THE HMI/SCADA IN CONTROL SYSTEMS AND SUPERVISION PROCESSES OF MANUFACTURING TRANSPORT

Jarosław Smoczek, Janusz Szpytko

AGH University of Science and Technology
Faculty of Mechanical Engineering and Robotics
Al. Mickiewicza 30, 30-059 Krakow, Poland
e-mail: smoczek@agh.edu.pl
szpytko@agh.edu.pl

Abstract

The aim of the paper is integrated control and supervisory systems of works transport process which were realized using programming application type of HMI/SCADA (Human Machine Interface/Supervisory Control and Data Acquisition). The grater requirements put before automation and HMI/SCADA systems in range of controlling and supervising industrial processes cause that is more and more expected evolution of such system to integrate solutions and tools which allow realizing compound tasks connected with control, diagnostic, monitoring and managing. From supervisory systems are expected solutions which enable to aid decision-making processes for making faster and adequate diagnosis of occurrences and failures, proper estimating technical states of devices, formulating conclusions about symptoms-failures relationships and preventive or removing actions. It needs to develop tools using intelligent methods and algorithms based on fuzzy logic, experts systems and artificial neural networks which can be applied to realize inference systems to help decision-making processes, control and diagnostic tasks. Presented in the paper examples of HMI/SCADA systems consider realization of controlling and supervising tasks with the aid of fuzzy logic and heuristic algorithms. Supervisory system of works transport process shown in the paper was based on heuristic base of knowledge used to aid decision-making process of operator.

Keywords: *works transport, crane, intelligent control, supervising, monitoring*

1. Introduction

Along with rapid development of automation in industrial processes the human function in Man-machine System (M-MS) was moved more to the role of supervisor [5]. Simultaneously, increasing demands in range of ensuring safety, exploitation, dependability and maintenance quality of process and its elements require from users realization more and more compound tasks connected with estimating quality of control process and technical state as well as managing the whole or chosen aspects of the process [1, 3]. More and more data gathered from supervised process which are source of increasing quantity of information about operated objects require more and more compound software-hardware tools to aid human decision-making process [8, 9, 10]. Growing significance in automated industrial processes have systems type of HMI/SCADA (Human Machine Interface/Supervisory Control and Data Acquisition) which exemplify the higher level of control system. The aims of HMI/SCADA systems are mainly controlling and visualization, shorten the time of realized tasks in industrial processes, monitoring and controlling its chosen elements and enabling to quick react on appearing problems which require effective turn-reactions. The most popular and frequently implemented in Polish industrial system HMI/SCADA software are for example Asix, Citect, iFix, IndustrialIT, InTouch, Plant View, Pro2000, RSView, WinCC. Observed development of HMI/SCADA interfaces is directed to realization more and more compound tasks not only on a range of controlling, visualization and data acquisition but also to develop tools which allow to realize diagnostics and monitoring functions, alarming and reporting about disadvantageous occurrences appeared in supervised process or other mechanisms and tools to aid man decision-making processes. Contemporary is observed direction of integrating SCADA software environments with managing systems like MES (Manufacturing Execution System) and ERP (Enteprise Resource Planning) which requires to use real-time data-bases (mostly SQL data-bases). From supervisory systems as well as from automation systems are more and more frequently expected uniform engineering environments which realize control, visualization, diagnostic, optimization and managing tasks. Integration of those tasks in supervisory systems require to create systems which allow to configure hardware and software structures in a range of controlling, communication and access to common data-bases. Supervisory systems evolve from HMI/SCADA tools which realize only control and visualization tasks to systems in which the greater and grater significance have inference methods. The standard alarming and reporting mechanisms included in SCADA software are more frequently no sufficient for diagnostic purposes and to aid decision-making processes. Therefore the direction of developing HMI/SCADA systems is towards employing advanced tools which enable to formulate diagnosis and conclusions on the basis of information about supervised system and its elements. Developing making-decision systems can be realized in HMI/SCADA by applying intelligent methods like fuzzy logic, artificial neural networks and experts systems for control and diagnostic tasks executing. Especially effective tools used for control and diagnostic tasks realization can be created basis on fuzzy logic and experts systems used for process modeling, descriptions of symptoms-failures relationships and control algorithms building and optimization [6]. The important element of such inference system for decision-making process aiding could be the base of knowledge formulated by engineers, technologists or operator basis on heuristic knowledge about process/objects. Heuristic base of knowledge included in supervisory systems can be used for monitoring and diagnostic aims, data analyzing and estimating compound information obtained from technical objects, formulating proper diagnosis and conclusions about reasons, dangerous and effects of appeared occurrences as well as effective preventive or removing reactions. In control tasks the heuristic base of knowledge can be used for describing the effective control strategy especially when other conventional control methods which requires identification and mathematical description of the process formulating cause problems to achieve proper control quality. In this situation control strategy can be expressed by user/operator basis on his heuristic knowledge in form of fuzzy implications IF-THEN. Also artificial neural networks can be helpful in diagnostic tasks, process modeling and simulation and detecting symptoms of defects and „abnormal" states for the process and technical objects.

