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Human - Machine Interface Implementation in Designing Crane Control Based on Fuzzy Logic Algorithm

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Abstract: The paper is focusing on Human Machine-Interface implementation in designing crane control based on fuzzy logic algorithm. The Human Machine-Interface application was created for visualization, monitoring and managing the transportation process realized by the crane. Control systems based on fuzzy controllers with Mamdani and Sugeno inference systems were elaborated and built using prototyping methods and tools enable for control object identification, real time tests on the control object and control algorithm implementation on target Programmable Logic Controller.

1. INTRODUCTION

The result of integration within the manufacturing system and the required improvement of quality product levels, are more and more severe and variable requirements concerning devices working in CIM (Computer Integrated Manufacturing). The required devices` level is dependent on their reliability, safety, diagnosis, precision and reproducible operations, as well as the possibility of cooperating with other, modern devices, also those with the characteristics of *artificial intelligence* (Szpytko, 2004a). Materials handling devices play the key part in a manufacturing system.

Transportation process efficiency and safety, as well as device's exploitation quality require positioning accuracy, swing motion of the load and overloads reducing with minimizing positioning time simultaneously. The paper is focusing on overhead cranes, as transportation device examples (Szpytko, 2004b). A crane is most often the neuralgic tie in modern manufacturing systems and storage, especially in the extremely hazardous places (metallurgy, aviation, shipyards, nuclear power plants, special branches of industry with health hazard elements), where the quality of realized operations is particularly important. In many of research works proposals of crane's control systems are shown, both open and closed loop control.

Complexity of phenomenon occurred during loads transportation process using cranes because of wide change exploitation parameters causes that in crane's control systems are required tools taking into consideration complexity of such systems characterized by uncertainty, imprecision and subjectivity of parameters. One of those mathematical tools is fuzzy logic that is a nonlinear system that convert a crisp input vector into a crisp output vector (Zadeh, 1965). Fuzzy models are experts systems in which control strategy is expressed in form of IF-THEN rules built using linguistic terms basis on heuristic knowledge and without necessity of having mathematical object's description.

Many of presented approaches are based on intelligent control systems using artificial neural networks (Mendez et al, 1999) or/and fuzzy logic (Benhidjeb & Gissinger, 1995; Mahfouf et al, 2000; Nalley & Trabia, 2000; Suzuki et al, 2000; Yi et al, 2002), especially Mamdani inference system. However the most research works concern control systems realized and tested only during simulations conducted on mathematical or laboratory models of a device. The application of fuzzy logic control system implementation in real overhead cranes operating in manufacture, which have been done by authors, have been presented in (Szpytko et al, 2005).

Taking into consideration users requirements concerning crane's exploitation and control quality improving realization of new solutions in executing and control systems is more and more significance at present. It is especially because of many devices has still slip-ring motors in driving mechanisms. Therefore, on the one hand it requires implementing in crane's power transmission systems solutions based on frequency inverters, on the other hand requires methods and tools enable to elaborate and built control systems, which ensure crane's dynamic performance optimization. Time-consuming process of building control system can be shorten by using prototyping process requires integrated hardware and software tools enable to conduct real-time experiments and implementing control algorithm on the target controller, e.g. Programmable Logic Controller (PLC), which can be used in industrial practice.

The paper presents human - machine interface implementation in designing crane control based on fuzzy logic algorithm (Zadeh, 1965). The designed control algorithms with Mamdani and Takagi-Sugeno-Kang TSK

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inference systems were dedicated for reducing swing of the load while shifting it by crane's bridge to the desired position as fast as possible. Control systems were tested and realized on the real overhead traveling crane with hoisting capacity of 125 [kN]. Both Mamdani and TSK control algorithms were implemented on PLC controllers FX type of Mitsubishi using standard instructions of PLC and lager program's format.

Proposed control algorithms based on Mamdani and Takagi-Sugeno-Kang (TSK) fuzzy inference system were elaborated in rapid prototyping process divided into two steps. In the first step the control algorithms were elaborated using computer PC with data acquisition cards and *Matlab The MathWorks Inc.* program (Smoczek & Szpytko, 2006). Using rapid prototyping process shorten the time of control system designing: control algorithm optimization, sampling time selection, testing proper working measurement circuit. In the second step the control algorithm was implemented on the target controller: programmable logic controller PLC. Using *InTouch Wonderware Corporation* program the HMI (*Human Machine-Interface*) application was created for visualization, monitoring and managing the transportation process realized by the crane.

