the 13th IFAC Symposium on Information Control Problems in Manufacturing, pp. 157-162, Moscow, June 2009.
9. Szpytko J.: *Integrated decision-making supporting the exploitation and control of transport devices.* Uczelniane Wydawnictwa Naukowo-Dydaktyczne AGH, Kraków 2004.

10. Szpytko J.: *Kształtowanie procesu eksploatacji środków transportu bliskiego*. Wydawnictwo Instytutu Technologii Eksploatacji, Kraków-Radom 2004.
11. Szpytko J.: *Metodyka zapewnienia bezpieczeństwa i niezawodności środka transportu bliskiego - Methodology of transportation security and reliability secure*. Problemy Eksploatacji, Maintenance Problems, nr 4, pp. 315–326, 2005 (ISSN 1232-9312).
12. Szpytko J.: *Transport devices quality control process integration*. Proceedings of the International Conference on CAD/CAM Robotics and Factories of the Future, pp. 859–867, Vellore, 2006.
13. Vernadat F.B.: *Interoperable enterprise systems: Principles, concepts, and methods.* Annual reviews in Control 31, pp. 137-145, 2007.

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