In the paper were presented examples of supervisory systems for works transport process realized by overhead traveling cranes. Hardware and software applications of supervisory systems were built using PLC (Programmable Logic Controller), InTouch and Industrial Application Server software environment working under the Microsoft's operating systems delivered by Invensys Wonderware. The examples of HMI/SCADA software applications were equipped in tools which allow to realize control, visualization and monitoring tasks with the aid of base of knowledge created basis on heuristic knowledge about transportation process and control object and included in software application. Proposed software application of HMI/SCADA enables to create fuzzy control algorithm by formulating control strategy using IF-THEN rules. Basis on information and heuristic knowledge about control object control strategy can be described by experienced user/operator and formulated using fuzzy implications in base of knowledge and next realized by PLC on which fuzzy algorithm was implemented. In range of realizing tasks of monitoring and supervising of exploitation process the HMI/SCADA system was elaborated in which the base of knowledge consists heuristic description of the process and technical object used next for user's decision-making process aiding and formulating diagnosis about chosen occurrences which appear in the process.

2. Intelligent control systems of works transport means with the aid of HMI/SCADA

The main aim of the HMI/SCADA programming applications is realizing control and visualization tasks. Software environment delivered by popular HMI/SCADA producers is usually equipped with tools for creating graphical user's interfaces, panels which allow to influence on chosen aspects of the process and receive on-line and off-line information essential for supervising and managing the whole process. Usually in such systems control decisions are made by user/operator in the result of decision-making process realized basis on information received from HMI/SCADA application. However in most cases the operator from the level of supervisory system (higher level of control system) does not have possibility to create or modify the control algorithm which is realized in lower level of control system by control devices (e.g. PLC). The operator role is rather limited to manage the supervised process. Frequently experienced operator/engineer possesses knowledge about control object to create successful heuristic control strategy which can improve control quality and can be easier to implement especially in comparison with control algorithms and systems which require compound methods of elaborating. By equipping HMI/SCADA systems in tools which allow to implement heuristic knowledge in control system of supervised process/objects the user/operator has greater possibility to influence on lower level of control system and its working quality.

Example of intelligent control system in which human heuristic knowledge can be used for creating expert's control strategy is fuzzy logic. Fuzzy logic control algorithms applying in HMI/SCADA application gives possibility for user to implement his heuristic knowledge in control systems of supervised process. Example of such HMI/SCADA hardware and software system was elaborated using PLC on which the control fuzzy algorithms (Mamdani and Sugeno inference systems) were realized using ladder format and structured text. The HMI/SCADA applications in which graphical user's interfaces for controllers parameters defining and modifying were built using Wonderware software environment. Experiments were tested for works transport process realized by overhead traveling cranes which worked in workshop and laboratory localized in AGH University of Science and Technology.

Restrictions caused by PLC unit (FX2N48MR produces by Mitsubishi firm) processor and memory capacities gave possibility to implement Mamdani's control algorithm in form of structured text with some limitation in range of membership function and fuzzy implications IF-THEN. In HMI/SCADA programming application was created user's graphical interface which enables to define the main controller parameters including base of knowledge in which control strategy can be formulated by operator/user in form of IF-THEN rules. Those parameters are set on-line in control algorithm realized in PLC unit [2].