2. CONTROL ALGORITHMS BASED ON MAMDANI AND TAKAGI-SUGENO-KANG INFERENCE SYSTEMS

The aim of control systems based on fuzzy inference systems Mamdani and Takagi Sugeno-Kang (TSK) was precision positioning of the load transported by crane's bridge to the final position with reducing swing of the load after starting and during braking. The fixed mass of the load and length of the rope were assumed. For Mamdani controller the input signals were error of bridge's position $e_x = x_d - x$ (where: x_d - desired bridge's position, x - actual bridge's position) and swing angle of the load α measured in bridge movement direction (Fig. 1).

In fuzzyfication and defuzzyfication algorithms of Mamdani's controller were used seven fuzzy sets for each input signal as well as for controller's output signal u (entitled using linguistic terms: *Big*, *Medium* and *Small* - *Negative* or *Positive* respectively - and *Zero*). For all fuzzy sets used in fuzzyfication and defuzzyfication phases triangular membership functions were applied. The base of knowledge Mamdani's controller is composed of nine IF-THEN rules type of conjunctions and disjunctions. The function *minimum* was assumed for realizing implications in fuzzy inference method. The crisp output signal is calculated as a result of fuzzy sets aggregation using *max-min* composition (composition of fuzzy function *maximum* and *minimum*) and next *Center of Gravity* (COG) defuzzyfication method.

In case of control algorithm elaborated based on TSK inference system there were used three input signals: error of bridge position e_x, velocity of the bridge $\dot{x}$ and swing angle of the load α (Fig. 2).

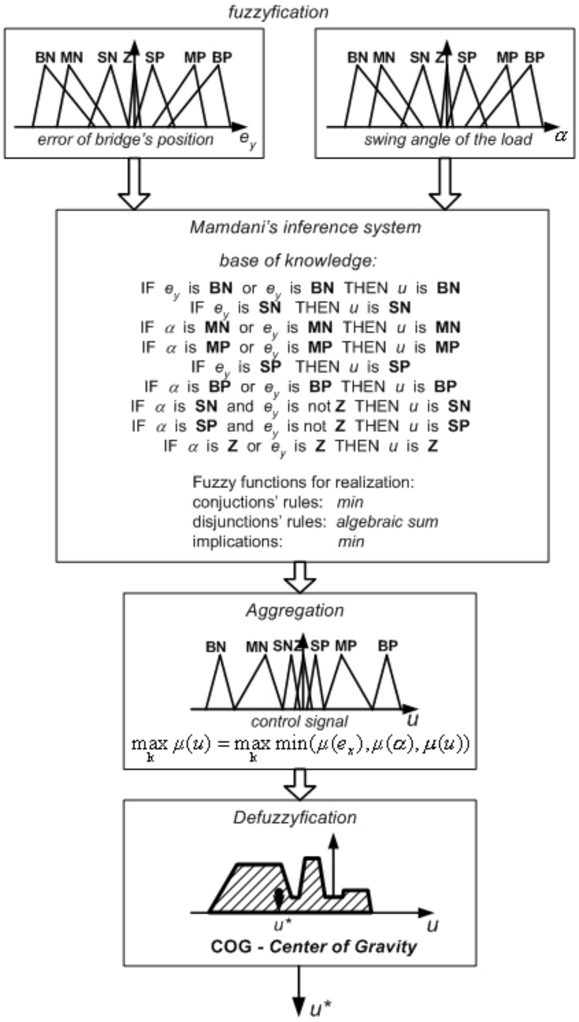

Fig. 1. The crane control algorithm based on Mamdani fuzzy inference system

The significant difference between both fuzzy inference systems is in consequent of the rules IF-THEN [2, 8, 10]. In TSK model the compound process of deffuzification is replace by function of inputs variables. In fuzzyfication process of TSK controller were used three fuzzy sets for each input of the controller represented by triangular membership functions (*Negative*, *Zero* and *Positive*). The base of knowledge expresses heuristic control strategy is composed of 27 rules using only AND method (Fig. 2).

