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A MECHATRONICS APPROACH IN INTELLIGENT CONTROL SYSTEMS OF THE OVERHEAD TRAVELING CRANES PROTOTYPING

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Abstract. The paper presents a mechatronics approach to elaborate intelligent control system of the real device: the two-spares overhead crane. The control system, based on fuzzy controller with Takagi-Sugeno-Kang fuzzy inference system, was elaborated, built and optimized during simulations conducted on mathematical models of the device and experiments conducted on the real device and next the control algorithm was implemented on the final control device, programmable logic controller PLC. Applied programming environment based on Matlab program and HMI (*Human Machine-Interface*) application as well as hardware's solutions gave a possibility to build the control system using rapid prototyping method.

Keywords: overhead crane, fuzzy control, prototyping, human machine-interface.

1. Introduction

In manufacturing industrial systems the greater and greater requirements are put before operation quality and precision of automated transportation systems. One of the important elements of works transport is the overhead traveling crane. The issues of minimizing transport time, precision of positioning with swing of the load reducings are more and more significant in practice as well as exploitation quality of a device [7]. Complexity of phenomenon occurred during loads transportation process using cranes as a result of wide change exploitation parameters causes that in crane's control systems are required tools taking into consideration the complexity of such systems characterized by uncertainty, imprecision and subjectivity of parameters. One of those mathematical tools is fuzzy logic which is a nonlinear system that converts a crisp input vector into a crisp output vector [9].

Fuzzy models are expert systems in which the control strategy is expressed in the form of IF-THEN rules built using linguistic terms based on heuristic knowledge. In many of research works the problem of crane control movement is solved using artificial intelligence approach [1, 2, 3, 4, 6, 8]. However, the most solutions concern control system realized and tested only during simulations conducted on mathematical models of a device and seldom tests on laboratory models. Implementation of the control system on the real device is a time-consuming process that can be shorten by using prototyping methods and integrated software and hardware computers' tools enabling to design control systems during simulations on the mathematical models and experiments conducted on the real devices and finally implementing elaborated control algorithm on the target control device, e.g. programmable logic controller (PLC). Programmable logic controllers are very popular in industrial practice and used in many of control systems. Some PLC's producers coming to the users requirements offer specials additional extended modules giving a possibility to build fuzzy control algorithm using their PLC. However, such solutions cause raising cost of designed control system.

In industrial processes greater and greater significance have HMI (*Human Machine-Interface*) systems that are direct communication systems between human (operator) and managed because of him process, supplied tools for visualization of the industrial process using synoptic images, controlling, monitoring and managing the whole process or choosing devices and means of manufacturing process, acquisition and presentation dates. HMI is the higher level of control systems which enables raising quality and shorten the time of manufacturing tasks realization, monitoring and controlling the whole or chosen productions' aspects and fast reaction on appearing problems. The development of software and hardware architecture of HMI systems enables to realize lots of tasks, not only main functions related with visualization and managing but also useful in data acquisition and analyzing, diagnostic and monitoring processes' states.

In the paper, results of researches conducted towards elaborating fuzzy control system of overhead traveling crane movement are presented. The proposed control algorithm based on Takagi-Sugeno-Kang (TSK) fuzzy inference system was elaborated in rapid prototyping process divided into two steps. In the first step, the control algorithm was elaborated using computer PC with data acquisition cards and *Matlab The MathWorks Inc.* program. The prototyping process was performed in the result of testing virtual controller during computer simulations conducted on the mathematical models of the control object and then the control system was verified and validated during experiments on the real device [5]. Using rapid prototyping process shortens the time of control system designing: control algorithm optimization, sampling time selection, testing proper working of measurement circuit. In the next step, the control algorithm was implemented on the target controller: programmable logic controller PLC. Using *InTouch Wonderware Corporation* program, the HMI application was created for visualization, monitoring and managing the transportation process realized by the crane. One of the important elements of this application was a possibility of fuzzy control algorithm modification in PLC without necessity of time-consuming PLC's program changing.

2. Fuzzy control algorithm of the crane movement

The crane's control system is based on Takagi-Sugeno-Kang (TSK) fuzzy model. The aim of the proposed control system was precision positioning of the transported load to the final position with minimizing swing of the load after starting and during braking movements' mechanisms. The base of knowledge crane's bridge control algorithm shown in Figure 1 is composed of 27 rules of type IF-THEN expressed control strategy based on information from three input signals: error of bridge position $e_y = y_d - y$ (where: y_d – desired bridge's position, y – actual bridge's position), velocity of the bridge $\dot{y}$ and swing angle of the load measured in bridge movement direction α .