Programming interface, shown in the Fig. 1 which was created using HMI/SCADA software enables to built structure of Mamdani controller compound of fuzzification, base of knowledge and defuzzification phases. Control algorithm can be created basis on up to fourth input and one output signals and up to fifth triangular and/or trapezoidal membership functions which can be defined for each input and output signals using lingwistic terms Positive or Negative Small, Big and Zero (BN, SN, Z, SP, BP). Graphical interface built in HMI/SCADA application allows for user to define number of inputs, number of fuzzy sets and field on which the variables are considered for each inputs and output signals as well as parameters (a, b, c, d) which determine membership functions shapes. The base of knowledge can be built basis on user's heuristic knowledge with using up to 20 IF-THEN rules which express relationship between input and control signals. Rules IF-THEN can be defined using AND-OR operations in rule's antecedent and value of rule's weight can be set in range of $w_k = <0, 100>$ where k is a number of rule defined in base of knowledge. In defuzzification user can chose one of two popular methods Center of Gravity (COG) or High Method (HM) to obtain crisp value of output signal. Those parameters of Mamdani's controller are set on-line using HMI/SCADA application on PLC unit which realizes Mamdani's algorithm written using structured text.

Presented tool was implemented to the HMI/SCADA system realized for controlling and visualizing the overhead traveling crane transportation process. The programming application was used for creating fuzzy anti-sway crane's control system of which aim was to shift the load by crane's movement mechanism (bridge) with assumed precision and reducing the load's swinging. The software and hardware architecture of control system as well as the Mamdani's control algorithm were presented in simplified way in the Fig. 2. The HMI/SCADA programming application was realized with the aid of Wonderware software environment: Industrial Application Server and InTouch programs. Fuzzy control algorithm was written using structured text on PLC type of FX2N48MR.