In the result of using single *k*-rule desired velocity of the bridge is counted $\dot{x}_d^k$. The output signal of the TSK model $\dot{x}_d$ is calculated as a sum of desired velocities calculated from each of the rule multiplied by rules' weight coefficients (1):

$$\dot{x}_d = \sum_{k=1}^{n} \mu_k \cdot \dot{x}_d^k \qquad (1)$$

where:

μ_k - rule weight [0, 1],
k - number of rule,
$n = 1, 2..., 27$

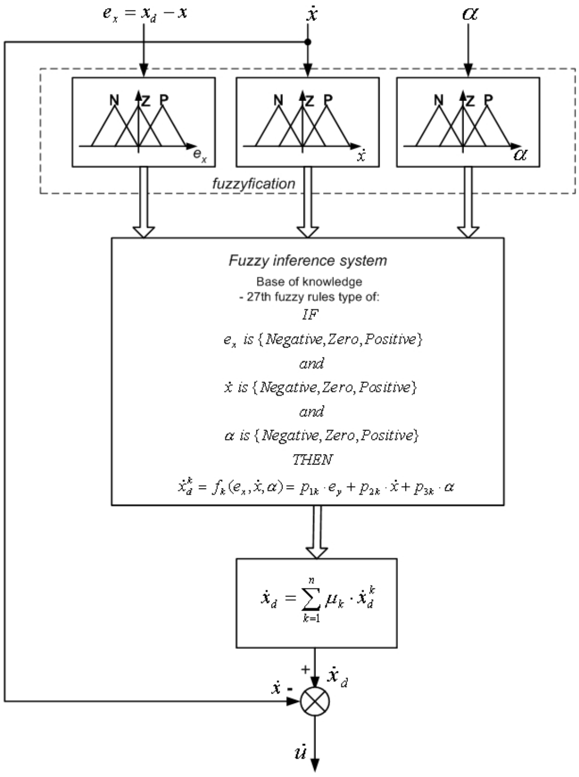

Fig. 2. The crane control algorithm based on TSK fuzzy inference system

The increase of signal control $\dot{u}$ is calculated as a difference of output signal from TSK model $\dot{x}_d$ and actual velocity of the bridge $\dot{x}$ (2).

$$\Delta u = \dot{x}_d - \dot{x} \tag{2}$$

3. CRANE'S HUMAN MACHINE-INTERFACE CONTROL SYSTEM

Rapid prototyping methods enable shorten the time of control system designing: control algorithm optimization, sampling time selection, testing proper working measurement circuit, signals filtering. The prototyping process is performed in the result of elaborating and testing virtual controller during computer simulations conducted on the digital models of the control object, verifying and validating control system during experiments on the real device and implementing control algorithm on the target control device (controller).

During researches conducted towards elaborating control system of the crane's movement, prototyping process was based on Matlab program package equipped in Simulink, Fuzzy Logic Toolbox (FLT), Real Time Workshop (RTW) enable building mathematical models of control object and fuzzy controllers as well as conducting real time experiments on the device. Equipment's architecture of the measurement-control circuit was based on PC computer with multifunction data acquisition cards (Fig. 3).