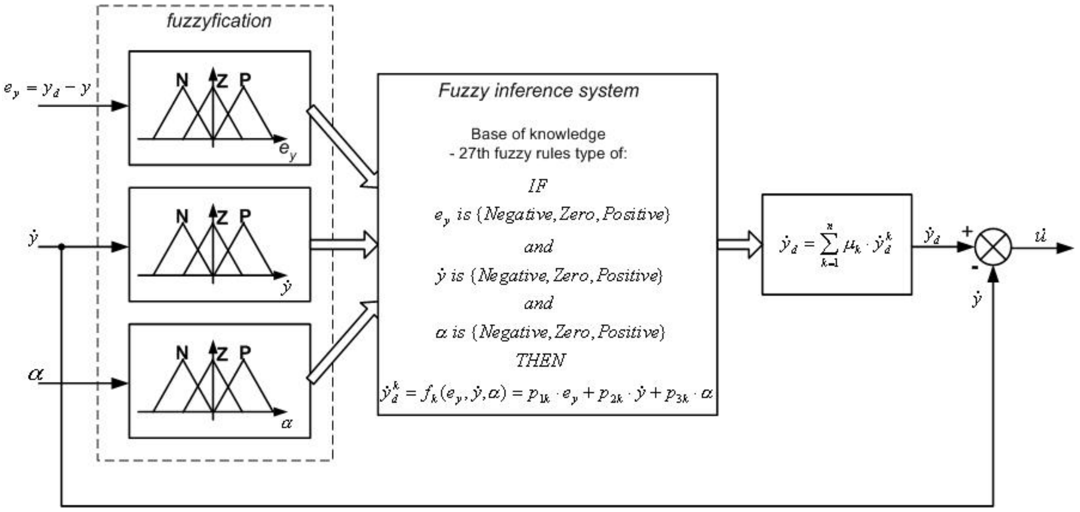

Figure 1. TSK control algorithm of the crane's bridge velocity

In fuzzification algorithm there were used three fuzzy sets (entitled using linguistic terms: *Negative*, *Zero* and *Positive*) for each input of the controller and triangular membership functions.

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

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

where: μ_k – the weight of the *k*-th rule taken from the interval [0, 1], *k* - number of rule, *n* = 1, 2..., 27.

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

3. Prototyping crane control system

Using rapid prototyping process shortens the time of control system designing: control algorithm optimization, sampling time selection, testing proper working measurement circuit. The prototyping process is performed in the result of testing virtual controller during computer simulations conducted on the mathematical models of the control object and then control system is verified and validated during experiments on the real device. During experiments conducted on the device, mathematical models can be validated and controller's parameters can be adjusted (sampling time, measurement and control signals quantization). As a result of elaborated and tested control system, the ready control algorithm can be implemented on the target controller, e.g. PC, programmable logic controller PLC or other control device.

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 with multifunction data acquisition card of type PCL818HG produced by *Advantech* firm (Figure 2).