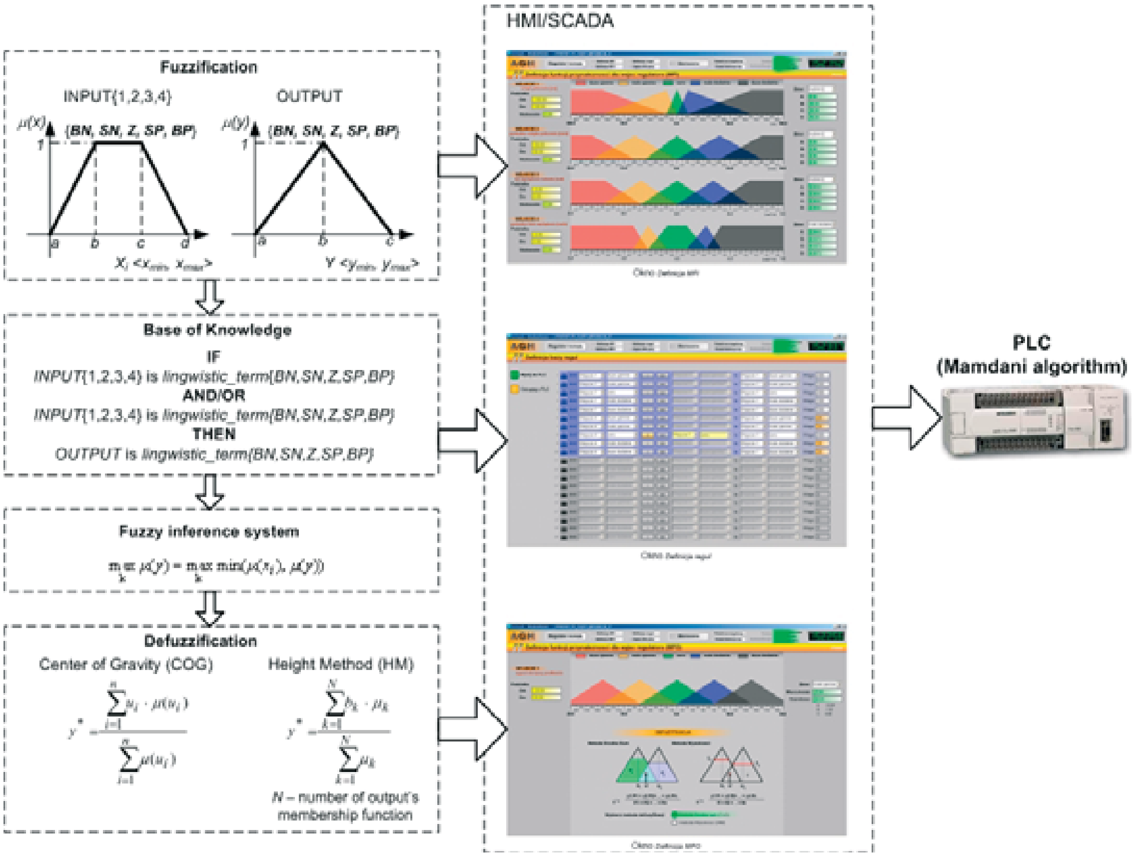

Fig. 1. Simplified diagram of Mamdani's control algorithm projecting using graphical interface built in HMI/SCADA application

In the Mamdani's control algorithm the crane's position x and velocity of swing angle of the load $\dot{\alpha}$ were taken into consideration as inputs' signals for which the triangular membership functions were defined. The base of knowledge was described using fifth rules IF-THEN with using OR operations in antecedents. The crisp value of output signal (u expected crane's velocity) was calculated with using center of gravity defuzzification method. The result of experiments of anti-sway crane's control system with using Mamdani's algorithm realized by PLC were presented in the Fig. 3-4 with comparison with results of experiments conducted for conventional discrete control algorithm based on proportional-derivative (PD) controllers. Examples of results were achieved from experiments of control systems in which expected position was $x_d = 1[m]$ and for constant mass of the load $m = 10[kg]$ and length of the rope $l = 1[m]$.

Basis on results of experiments (Fig. 3-4) it was stated that fuzzy controller with Mamdani's inference system improved control quality in comparison with PD controller by shorten the positioning time. The positioning and swing dumping time with assumed tolerances was about 6 second using Mamdani's controller while using conventional PD controller the control time was above 8 second. Simultaneously it was observed better resistance on rope length variation (in small range of changing l) during tests conducted with using Madani's controller.

The results of experiments with using Takagi-Sugeno-Kang (TSK) fuzzy controller used in anti-sway crane's control system were presented in [7]. Fuzzy control algorithm was implemented on PLC unit and control system was tested on real device, the two-spars overhead traveling crane working in workshop with hoisting capacity $Q = 12500[kg]$.

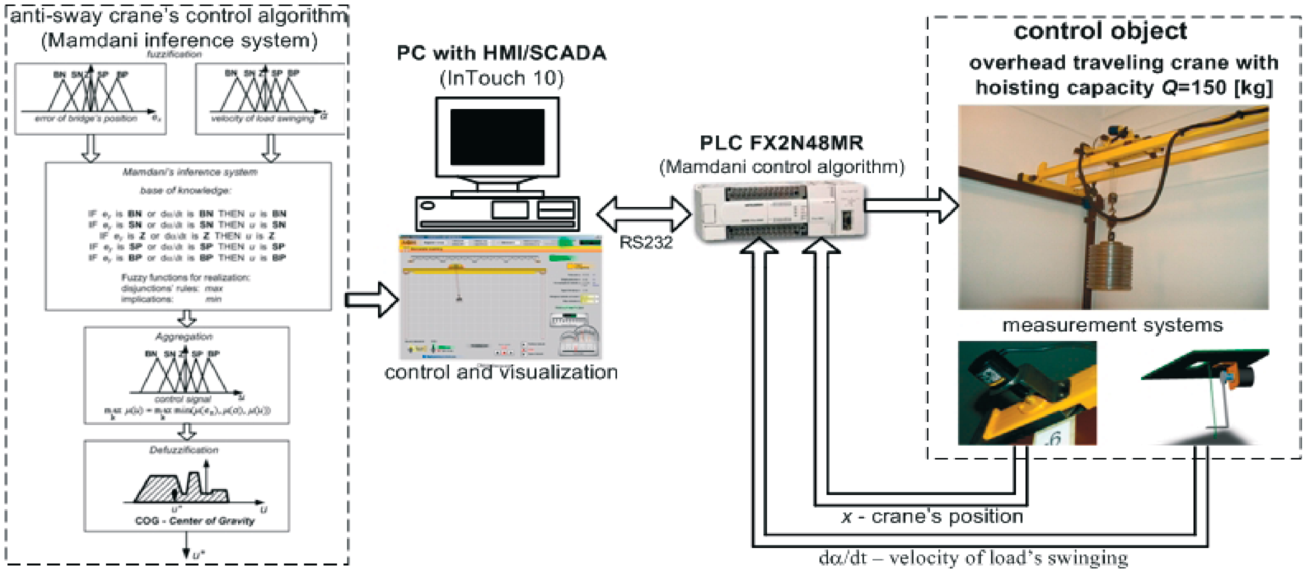

Fig. 2. Hardware and software structure of crane's control system for load shifting and swing reducing and Mamdani's control algorithm implemented on PLC using HMI/SCADA system