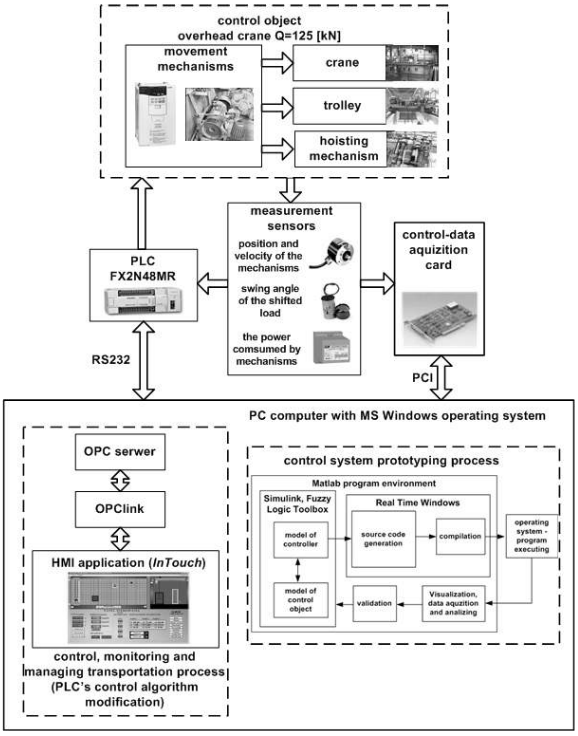

Fig. 3. Crane's human - machine interface control system

Mechanism of RTW enables to automatically generating of source code and its compilation from Simulink model which considerably shortens the time of building control system, giving possibility of concentrating only on control system designing. Designer's work can fluently gone from the stage of computer simulation conducted on the models, preparing virtual controller to the stage of experiments on the control object, if need giving possibility of quickly returning to the phase of simulation. Control systems based on Mamdani and TSK controllers built and tested during simulation in Matlab program using mathematical model of the device was next elaborated during experiments on the real object. Finally the ready control algorithm was implemented on the target controller: programmable logic controller PLC type of FX2N *Mitsubishi Electric* firm. Control algorithm was written to the PLC controller using standard instructions in ladder format understandable by series of FX controllers.

Hardware and software tools enable to shorten the time of control algorithm designing using mathematical model of the control object achieved in identification process. During identification of control object it was assumed that mathematical model is composed of two discrete transmittances $G_1(z)$ and $G_2(z)$ describing respectively input control signal relationship to velocity of the crane's bridge $\dot{x}$ and $\dot{x}$ to swing of the load α (Fig. 4).

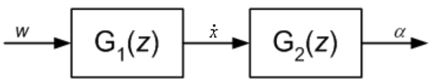

Fig.4. Model of control object presented as discrete transmittances

Implementation control algorithm on the PLC controller after testing it with PC computer with interface card's could require necessity of adjusting controller parameters because of change software environment. Modification of control algorithm requires time-consuming PLC's program changing and conducting tests on real object. For this reason the important element of realized HMI application was possibility of fuzzy control algorithm modification in real time without necessity of changing PLC's program. The HMI application enables modification fuzzy controller parameters by giving possibility of changing membership function parameters and vector of controller gains in rules' consequences.

HMI (*Human Machine-Interface*) systems have greater and greater significance in industrial processes. They are direct communication systems between human (operator) and industrial process. HMI supplies tools for visualization process using synoptic images, controlling, monitoring and managing the whale process or choosing devices and means of manufacturing process, acquisition and presentation dates. HMI systems are the higher level of control systems which enable raising quality and shorten the time manufacturing tasks realization, monitoring and controlling the whale or chosen productions aspects and fast reaction on appearing problems.

Realized HMI application enables monitoring and managing process of load's shifting realized by crane. Software-equipment architecture of HMI system was based on PC computer and programming application built in *InTouch Wonderware Corporation* software environment. Communication between HMI application and PLC controller was realized using client-server architecture with OPC (*OLE for process control*) standard. HMI application was equipped in tools gave possibility of:

- managing and controlling the shifting process,
- choosing manually or automatically type of device working,
- visualization of shifting process using synoptic image or cameras views,
- dates monitoring and acquisition and presentation in form of current and historical trends,
- generating alarms about dangerous states of the process or device,
- manual or automatic way of safety load's trajectory designing taking into consideration of obstructions in working space of the overhead crane,
- modification of fuzzy control algorithm in PLC controller without necessity the program changing.

4. EXPERIMENTS

Control systems were realized and tested on the real objects, two-spars overhead traveling cranes with Q = 12 500 [kg] hoisting capacity (working in the workshop) and with Q = 150 [kg] hoisting capacity (localized in the laboratory of AGH University of Science and Technology in Krakow, Poland). Fuzzy control algorithm based on TSK inference system was tested using the overhead crane working in the workshop with Q = 12 500 [kg] hoisting capacity and bridge width L = 16 [m]. Results of experiments with TSK controller were compared with results obtained using conventional control algorithm composed of PI (proportional-integral with gains: $K_{P1} = 0.17$; $K_I = 0.033$) controller used in the error of crane's position feedback loop and P ($K_{P2} = 10$) controller used in the swing angle feedback loop. The sum of outputs from controllers was the increment of control signal Δu. Both algorithms, fuzzy and conventional, were tested using PC computer with control-measurement cards for the same assumptions: about 10 tons mass of the load suspended on the rope with fixed length 6 meters. Next, the TSK control algorithm was implemented on PLC controller, and tested with about 5 tons mass of the load. The results of above experiments were presented in form of swing angle of the load and power consumed by crane's motors charts (Smoczek, & Szpytko, 2006).

The control algorithm based on TSK fuzzy controller was implemented on PLC controller FX248MR used in following equipment configuration:

- Central Processor Unit (CPU) with 24th digital inputs and 24th relay's outputs 24V DC,
- fast counter module with A/B phases 50 [kHz],
- module with 4th analog outputs,
- module with 4th analog inputs.