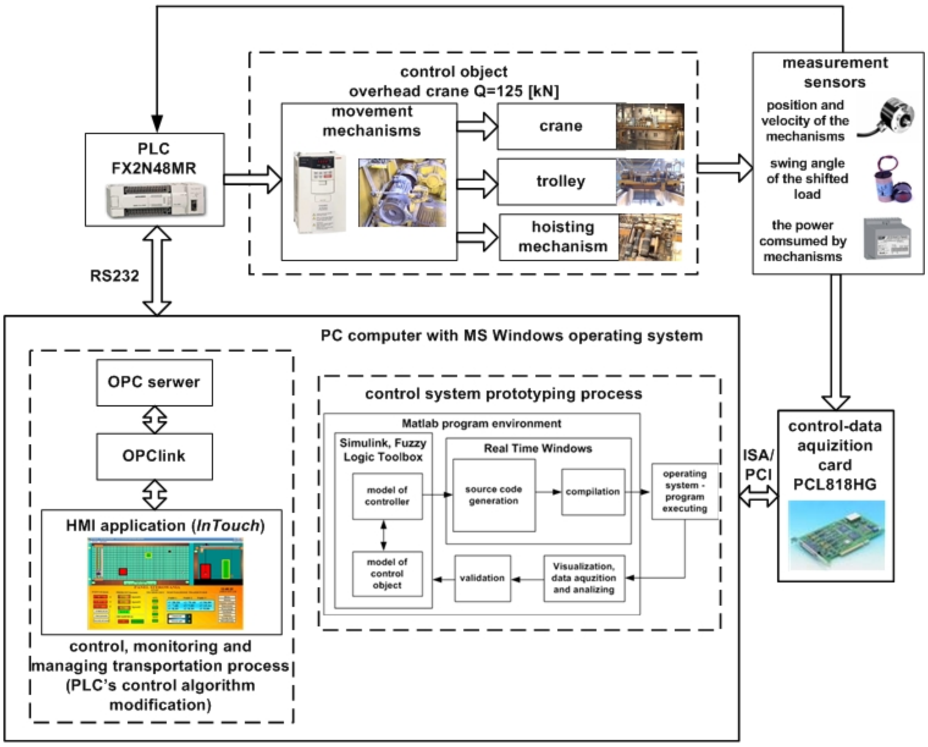

Figure 2. Prototyping the crane control system

RTW program delivers process of automatically generating of source code and its compilation from Simulink model which considerably shortens the time of building control system, giving a 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 a possibility of quickly returning to the phase of simulation. Control system based on TSK controller 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 FX2N produced by *Mitsubishi Electric* firm. The control algorithm was written for the PLC using standard instructions understandable by series of FX controllers. The control system based on PLC with TSK control algorithm was realized and tested on a real device as an application possibly used in industrial practice.

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

- managing and controlling shifting process,
- choosing manually or automatically the type of device working,
- visualization of shifting process using synoptic image or camera views,
- data monitoring and acquisition and presentation in the 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 without necessity of PLC's program changing.

Implementation of the control algorithm on the PLC after testing it with a PC with interface card's could require necessity of adjusting controller parameters because of changes in software environment. Modification of the control algorithm requires time-consuming PLC's program changing and conducting tests on a 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 of TSK fuzzy controller parameters in fuzzification and base of knowledge phases by giving a possibility of changing membership function parameters in fuzzy rules' antecedents (Figure 3) and vector of controller gains in rules' consequences.

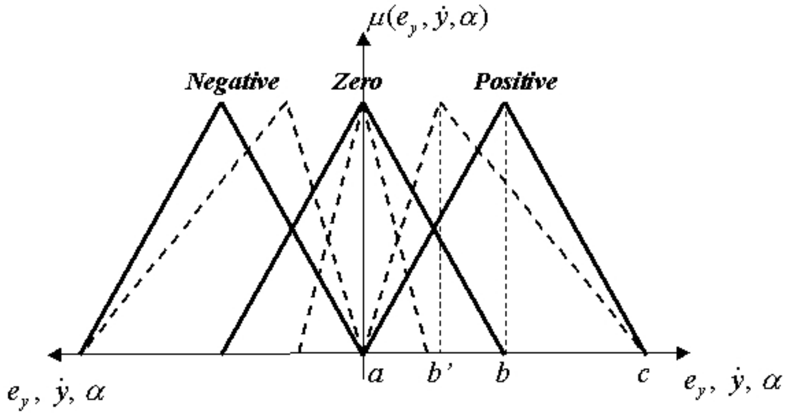

Figure 3. Modification of triangular membership functions' parameters (*a*, *b*, *c*)

4. Experiments on the device

The control system was realized on the real object, two-spars overhead traveling crane with Q = 125 [kN] hoisting capacity and bridge width L = 16 [m] working in the workshop. During experiments conducted on the real object, the PI and TSK controllers were tested and verified on the bridge motion mechanism using a PC with control-measurement card (assumptions: load was about m_3 = 100 [kN] suspended 4th meters above base - the length of string was l = 6 [m]) and using PLC (load was about m_3 = 50 [kN], the length of string was l = 6 [m]). The results of experiments are presented in Figures 4 to 7 in which courses obtained using PI and TSK controllers realized by computer with interface's card (*PI – computer* and *TSK – computer*) from experiments with 100 [kN] load were compared with results obtained using PLC with TSK algorithm (*TSK - PLC*) conducted when crane was shifting 50 [kN] load.