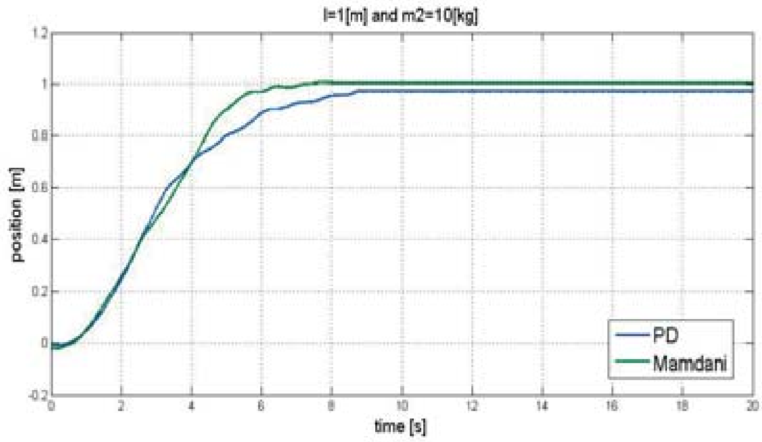

Fig. 3. Crane's position

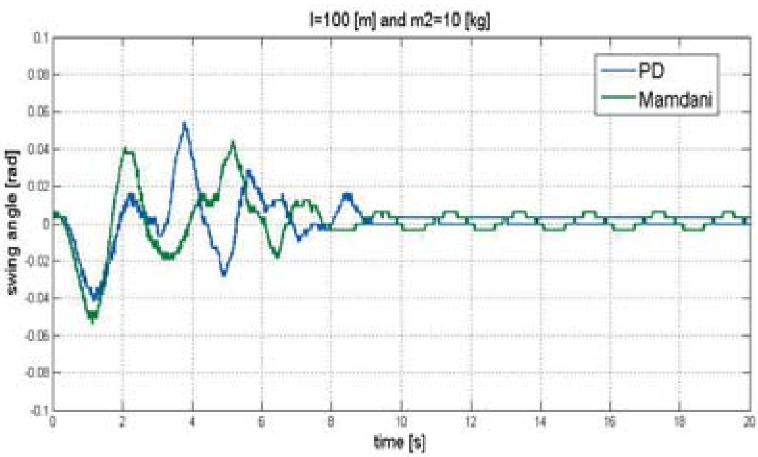

Fig. 4. Swing angle of the load

The next example of intelligent control algorithm implemented in HMI/SCADA system which was built for supervising transportation process is heuristic algorithm based on A-star algorithm used for designing non-collision trajectory for shifting the load by an overhead crane. Heuristic algorithm based on A-star algorithm was applied in HMI/SCADA application to elaborate and optimize safety movement trajectory between origin and destination points of load shifting process basis on information about co-ordinates of obstacles localized in three-dimensional OXYZ crane's workspace. Criterion of optimal movement trajectory designing was time of shifting process basis on velocities of crane's movement mechanisms. In order to solve the pathfinding problem the A-star algorithm takes into account the heuristic function used for estimating the cost of destination reaching which causes the algorithm is faster then most other graph searching algorithms. However the control algorithm written on PLC and used in control system of three crane's movement mechanisms had the aim of precisely following the movement trajectory which was appointed by given co-ordinates in OXYZ workspace fixed using HMI/SCADA application (InTouch program) working on PC in which the heuristic pathfinding algorithm was applied. The example of result achieved from experiment conducted on real device for transportation process realized by crane's movement mechanisms according to trajectory designed in HMI/SCADA application taking into consideration the co-ordinates of obstacles were presented in the Fig. 5.