Simplified diagram of connections PLC controller with sensors and frequency inverters was presented in the Fig. 5.

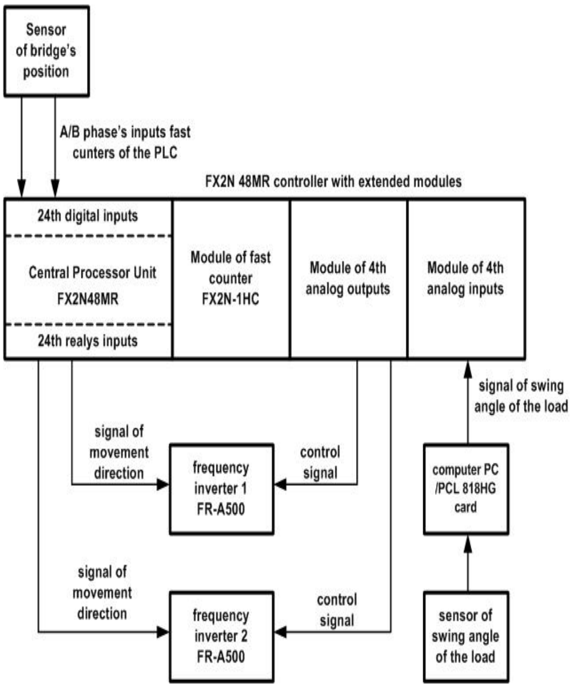

Fig.5. Block scheme of the PLC inputs and outputs connections

Basis of results from experiments with 100 [kN] transported load conducted using PC computer realized PI and TSK controller was stated. Uusing TSK controller the swing angle of the load was minimized better especially during starting (above 40%) and faster during braking the bridge mechanism (Fig. 6). The maximal value of swing angle during starting was 0.028 [rad] using PI controller and 0.016 [rad] using TSK controller. By using TSK controller overloads in the driving mechanism were decreased during starting above 12% in comparison with results obtained using PI controller (Fig. 7). Experiments conducted on the real object proved using control system based on fuzzy logic techniques in movement mechanisms of the overhead crane the improvement of device's controlling quality is possible.

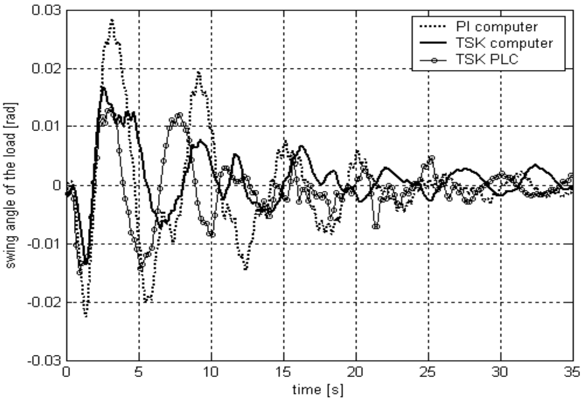

Fig. 6. Swing angle of the load

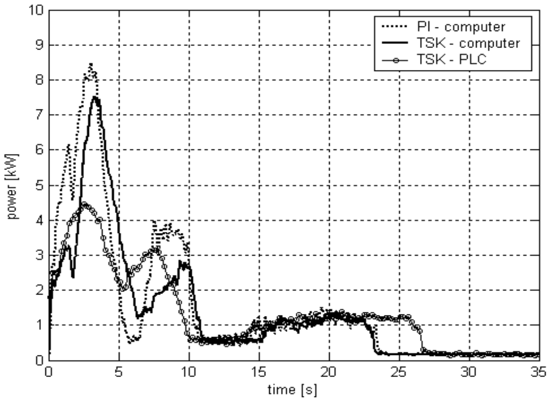

Fig. 7. Power consumed by motors

Using PLC controller with TSK control algorithm, during experiment with 50 [kN] mass of the load, required position of the load was achieved with satisfactory precision 0.04 [m], with minimization of the swing angle of the load to the value 0.005 [rad] (Fig. 6). The maximal value of swing angle during starting was 0.015 [rad].