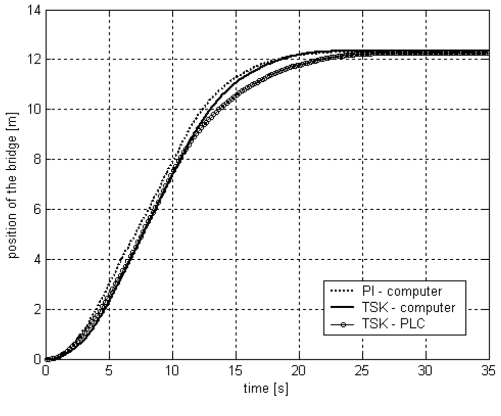

Figure 4. Position of the bridge

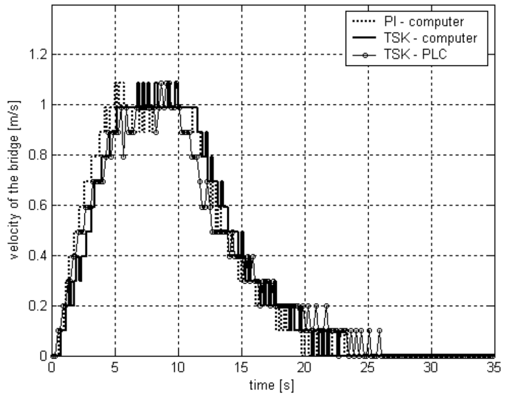

Figure 5. Velocity of the bridge

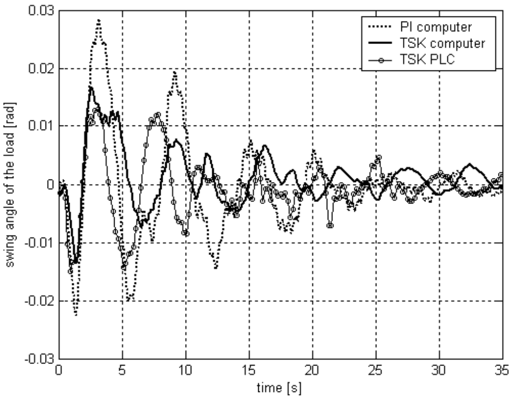

Figure 6. Swing angle of the load

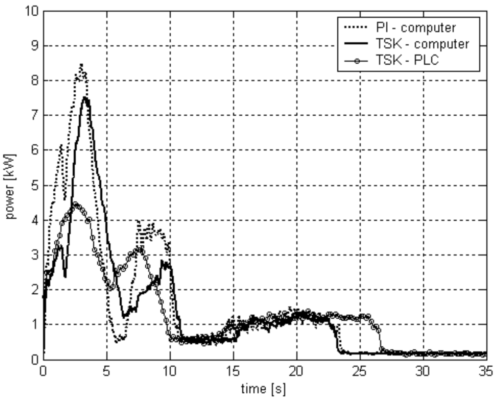

Figure 7. Power consumed by motors

Based on the results from experiments with 100 [kN] transported load conducted using a PC realized PI and TSK controller, it was found that using TSK controller the swing angle of the load was minimized better especially during starting (above 40%) and faster during braking the bridge mechanism (Figure 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 (Figure 7). Experiments conducted on the real object proved that, using control system based on fuzzy logic techniques in movement mechanisms of the overhead crane, the improvement of device's controlling quality is possible.

Using PLC with TSK control algorithm during experiment with 50 [kN] mass of the load desired position of the load was achieved with satisfactory precision 0,04 [m] (Fig. 4), 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]. The difference in time positioning between experiments with TSK controller using PC (t_r = 23 [s]) and using PLC (t_r = 26 [s]) could be caused by different mass of the loads and software environments used in both experiments.

5. Final remarks

Realized researches works based on rapid prototyping process enabled to elaborate a 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 a possibility to shorten the time of control system designing and further implementation on target control device (PLC). The 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 measurement circuits. The realized HMI application gave a possibility of modification in real time fuzzy control algorithm implemented on the PLC without necessity of time-consuming PLC's program changing.

Presented results of experiments conducted on the overhead crane proved that employing fuzzy controller can be very useful in automated control systems of the crane movement mechanisms. Using frequency inverters in crane's driving mechanisms and employing intelligent control system the accuracy of device's transportation tasks as well as exploitation of the device can be improved.

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