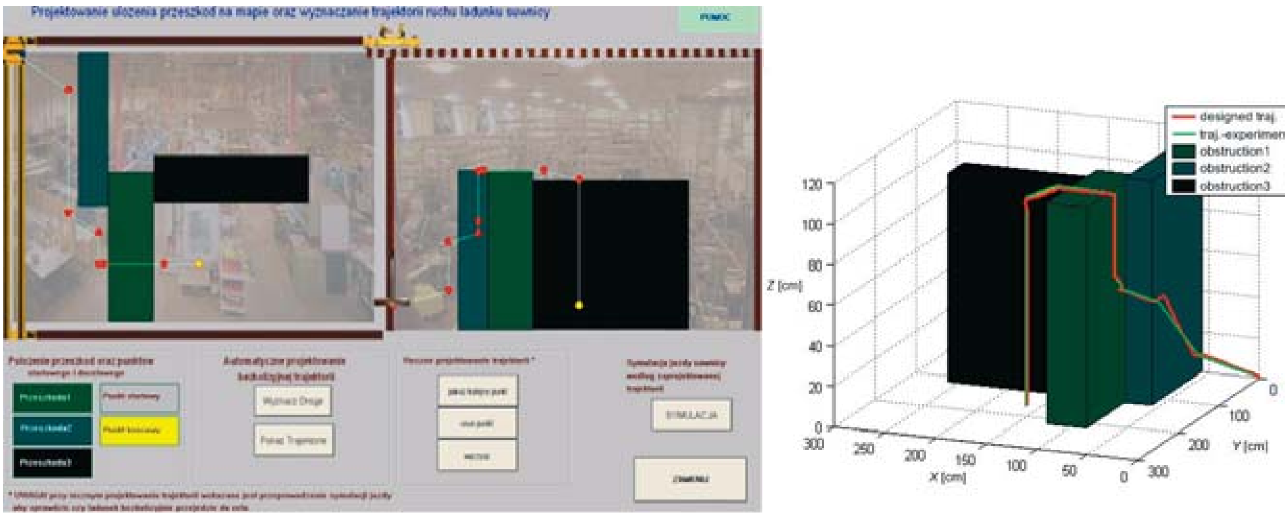

Fig. 5. The view of HMI/SCADA tool for designing and visualization of non-collision movement trajectory in load's shifting process and results of experiment conducted on real device for following the movement trajectory which was elaborated for three obstacles localized in three-dimensional OXYZ crane's workspace [4]

3. Inference systems with the aid of heuristic in HMI/SCADA systems

In most cases the supervisory systems of technical objects state use alarming and reporting mechanisms which deliver information about abnormal occurrences appeared in the process. Basis on those information user makes conclusions and decisions about proper preventive and removing operations required in ensuring adequate quality of exploitation process and dependability level. Decision-making process can be assisted by using inference system implemented in supervisory system in which diagnosis about technical states of objects in industrial processes are formulated basis on heuristic base of knowledge built by experienced process engineers and operators.

In proposed and realized HMI/SCADA system for supervising technical objects were created tools which allow to implement heuristic knowledge about process by user (process engineer or operator). The heuristic base of knowledge includes supervised process description in form of decomposition of process on systems (s_1, s_2, …, s_i), subsystems (sub_1, sub_2, …, sub_j) and elements (e_1, e_2, …, e_k) which helps to localize the defined occurrences. Decomposition can be expressed as a sum of process systems, subsystems and their elements (1):

$$P = \sum_{i=0}^{n} s_i = \sum_{i=0}^{n} \sum_{j=0}^{m(i)} sub_{i,j} = \sum_{i=0}^{n} \sum_{j=0}^{m(i)} \sum_{k=0}^{r(j)} e_{i,j,k} , \qquad (1)$$

where:

n, m, r - respectively: number of systems, number of subsystems in each *i*-system and number of elements in each *j*-subsystem.