Control system with Mamdani controller was elaborated and tested on the overhead traveling crane with 150 [kg] hoisting capacity. Results of experiments conducted with using Mamdani controller were compared with results obtained from tests with PD (proportional-derivative) controllers used in feedback loops from error of mechanism position signal ($K_{P1} = 64.99; K_{D1} = 78.25$) and swing of the rope signal ($K_{P2} = 133; K_{D2} = 24.5$). During experiments fixed rope length l = 1 [m] and mass of the load m = 10 [kg] were assumed. Results of experiments on the control object using Mamdani and PD controllers are presented and compared on Figures: no 8 and no 9.

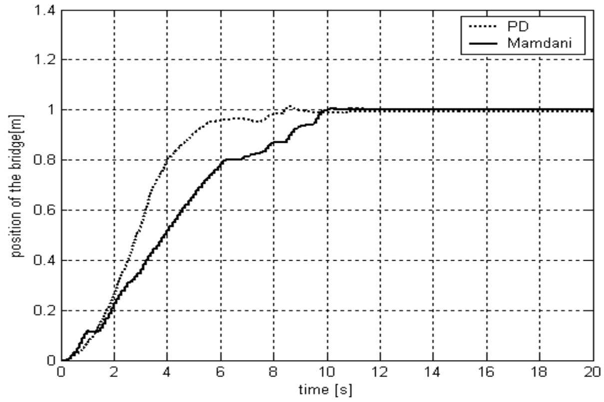

Fig. 8. Position of the crane's bridge

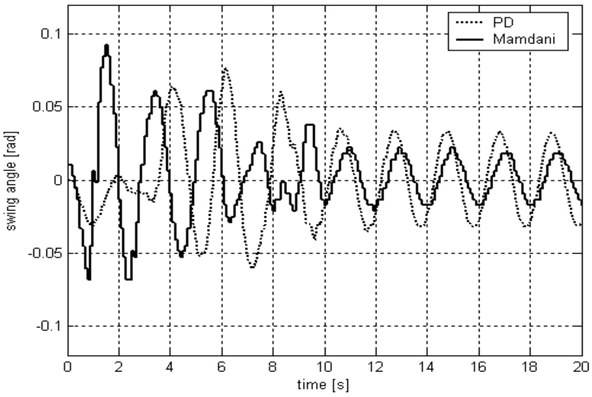

Fig. 9. Swing angle of the rope

Basis on results of experiments it was stated that using both controllers Mamdani and PD the time of positioning was similar, below 10 seconds with similar position error below 0.02 [m] (assumed acceptable tolerance). Using Mamdani controller the swing of the load was faster reducing during braking movement mechanisms below angle value 0.02 [rad] in comparison with PD controller – 0.03 [rad].

5. CONCLUSION

Researches conducted on the mathematical models and real device allows to state that quality of the overhead crane controlling is possible using control systems based on fuzzy logic. During experiments using TSK controller improving of load positioning and minimization overloads in transient states of working mechanisms were achieved.

Realizing researches works based on rapid prototyping process enabled to elaborate compound intelligent control algorithm during computer simulations and experiments on the real object. Applied software (Matlab/Simulink/RTW programs) and hardware (interface's cards) integrated tools gave possibility to shorten the time of control system design and further implementation on target control device (PLC controller). Process of source code generation and compilation realized automatically shortens the time of gone from the simulations conducted on the mathematical models to the experiments on the real object. Prototyping process enabled to concentrate only on developing control system elements: control algorithm optimization, adjusting the control system parameters and testing used measurements circuits.

Experiments on the real object proved that it is possible effectively implement of fuzzy logic algorithm in the PLC controllers using its standard instructions and using fuzzy logic in industrial control applications based on PLC controllers.

Realized researches works enabled to elaborate compound intelligent control algorithms using rapid prototyping process, during computer simulations and experiments on the real object. Applied software (Matlab/Simulink/RTW programs and HMI application built using InTouch programming environment) and hardware (interface's cards) integrated tools gave possibility to shorten the time of control system designing and further implementation on target control device (PLC controller). Prototyping process enabled to concentrate only on developing control system elements: control algorithm optimization, adjusting the control system parameters and testing used measurements circuits. Realized HMI application gave possibility of modification in real time fuzzy control algorithm implemented on the PLC controller without necessity of time-consuming PLC's program changing.

Implementation fuzzy algorithms on PLC controller shown problems with programming realization of control system based on Mamdani inference process because of compound defuzzyfication phase. TSK model was more effective algorithm in implementation on PLC controller owing to its consequence of the fuzzy rules.

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