Basis on knowledge and experience user can define for subsystems and elements of decomposed process occurrences by defining conditions of their appearances as exceeding or deviation one or more input variables from nominal values. Hierarchical structure of defined occurrences (events - compound events – alarms - compound alarms) gives possible to use occurrences with lower priorities as conditions of appearing occurrences with higher priorities. User can express his knowledge about defined events/alarms by including in base of knowledge 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. Total number of events/alarms defined in base of knowledge can be expressed as a sum of occurrences formulated for each subsystem and each elements of subsystems (2):

$$P = \sum_{i=0}^{n} \sum_{j=0}^{m(i)} o_{i,j} + \sum_{i=0}^{n} \sum_{j=0}^{m(i)} \sum_{k=0}^{r(j)} o_{i,j,k} . \qquad (2)$$

Heuristic base of knowledge can be created and modified off-line or on-line in HMI/SCADA system. The HMI/SCADA application was equipped also with tools which enable to realize visualization and monitoring supervised process and its chosen exploitation parameters as well as data analyzing in real-time or off-line. In the Fig. 6 the simplified diagram of creating heuristic base of knowledge about process and possible occurrences which can appear was presented.

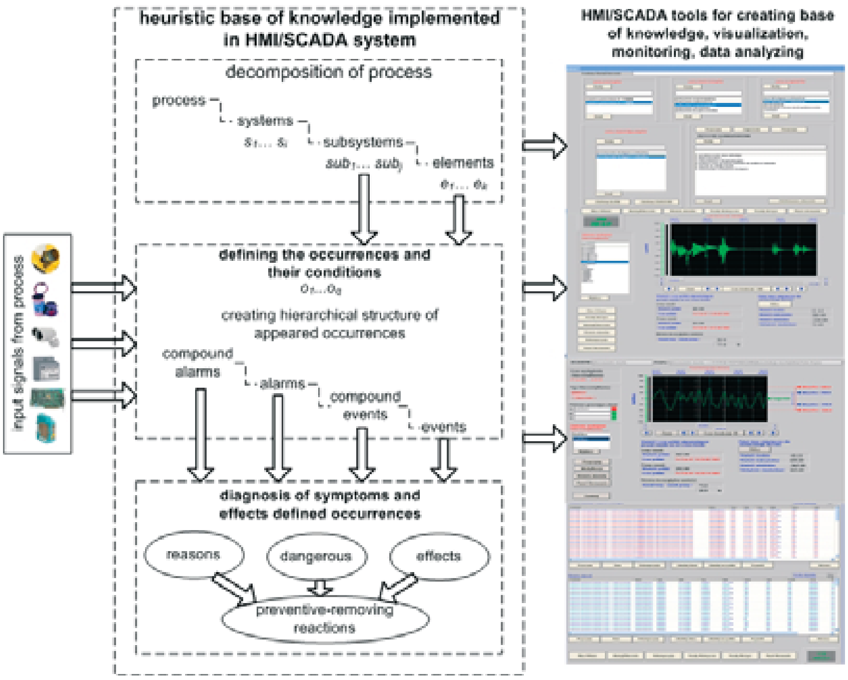

Fig. 6. Implementation of heuristic knowledge about supervised process to HMI/SCADA system

Realized HMI/SCADA application is composed of tools which enable user to realize main supervisory system functions:

- defining or modifying states which can occurred in considered process, specifying their priorities and defining and modifying in base of knowledge information about causes, effects and dangerous 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),
- tools which enable to device 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 *of-line* (using historical date).

Presented HMI/SCADA system was tested in supervisory of works transport process realized by the overhead crane for which the base of knowledge was formulated to aid decision-making process of operator.

4. Conclusions

The higher requirements put before automation and supervisory systems in range of control, monitoring as well as managing, diagnostic tasks realizing cause developing HMI/SCADA systems towards integration compound tools to aid making-decision processes in Man-Machine Systems (M-MS). Realization of more and more compound tasks in HMI/SCADA systems requires to use so called intelligent control mechanisms and tools: fuzzy logic, experts systems, artificial neural networks. More and more frequently from HMI/SCADA systems is required inference systems based on heuristic to aid decision-making process for formulating well-chosen diagnosis, conclusions and proper estimating symptoms-effects relationships. Employed in supervisory system heuristic base of knowledge can be used for building models of process and relationships between its elements used next to realize control, monitoring and managing tasks.

Presented examples of control and supervisory systems were applied and tested in works transport process realized by the overhead cranes. HMI/SCADA systems were built and equipped in intelligent algorithms for realizing control and supervisory tasks basis on heuristic which was implemented by process operator. Basis on experiments results analyzing it was stated that proposed solutions give possibility to improve control and exploitation quality of considered process and device.

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